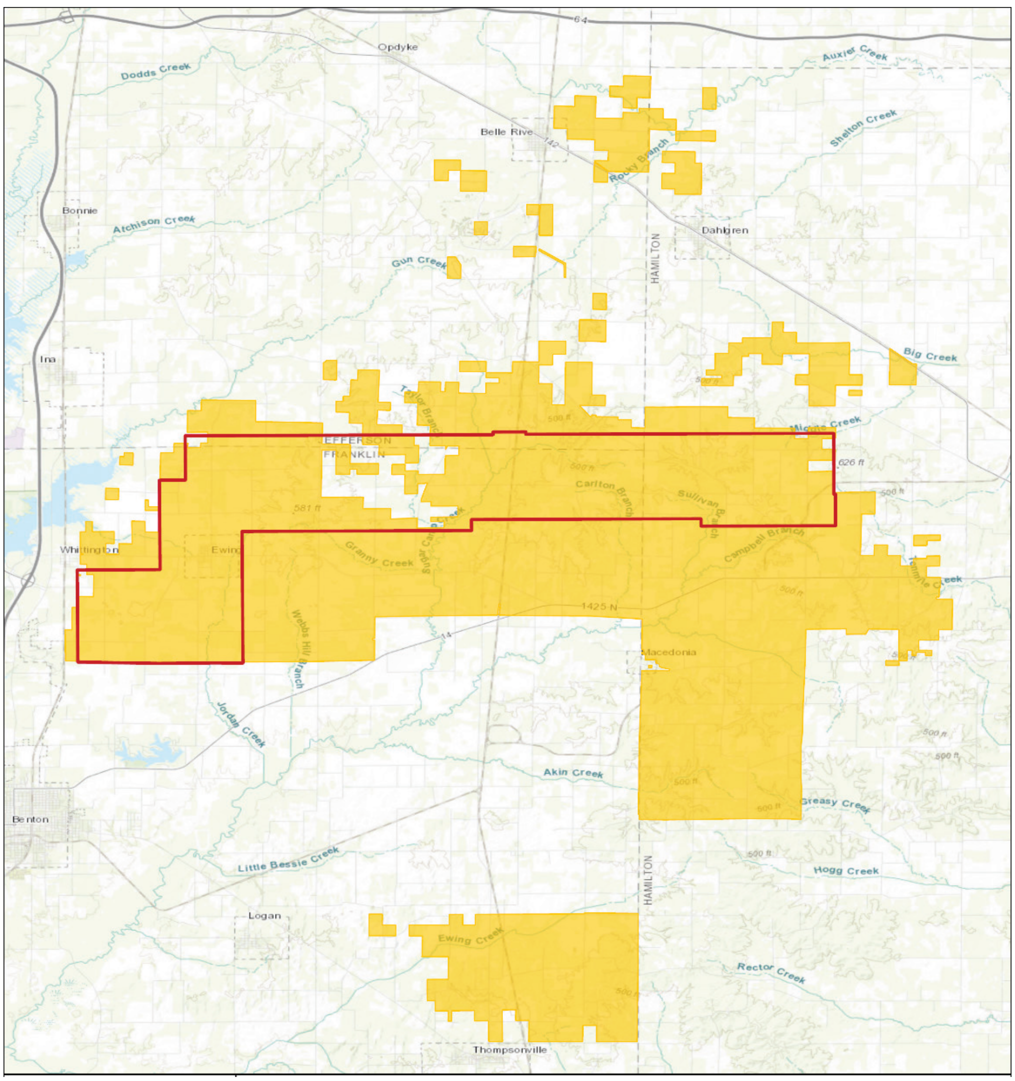
Sugar Camp Energy, LLC Mine No. 1 Significant Boundary Revision 8 Environmental Impact Statement

SCOPING REPORT

OCTOBER 16, 2023



TENNESSEE VALLEY AUTHORITY

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Scoping Report Executive Summary

The Tennessee Valley Authority (TVA) is preparing an environmental impact statement (EIS) evaluating the proposed expansion of mining operations by Sugar Camp Energy, LLC (Sugar Camp) to extract TVA-owned coal reserves in Franklin, Hamilton, and Jefferson counties, Illinois. Sugar Camp seeks to expand its underground longwall mining operations by approximately 22,414 acres (the project area) (Figure 1). TVA-owned coal reserves underlie approximately 21,868 acres of the project area. Under the proposed mine expansion, Sugar Camp would extract approximately 122 million raw tons of TVA-owned coal over a 25-year period.

In 2002 TVA issued a lease for the potential mining of coal underlying approximately 64,687 acres in southern Illinois. The lease included the stipulation that the mining of any of this TVA-owned coal is dependent on TVA's approval of the mine plan. The purpose of the TVA's proposed action is to decide whether to approve the mine plan and therefore implement the terms of the existing coal lease agreement.

TVA has identified four alternatives for evaluation in the EIS. These include a No Action Alternative and three Action Alternatives. Under the No Action Alternative, TVA would not approve the requested expansion to mine TVA-owned coal within the project area or sell its southern Illinois mineral reserves to another entity. Under Action Alternative A, TVA would implement the terms of the existing coal lease agreement, evaluate, and approve the plan to mine 21,868 acres of TVA-owned coal as submitted by Sugar Camp in the current Significant Boundary Revision (SBR) of Underground Coal Mine (UCM) Permit No. 382. Under Action Alternative B, TVA would implement the terms of the existing coal lease agreement, evaluate, and allow mining of the 21,868 acres of TVA-owned coal, and divest the remaining TVA-owned mineral rights/reserves including coal, oil, and gas in Illinois, and all associated surface rights. Under Action Alternative C, TVA would not approve Sugar Camp's expansion request as detailed under UCM Permit No. 382 and would divest all remaining TVA-owned mineral rights/reserves including coal, oil, and gas in Illinois, and all associated surface rights, and would.

The National Environmental Policy Act (NEPA) requires federal agencies to consider the potential environmental consequences of proposed actions. The NEPA review process is intended to help federal agencies make decisions based on an understanding of the proposed action's impacts and, if necessary, to take actions that protect, restore, and enhance the environment. NEPA also requires that federal agencies provide opportunities for public involvement in the decision-making process. One of those opportunities is through public scoping.

TVA initiated a 30-day public scoping period on September 1, 2023, when it published a Notice of Intent in the *Federal Register* announcing its plan to prepare an EIS. During the scoping period, from September 1, 2023, to October 2, 2023, the public provided input to help TVA identify issues that are important to the public and to help lay the foundation for development of the EIS. This Scoping Report describes comments that were submitted electronically or by mail, as well as information on how the EIS is being developed.

During the EIS scoping period, TVA received comment letters from agencies, non-governmental organizations, and private citizens. Comments about the EIS process were related to the purpose and need, project description, alternatives, subsidence, natural resources, threatened and endangered species, air quality, water quality, greenhouse gas (GHG) emissions and climate change, socioeconomics, and safety. The Scoping Report also includes information about NEPA, applicable federal laws and executive orders, and environmental documents and reviews that are relevant to the EIS.

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List of Acronyms

CFR	Code of Federal Regulations
EA	Environmental Assessment
EIS	Environmental Impact Statement
EO	Executive Order
GHG	Greenhouse Gas
IDNR	Illinois Department of Natural Resources
IPCC	Intergovernmental Panel on Climate Change
NEPA	National Environmental Policy Act
NOI	Notice of Intent
OMM	Office of Mines and Minerals
SBR	Significant Boundary Revision
SEA	Supplemental Environmental Assessment
TVA	Tennessee Valley Authority
UCM	Underground Coal Mine
USEPA	United States Environmental Protection Agency

1 Introduction

The Tennessee Valley Authority (TVA) previously acquired mineral rights in the southwestern section of the Illinois Basin coalfield. TVA generally leases its mineral rights to private coal mining companies and receives royalties on the amount of coal recovered under such lease agreements. In 2002, TVA leased Illinois Basin coalfield reserves to a mining company with the condition that any proposed mine plan must be subject to environmental review and TVA approval. The mine plan is also subject to review and approval by the State of Illinois, which has regulatory authority delegated by the Department of Interior, Office of Surface Mining Reclamation and Enforcement under the Surface Mining Control and Reclamation Act of 1977.

In 2008, Sugar Camp Energy, LLC (Sugar Camp) obtained Underground Coal Mine (UCM) Permit No. 382 from the Illinois Department of Natural Resources (IDNR), Office of Mines and Minerals (OMM), Land Reclamation Division for underground longwall mining operations on approximately 12,103 acres in Franklin and Hamilton counties. The original permit did not include TVA-owned coal reserves. In 2010, Sugar Camp applied to IDNR for an expansion associated with UCM Permit No. 382 to mine TVA-owned coal under an additional 817-acre area. The permit was issued in May 2010. In 2011, TVA prepared an environmental assessment (EA) to document the potential effects of Sugar Camp's proposed mining of TVA-owned coal underlying a 2,600-acre area.

In November 2017, Sugar Camp received Significant Boundary Revision (SBR) No. 6 of UCM Permit No. 382, from IDNR-OMM, for an expansion of 37,972 acres. TVA prepared additional EAs to document the potential effects of Sugar Camp's proposed mining of TVA-owned coal within portions of the Sugar Camp Mine No. 1 Revision 6 area. In August 2019, TVA issued a Notice of Intent (NOI) in the *Federal Register* to complete an environmental impact statement (EIS) for the mining of approximately 12,125 acres of TVA-owned coal reserves associated with SBR No. 6 of UCM Permit No. 382. In October 2020, TVA issued the Final EIS on this additional mining of TVA coal reserves. In November 2020, TVA published a Record of Decision and approved Sugar Camp's application to mine the additional TVA-owned coal reserves under the IDNR-approved SBR No. 6.

Sugar Camp proposes to expand its underground longwall mining operations at Sugar Camp Mine No. 1 in Franklin, Hamilton, and Jefferson counties, Illinois, by approximately 22,414 acres (the project area). TVA-owned coal reserves underlie approximately 21,868 acres of the project area (Figure 1).

The purpose of the proposed action is to implement the terms of the existing coal lease agreement between TVA and Sugar Camp. As part of that agreement, TVA reserved the right of review and approval of Sugar Camp's mining activities of TVA-owned coal. TVA is preparing an EIS to inform its decision on whether to approve Sugar Camp's application to mine TVA-owned coal reserves within the project area and/or divest all remaining TVA-owned mineral reserves in Illinois. The location of these reserves is shown in Figure 1.

Under Sugar Camp's mining proposal, underground disturbance would occur, including the extraction of approximately 122 million raw tons of TVA-owned coal over a 25-year period (this excludes the 45 million tons currently permitted). Underground mining would be performed using room-and-pillar and continuous mining techniques during a development period, followed by longwall mining and associated planned subsidence at a later time. Subsidence is the settlement of the ground surface following the collapse of underground mining shafts or voids once the coal has been removed. Planned subsidence is included in Sugar Camp's proposed mining plan.

Surface activities to support underground mining of TVA-owned coal would include partial operation of the existing coal preparation plant, treatment of the byproducts, storage, and transport of the coal. Sugar Camp would utilize its existing Sugar Camp Mine No. 1 facilities to process and ship the extracted coal, and expansion of these facilities is not needed to support the proposed mine expansion. Sugar Camp would also construct approximately six bleeder ventilation shafts and install associated utilities needed to operate the bleeder shafts within the project area.

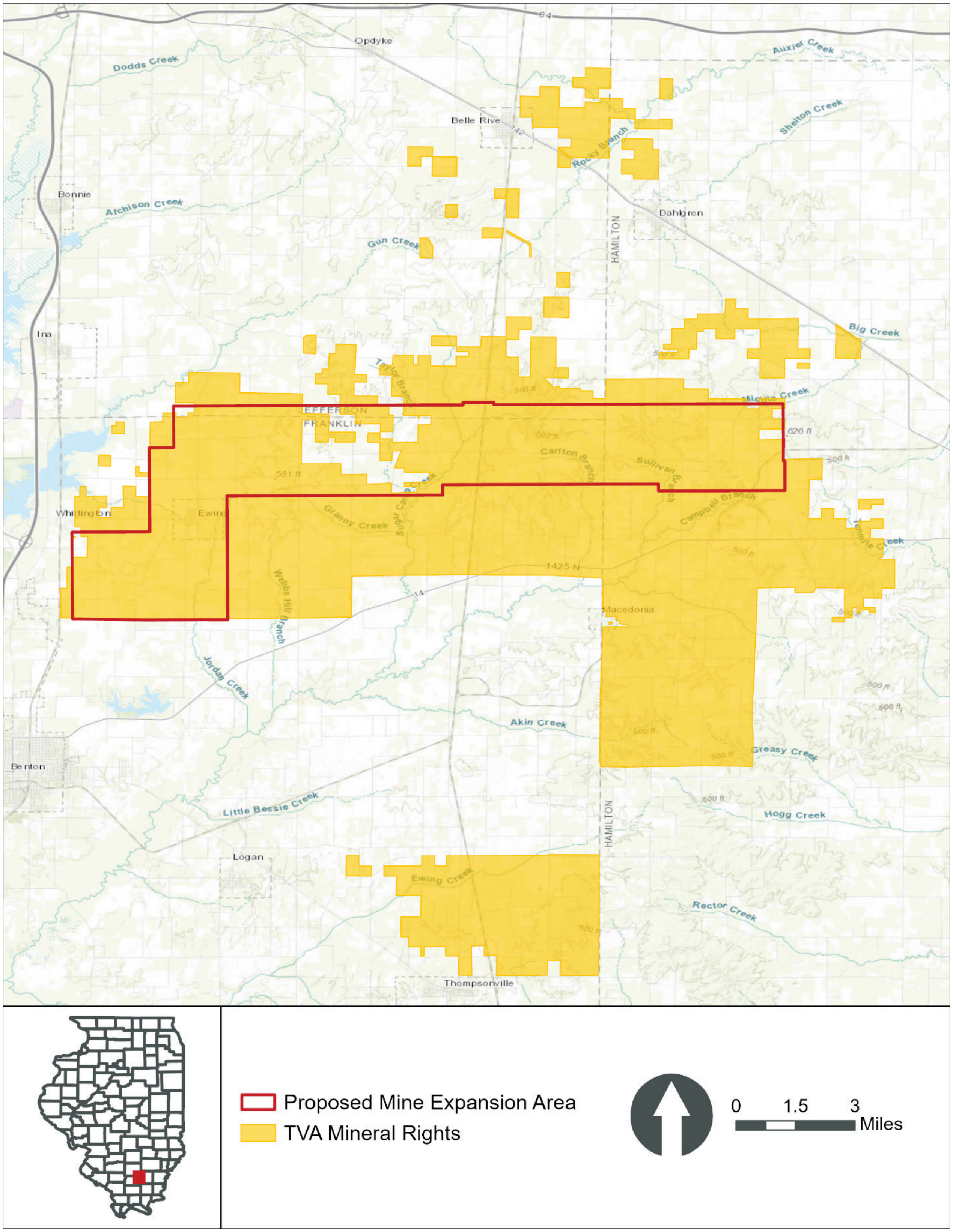

Figure 1. Project Location.

2 Purpose and Need

TVA owns the coal reserves beneath the project area and executed a coal lease agreement in July 2002 which allows Sugar Camp to mine the portion of the reserves that TVA owns. The purpose of the agreement is to facilitate the recovery of TVA-owned coal reserves in an environmentally sound manner. Under the terms of the agreement, Sugar Camp may not commence mining of TVA-owned coal reserves under a mining plan or any revision until completion of all environmental reviews required for compliance with applicable laws and regulations have been finalized. Given that TVA plans to eliminate its use of coal and as part of TVA's aspirational goal of being carbon free by 2050, the purpose of the EIS is to inform TVA's decision on whether TVA will approve Sugar Camp's application to mine TVA-owned coal reserves within the project area and/or divest all remaining TVA-owned mineral reserves in Illinois. The purpose of executing the lease agreement is to recoup the investment that TVA has already made. The purpose of divesting all remaining TVA-owned mineral rights/reserves is for TVA to recover economic value from the initial expenditure and reduce its exposure to future environmental liability associated with the continued ownership of coal rights underlying the properties.

3 Alternatives

Preliminary internal scoping by TVA has determined that from the standpoint of the National Environmental Policy Act (NEPA), there are initially four alternatives available to TVA: the No Action Alternative and three Action Alternatives.

3.1 No Action Alternative

Under the No Action Alternative, TVA would not approve the plan to mine TVA-owned coal within the project area. Although Sugar Camp has secured permits for mining this and adjacent non-TVA coal from the State of Illinois, the proposed mining requires approval from TVA for TVA-owned coal. Thus, in the absence of TVA approval, Sugar Camp would be limited in expanding its underground mining operations. TVA assumes that Sugar Camp would continue the previously approved mining of approximately 25,847 acres of TVA-owned coal and privately owned coal. Sugar Camp projections are to mine up to 14 million tons per year. Some TVA coal has already been approved for mining (Viking District #2 and SBR No. 6 Shadow Area). The associated coal processing facilitates would still be in use under the No Action Alternative.

3.2 Action Alternative A

Under Action Alternative A, TVA would implement the terms of the existing coal lease agreement and approve the plan to mine TVA-owned coal as submitted by Sugar Camp in the SBR No. 8 of UCM Permit No. 382. TVA proposes to assess the effects of the mining operations to extract TVA-owned coal reserves underlying approximately 21,868 acres within the project area, as well as the non-TVA-owned coal that would be mined in conjunction with the TVA-owned coal. Under Action Alternative A, TVA will address the cumulative impacts from other coal mining activities and identified federal and private actions. The cumulative impacts considered will include approved or completed activities as well as foreseeable future activities associated with Sugar Camp Mine No. 1.

Room-and-pillar mining would be used during initial development of the mine expansion, after which longwall mining would be used. Room-and-pillar mining involves the extraction of coal in a grid-like pattern such that portions of the coal seam are left intact to support the roof of the mine. The series of parallel areas in which coal is extracted are called entries. For areas to be mined by the room-and-pillar method, entry and crosscut spacing would typically be on 120-foot centers, with an entry and crosscut width of 20 feet maximum. The referenced dimensions for conventional mining are based on site-specific strength values for coal pillars and floor for an adequate factor of safety for roof stability and to prevent unplanned subsidence. Plate testing would be conducted in conventional room-and-pillar sections within the first 1,000 feet of entering the area. Should any changes in mine stability or conditions be encountered, a more detailed study of floor, roof, and pillars would be performed at that time. The entryways provide access for workers, ventilation, and mining equipment. Room-and-pillar equipment includes continuous miners, shuttlecars, conveyor belts, and roofbolters. The coal would be transported by conveyor from the project area to the existing coal preparation plant.

Longwall mining involves the full extraction of coal from a section of the seam or face using mechanical shearers. Longwall mining creates an almost complete extraction of the coal reserve, which allows the overburden to subside (sink) in a controlled and predictable manner. The area of mining within this planned subsidence is defined as a longwall panel. Approximately 18 panels would be 1,400 feet wide and up to 19,750 feet long. Extraction height would average 7.7 feet and the total percentage of coal to be removed in the longwall extraction areas would be 90%. Up to 14 million tons per year would be extracted.

Walls consisting of standing coal pillars separate the panels and support the roof as well as providing access between panels. Longwall mining machinery includes hydraulic roof supports (shields), a conveyor system, and a coal shearer. A cut of the longwall panel is made by the shearer and the coal is transported by the conveyor system. The shields are advanced as the shearer cuts the coal to allow for a safe workspace for the mine workers. The removal of coal sequentially allows the overburden to fill the void with a resultant movement of the surface. This collapse results in a subsidence on the surface. This movement is predictable, uniform, and minimizes damage to surface structures as mining progresses. Consistent with the requirements given in 30 Code of Federal Regulations [CFR] 817.121 of the Surface Mining Control and Reclamation Act, Sugar Camp must promptly repair or compensate the owner for material damage resulting from subsidence caused to any structure or facility that existed at the time of the coal extraction under or adjacent to the materially damaged structure. In addition, Sugar Camp must correct any material damage resulting from subsidence, to the extent technologically and economically feasible, by restoring the land to a condition capable of maintaining the value and reasonably foreseeable uses that it could support before subsidence damage.

The extraction of TVA-owned coal reserves under Action Alternative A would occur over an estimated 25-year period and would produce approximately 122 million tons of raw coal. The extracted coal would be processed at the existing preparation plant approved by IDNR in 2008, separate from any TVA-owned coal activities. The facilities for this connected action, including refuse ponds and offsite transport, cover about 2,420 acres (Figure 1). Water used for various mining purposes including cooling and GHG capture at the site is treated onsite and discharged under terms of one or more National Pollutant Discharge Elimination System permits.

3.3 Action Alternative B

Under Action Alternative B, TVA would implement the terms of the existing coal lease agreement and approve the plan to mine TVA-owned coal as submitted by Sugar Camp in the SBR No. 8 of UCM Permit No. 382 and divest the remaining TVA-owned Illinois mineral reserves. The mining of the TVA-owned coal would be as described under Alternative A.

Based in part on TVA's evolving electricity generation priorities, and TVA's diminishing need for coal to supply TVA's electricity generating portfolio, Alternative B includes TVA divesting the remaining TVA-owned mineral rights/reserves including coal, oil, and gas in Illinois, and all associated surface rights (approximately 42,819 acres and 676 million tons of raw coal). The divestment of TVA's mineral rights would allow TVA to recover economic value from the initial expenditure and reduce its exposure to environmental liability associated with the continued ownership of coal rights underlying the properties.

3.4 Action Alternative C

Under Action Alternative C, TVA would not approve Sugar Camp's expansion request as detailed under SBR No. 8 of UCM Permit No. 382 and would divest all remaining TVA-owned mineral rights/reserves including coal, oil, and gas in Illinois, and all associated surface rights (approximately 64,687 acres and 798 million tons of TVA Illinois coal reserves).

4 Environmental Review Process

NEPA requires federal agencies to the potential environmental consequences of proposed actions. Actions, in this context, can include new and continuing activities that are conducted, financed, assisted, regulated, or approved by federal agencies, as well as new or revised plans, policies or procedures. The NEPA review process is intended to help federal agencies make decisions that are based on an understanding of the action's impacts and, if necessary, to take actions that protect, restore, and enhance the environment (40 CFR 1500.1(c)). NEPA also requires that federal agencies provide opportunities for public involvement in the decision-making process.

TVA is initiating the preparation of this EIS to assess the environmental impacts of the proposed action. TVA is using the input from the scoping period, summarized below, in developing the Draft EIS. The Draft EIS will be distributed to interested individuals; groups; and federal, state, and local agencies for their review and comment. Following the public comment period, TVA will respond to the comments received on the Draft EIS and incorporate any necessary changes into the Final EIS. TVA will make a final decision regarding the proposed action no earlier than 30 days after the Final EIS is published.

The completed Final EIS will be placed on TVA's website, and notices of its availability will be sent to those who received the Draft EIS or submitted comments on the Draft EIS. TVA also will send the Final EIS to the United States Environmental Protection Agency (USEPA), which will publish a notice of its availability in the *Federal Register*. TVA will then issue a Record of Decision, which will include (1) the decision; (2) the rationale for the decision; (3) alternatives that were considered; (4) the alternative that was considered environmentally preferable; and (5) associated mitigation measures and monitoring, and enforcement requirements. TVA intends to publish the Draft EIS in mid to late 2024 and publish the Final EIS in late 2024 or early 2025.

4.1 Applicable Federal Laws and Executive Orders

4.1.1 National Environmental Policy Act

This EIS is being prepared by TVA in accordance with NEPA (42 United States Code §§ 4321 et seq.), regulations implementing NEPA promulgated by the Council on Environmental Quality (40 CFR Parts 1500 to 1508), and TVA NEPA regulations and procedures (18 CFR 1318). For major federal actions with significant environmental impacts, NEPA requires that an EIS be prepared. This process must include public involvement and analysis of a reasonable range of alternatives.

4.1.2 Other Laws and Executive Orders

Other laws and executive orders (EOs) are relevant to the operation of Sugar Camp Mine No. 1 and may affect the environmental consequences of the mining plan, or measures needed, during its implementation (Table 1). The Draft EIS will describe the regulatory setting for each resource in more detail.

Since TVA does not own the land or operate the mine, it is the responsibility of Sugar Camp to comply with all applicable laws. However, permit requirements will be reviewed in the Draft EIS.

Table 1. Laws and Executive Orders Relevant to the Sugar Camp Mine No. 1 SBR 8.

Environmental Resource Area	Law / Executive Order
Water Quality	Clean Water Act
Groundwater	Safe Drinking Water Act Resource Conservation and Recovery Act
Air Quality and Noise	Clean Air Act
Wetlands and Waters	Clean Water Act EO 11990 – Protection of Wetlands EO 13778 – Restoring the Rule of Law, Federalism, and Economic Growth by Reviewing the “Waters of the United States” Rule
Floodplains	EO 11988 – Floodplain Management
Migratory Birds	EO 13186 – Responsibilities of Federal Agencies to Protect Migratory Birds Migratory Bird Treaty Act
Endangered and Threatened Species	Endangered Species Act Illinois Endangered Species Protection Act
Cultural Resources	National Historic Preservation Act Archaeological Resource Protection Act Native American Graves Protection and Repatriation Act Illinois State Agency Historic Resources Preservation Act
Environmental Justice	EO 12898 – Federal Actions to Address Environmental Justice in Minority and Low-Income Populations
Land Use	Farmland Protection Policy Act
Coal Mining	Surface Mining Control and Reclamation Act
Waste Management	Resource Conservation and Recovery Act Comprehensive Environmental Response, Compensation, and Liability Act Toxic Substances Control Act Emergency Planning and Community Right to Know Act Solid Waste Disposal Act
Safety	Occupational Safety and Health Act EO 13045 – Protection of Children from Environmental Health Risks and Safety Risks Federal Mine Safety and Health Act

4.2 Environmental Resources to Be Considered in EIS

Based on internal and public scoping, identification of applicable laws, regulations, EOs, and policies, TVA identified the resource areas listed below as requiring review within the EIS:

- Physical characteristics
  - Geology/hydrology
  - Soils and Prime Farmland
  - Floodplains
- Water resources
  - Groundwater/aquifers
  - Surface water
  - Water quality
  - Water supply (wells, municipal, etc.)
  - Wetlands
- Air quality and Greenhouse Gases (GHG)
- Biological Environment
  - Wildlife
  - Vegetation
  - Aquatic life
  - Threatened and endangered species
- Natural areas, parks, and recreation
- Land use
- Transportation
- Utilities
- Cultural resources
- Solid and hazardous waste
- Public and Occupational Health and Safety
- Socioeconomics and Environmental Justice
- Visual resources
- Noise

5 Public Outreach during Scoping Period

On September 1, 2023, TVA published a NOI in the *Federal Registe*r announcing that it planned to prepare an EIS to address the potential environmental effects associated with the proposed mine expansion and/or divesting TVA-owned mineral rights (Appendix A). The NOI initiated a 30-day public scoping period, which concluded on October 2, 2023. The NOI included solicited public input on other reasonable alternatives that should be considered in the EIS.

In addition to the NOI in the *Federal Register*, TVA sent notification of the NOI to local and state government entities and federal agencies; issued a news release to media; and posted the news release on the TVA website (Appendix B). TVA sent the scoping notice via email to agencies and organizations. TVA published notices regarding the NOI in local newspapers, including the following cities and associated newspapers:

- Benton, IL – *Benton Evening News*
- Mt Vernon, IL – *The Southern Illinoisan*
- Marion, IL – *Marion Republican*
- Harrisburg, IL – *Harrisburg Register*

The purpose of the scoping period was to present TVA's project objectives and initial alternatives for input from the public and interested stakeholders.

6 Summary of Public Scoping Comments

Comments were received from the USEPA, Sierra Club, Prairie Rivers Network, and private individuals. Most of the comments from individuals were through a letter campaign promoted by the Illinois chapter of the Sierra Club. Comment submissions are included in Appendix B and summarized by topic below.

6.1 Scope of the EIS

Analyze the potential impacts related to the approval of the plan to mine 21,868 acres of TVA-owned coal and/or divesting all TVA-owned mineral reserves in Illinois, the disturbance and development of land for multiple bleeder shafts at unknown locations, and related processing of the extracted coal at an existing preparation plant, on the resources listed in Section 4.2.

6.2 Response to TVA Scoping Questions

As described above in Section 5, TVA asked for public input on other reasonable alternatives that should be considered in the EIS. The USEPA made the following recommendation:

"Based on articulation of the purpose and need [presented], the Draft EIS should consider a sufficient range of alternatives. EPA understands that coal resources are in a fixed location; however, alternatives may consider alternative site configuration, mining methods, mine locations, coal resources, or sources of energy." TVA will consider such alternatives in the EIS.

Comments were also received regarding the NEPA process and several resource categories. A summary of how TVA plans to approach these items is provided below.

NEPA Process
As previously discussed within this report, TVA will follow the NEPA process.

Water Resources
Potential impacts to water quality, including chloride toxicity, water quantity, and waters of the US will be discussed in the EIS and shown on a map when applicable.

Biological Environment
Potential impacts to wildlife, vegetation, aquatic life, and threatened and endangered species will be analyzed in the EIS.

Socioeconomics and Environmental Justice
Socioeconomic and environmental justice consequences will be discussed in the EIS. The EIS will use appropriate tools, such as EJSCREEN, to assess environmental justice in minority populations and low-income populations.

Public and Occupational Health and Safety
Occupational health and safety measures will be included in the EIS. Safety related to humans and infrastructure in the project area during planned subsidence will also be included.

Subsidence
The risk of subsidence, anticipated location of subsidence, predicted amount of subsidence and potential impacts of subsidence will be discussed in the EIS.

Air Quality and GHG Emissions
The EIS will quantify the GHG emissions under the various alternatives and describe their reasonably foreseeable climate-related effects, including an analysis of the social cost of the GHG emissions. It will also evaluate the effects of climate change on the activities and infrastructure associated with the various alternatives.

Past Violations
Numerous commenters described past violations of environmental regulations by Sugar Camp and requested that TVA consider these violations in its decision-making.

7 Relevant Environmental Documents and Reviews

Several environmental documents and reviews are relevant to this EIS and are listed below.

TVA Sugar Camp Mine No. 1 EA (May 2011)
This EA evaluated the potential environmental effects of Sugar Camp's proposed mining of TVA-owned coal underneath approximately 2,600 acres underneath the Revision 2 shadow area and a portion of the original shadow area of the Sugar Camp Mine No. 1.

TVA Sugar Camp Mine No. 1 Supplemental EA (SEA) (May 2013)
This SEA evaluated the potential environmental effects of Sugar Camp's proposed mining of TVA-owned coal underneath an additional 880 acres of Sugar Camp Mine No. 1 Revision 3 shadow area.

Significant Revision Application No. 6 to Permit No. 382 (August 2017)
This application, prepared by Sugar Camp, proposed an underground shadow area revision of an additional 37,972 acres to be mined with the extraction of coal in the Herrin No. 6 seam via longwall mining.

Results of Review: Permanent Program Significant Revision Application No. 6 to Permit No. 382 (November 2017)
This permanent program finding from IDNR concluded that there was reasonable basis on which to issue a significant revision for the application, as modified.

TVA Sugar Camp Mine No. 1 Expansion Viking District #2 EA (November 2018)
This EA evaluated the potential environmental effects of the proposed expansion along the north perimeter of its original mine perimeter, into a 2,250-acre area referred to as Viking District #2.

TVA Sugar Camp Mine No. 1 Expansion Viking District #2 SEA (May 2019)
This SEA evaluated the potential environmental effects of the proposed expansion of mining into a 155-acre area adjacent to Viking District #2.

TVA Sugar Camp Mine No. 1 Boundary Revision 6 EIS (October 2020)
This EIS evaluated the potential environmental effects of the proposed mining of approximately 12,125 acres of TVA-owned coal reserves associated with SBR No. 6 of UCM Permit No. 382.

8 Potential Mitigation Measures

During scoping, commenters suggested that avoidance, minimization, and mitigation measures be considered for the Draft EIS. Sugar Camp mining operations would be carried out in compliance with 62 Illinois Administrative Code 1700-1850 which specifies a comprehensive set of environmental protection measures for the control of adverse ecological impacts resulting from coal mining. General protective measures for all environmental values are inherent within the regulatory program. The expanse of mining and mining-related disturbances would be limited to the acreage necessary for conducting mining operations in compliance with the applicable land reclamation regulatory requirements. Disturbance would be held to a minimum at sites not required for mining or mining-related activities.

IDNR-OMM would require Sugar Camp to implement best management practices and mitigation to minimize potential adverse environmental effects throughout the project area as conditions of their mine permit. Permit conditions would be enforced by the State of Illinois under the Surface Mining Control and Reclamation Act with oversight by the U.S. Department of Interior Office of Surface Mining Reclamation and Enforcement.; TVA does not regulate the mining activities of Sugar Camp. Potential mitigation measures include: implementation of sediment and erosion control practices (e.g., silt fences, straw, mulch, or vegetative cover) and fugitive dust minimization (e.g., wetting roads prior to heavy use); implementation of water quality protection measures (e.g., sediment pond treatment, water quality monitoring, or establishment of riparian zone buffer zones); repair of any damage to buildings or other structures caused by subsidence; minimization of invasive species transmission per the requirements of the Illinois Noxious Weed Law; compensation for any interruption to well water quality or quantity caused by subsidence until the groundwater is restored; the repair of any damage to roads or drainage alteration caused by subsidence; compensatory mitigation of wetlands and streams impacted by subsidence, if necessary; and repair of any damage to utilities caused by subsidence.

A

Appendix A – Federal Register Notice of Intent

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been decided in favor of a complainant within the two-year period; and (4) the requirements at 49 CFR 1105.7(b) and 1105.8(c) (notice of environmental and historic reports), 49 CFR 1105.12 (newspaper publication), and 49 CFR 1152.50(d)(1) (notice to government agencies) have been met.

As a condition to this exemption, any employee adversely affected by the abandonment shall be protected under *Oregon Short Line Railroad—Abandonment Portion Goshen Branch Between Firth & Ammon, in Bingham & Bonneville Counties, Idaho,* 360 I.C.C. 91 (1979). To address whether this condition adequately protects affected employees, a petition for partial revocation under 49 U.S.C. 10502(d) must be filed.

Provided no formal expression of intent to file an offer of financial assistance (OFA) has been received,[1] this exemption will be effective on October 1, 2023, unless stayed pending reconsideration. Petitions to stay that do not involve environmental issues,[2] formal expressions of intent to file an OFA under 49 CFR 1152.27(c)(2), and interim trail use/railbanking requests under 49 CFR 1152.29 must be filed by September 11, 2023.[3] Petitions to reopen and requests for public use conditions under 49 CFR 1152.28 must be filed by September 21, 2023.

All pleadings, referring to Docket No. AB 55 (Sub-No. 812X), must be filed with the Surface Transportation Board either via e-filing on the Board's website or in writing addressed to 395 E Street SW, Washington, DC 20423–0001. In addition, a copy of each pleading must be served on CSXT's representative, Louis E. Gitomer, Law Offices of Louis E. Gitomer, LLC, 600 Baltimore Avenue, Suite 301, Towson, MD 21204.

If the verified notice contains false or misleading information, the exemption is void ab initio.

CSXT has filed a combined environmental and historic report that addresses the potential effects, if any, of the abandonment on the environment and historic resources. OEA will issue a Draft Environmental Assessment (Draft EA) by September 8, 2023. The Draft EA will be available to interested persons on the Board's website, by writing to OEA, or by calling OEA at (202) 245–0294. If you require an accommodation under the Americans with Disabilities Act, please call (202) 245–0245. Comments on environmental or historic preservation matters must be filed within 15 days after the Draft EA becomes available to the public.

Environmental, historic preservation, public use, or trail use/railbanking conditions will be imposed, where appropriate, in a subsequent decision.

Pursuant to the provisions of 49 CFR 1152.29(e)(2), CSXT shall file a notice of consummation with the Board to signify that it has exercised the authority granted and fully abandoned the Line. If consummation has not been effected by CSXT's filing of a notice of consummation by September 1, 2024, and there are no legal or regulatory barriers to consummation, the authority to abandon will automatically expire.

Board decisions and notices are available at *www.stb.gov.*

Decided: August 29, 2023.

By the Board, Mai T. Dinh, Director, Office of Proceedings.

Jeffrey Herzig,

Clearance Clerk.

[FR Doc. 2023–18981 Filed 8–31–23; 8:45 am]

BILLING CODE 4915–01–P

[1] Persons interested in submitting an OFA must first file a formal expression of intent to file an offer, indicating the type of financial assistance they wish to provide (*i.e.,* subsidy or purchase) and demonstrating that they are preliminarily financially responsible. *See* 49 CFR 1152.27(c)(2)(i).

[2] The Board will grant a stay if an informed decision on environmental issues (whether raised by a party or by the Board's Office of Environmental Analysis (OEA) in its independent investigation) cannot be made before the exemption's effective date. *See Exemption of Out-of-Serv. Rail Lines,* 5 I.C.C.2d 377 (1989). Any request for a stay should be filed as soon as possible so that the Board may take appropriate action before the exemption's effective date.

[3] Filing fees for OFAs and trail use requests can be found at 49 CFR 1002.2(f)(25) and (27), respectively.

TENNESSEE VALLEY AUTHORITY

Sugar Camp Energy LLC Mine No. 1 Significant Boundary Revision 8 Environmental Impact Statement

AGENCY: Tennessee Valley Authority.

ACTION: Notice of intent.

SUMMARY: The Tennessee Valley Authority (TVA) intends to prepare an Environmental Impact Statement evaluating the proposed expansion of mining operations (proposed mine expansion) by Sugar Camp Energy, LLC (Sugar Camp) to extract TVA-owned coal reserves in Franklin, Hamilton, and Jefferson counties, Illinois. The proposed 22,414-acre expansion area contains 21,868 acres of coal reserves owned by TVA that are under a coal lease agreement with Sugar Camp. TVA will consider whether to approve Sugar Camp's application to mine TVA-owned coal reserves within the project area. Additionally, TVA will evaluate the divestiture of TVA's mineral rights and associated land rights in Franklin, Hamilton and Jefferson counties, Illinois.

DATES: To ensure considerations, comments on the scope, alternatives being considered, and environmental issues must be received or postmarked, emailed, or submitted online no later than October 2, 2023.

ADDRESSES: Written comments should be sent to Elizabeth Smith, NEPA Specialist, TVA, 400 W. Summit Hill Drive #WT11B, Knoxville, Tennessee 37902. Comments may be sent submitted online at *https://www.tva.gov/NEPA* or by email at *NEPA@tva.gov.*

FOR FURTHER INFORMATION CONTACT: Elizabeth Smith by phone at 865–632–3053, by email at *esmith14@tva.gov,* or by mail at the address above.

SUPPLEMENTARY INFORMATION: This notice is provided in accordance with the Council on Environmental Quality regulations (40 CFR parts 1500 to 1508) and TVA procedures for implementing the National Environmental Policy Act (NEPA). TVA is a federal corporation and instrumentality of the United States government, created in 1933 by an act of Congress to foster the social and economic well-being of the residents of the Tennessee Valley region. As part of its diversified energy strategy, TVA completed a series of land and coal mineral acquisitions from the 1960s through the mid-1980s that resulted in the ownership of approximately 65,000 acres of coal reserves. These reserves consist of approximately 1.35 billion tons of Illinois coal, including portions of the Springfield (also known as Number [No.] 5) and Herrin (also known as No. 6) coal seams. TVA executed a coal lease agreement with Sugar Camp in July 2002 to mine portions of the TVA Illinois coal reserves in an environmentally sound manner, as subject to environmental reviews in accordance with NEPA and other applicable laws and regulations. Based in part on TVA's evolving electricity generation priorities, and TVA's diminishing need for coal to supply TVA's electricity generating portfolio, TVA is considering divesting itself of these same land and mineral acquisitions.

Background

On January 4, 2023, Sugar Camp submitted Permit 382 Significant Boundary Revision (SBR) 8 application to Illinois Department of Natural Resources (IDNR) proposing to expand its underground longwall mining operations at its Sugar Camp Mine No. 1 in Franklin, Hamilton, and Jefferson counties, Illinois, by approximately

22,414 acres (the project area). TVA-owned coal reserves underlie approximately 21,868 acres of the project area. Under the proposal, Sugar Camp would extract approximately 122 million raw tons of TVA-owned coal over a 25-year period (this excludes 45M tons currently permitted). Underground mining would be performed using room and pillar and continuous mining techniques during a development period, followed by longwall mining and associated planned subsidence (controlled settlement of the ground surface). Planned subsidence would occur within the project area once the coal has been removed through longwall mining methods. Sugar Camp would utilize its existing Sugar Camp Mine No. 1 facilities to process and ship the extracted coal, and expansion of these facilities is not needed to support the proposed mine expansion. Sugar Camp would also construct approximately six bleeder ventilation shafts (bleeder shafts, which ventilate the underground mine area) and install associated utilities needed to operate the bleeder shafts within the project area.

Under the terms of the lease agreement, Sugar Camp cannot commence mining of TVA-owned coal reserves until completion of all environmental reviews required under applicable laws and regulations have been finalized. TVA intends to prepare an Environmental Impact Statement (EIS) to consider whether to approve Sugar Camp's application to mine the TVA-owned coal reserves underlying the project area and/or divest all remaining TVA-owned mineral reserves in Illinois.

The EIS initiated by TVA will assess the environmental impact of approving the mining of TVA-owned coal under the mine plan and/or divesting all TVA-owned mineral reserves in IL. In doing so, TVA will address the cumulative impacts from other coal mining activities and identified federal and private actions. The cumulative impacts considered will include approved or completed activities associated with Sugar Camp Mine No. 1.

The operations of Sugar Camp Mine No. 1 have previously been subject to TVA review and approval. In 2008, Sugar Camp obtained Underground Coal Mine (UCM) Permit No. 382 from IDNR for underground longwall mining operations within approximately 12,103 acres in Franklin and Hamilton counties; the original permit did not include TVA-owned coal reserves. In 2010, Sugar Camp applied to IDNR for an expansion associated with UCM Permit No. 382 to mine TVA-owned coal under an additional 817-acre area. The permit was issued in May 2010. In 2011, TVA prepared an Environmental Assessment (EA) to document the potential effects of Sugar Camp's proposed mining of TVA-owned coal underlying a 2,600-acre area.

In November 2017, Sugar Camp obtained approval from IDNR to expand Sugar Camp Mine No. 1 by 37,972 acres. This proposal included the expansion of operations along the northern perimeter of the original mine perimeter, into a 2,250-acre area referred to as Viking District No. 2. In November 2018, TVA completed an EA that addressed expansion of mining operations into Viking District No. 2. In May 2019, TVA supplemented this EA to consider Sugar Camp's proposal to expand its mining into a 155-acre area within the Viking District No. 3, adjacent to Viking District No. 2.

In August 2019, TVA issued a Notice of Intent in the **Federal Register** to complete an EIS for the mining of approximately 12,125 acres of TVA-owned coal reserves associated with SBR No. 6 of UCM Permit No. 382. In October 2020, TVA issued the Final EIS outlining the analysis of alternatives associated with this additional mining of TVA coal reserves. In November 2020, TVA published a Record of Decision and approved Sugar Camp's application to mine the additional TVA-owned coal reserves under the IDNR-approved SBR No. 6.

Alternatives

TVA has initially identified four alternatives for evaluation in the EIS associated with the proposed purpose and need. These include a No Action Alternative and three Action Alternatives. Under the No Action Alternative, TVA would not approve the requested expansion to mine TVA-owned coal within the project area. Under Action Alternative A, TVA would implement the terms of the existing coal lease agreement, evaluate, and potentially approve the plan to mine 21,868 acres of TVA-owned coal as submitted by Sugar Camp in the current SBR of UCM Permit No. 382. Under Action Alternative B, TVA would implement the terms of the existing coal lease agreement, evaluate, and potentially allow mining of the 21,868 acres of TVA-owned coal, and consider divesting the remaining TVA-owned mineral rights/reserves including coal, oil, and gas in IL, and all associated surface rights. Under Action Alternative C, TVA considers divesting all remaining TVA-owned mineral rights/reserves including coal, oil, and gas in IL, and all associated surface rights, and would not approve Sugar Camp's expansion request as detailed under UCM Permit No. 382.

The EIS will evaluate ways to mitigate impacts that cannot be avoided. The description and analysis of these alternatives in the EIS will inform decision makers, other agencies, and the public about the potential for environmental impacts associated with the proposed mine expansion and/or divesting TVA-owned mineral rights. TVA solicits comment on whether there are other alternatives that should be assessed in the EIS. TVA also requests information and analyses that may be relevant to the project.

Resource Areas and Issues To Be Considered

Public scoping is integral to the process for implementing NEPA and ensures that (1) issues are identified early and properly studied, (2) issues of little significance do not consume substantial time and effort, and (3) the analysis of identified issues is thorough and balanced. This EIS will identify the purpose and need of the Action Alternatives and will contain descriptions of the existing environmental and socioeconomic resources within the area that could be affected by the proposed mine expansion. Evaluation of potential environmental impacts to these resources will include, but not be limited to, air quality and greenhouse gas emissions, surface water, groundwater, wetlands, floodplains, vegetation, wildlife, threatened and endangered species, land use, natural areas and parks and recreation, geology, soils, prime farmland, visual resources, noise, cultural resources, socioeconomics and environmental justice, solid and hazardous waste, public and occupational health and safety, utilities, and transportation. The EIS will analyze measures that would avoid, minimize, or mitigate environmental effects.

The final range of issues to be addressed in the environmental review will be determined, in part, from scoping comments received. TVA is particularly interested in public input on the scope of the EIS, alternatives being considered, and environmental issues that should be addressed as part of this EIS. The preliminary identification of reasonable alternatives and environmental issues in this notice is not meant to be exhaustive or final.

Public Participation

The public is invited to submit comments on the scope of the EIS no later than the date identified in the

DATES section of this notice. Federal, state, and local agencies and Native American Tribes are also invited to provide comments. Information about this project is available on the TVA web page at *www.tva.gov/nepa,* including a link to an online public comment page. Any comments received, including names and addresses, will become part of the administrative record and will be available for public inspection.

After consideration of comments received during the scoping period, TVA will develop a scoping document that will summarize public and agency comments that were received and identify the schedule for completing the EIS process. Following analysis of the resources and issues, TVA will prepare a draft EIS for public review and comment tentatively scheduled for fall 2024; the final EIS and decision is tentatively scheduled for completion in early 2025. In finalizing the EIS and in making its final decision, TVA will consider the comments that it receives on the draft EIS.

Authority: 40 CFR 1501.9.

Rebecca Tolene,

Vice President, Environment and Sustainability.

[FR Doc. 2023–18756 Filed 8–31–23; 8:45 am]

BILLING CODE 8120–08–P

TENNESSEE VALLEY AUTHORITY

Hillsboro III Solar Project

AGENCY: Tennessee Valley Authority.

ACTION: Notice of intent.

SUMMARY: The Tennessee Valley Authority (TVA) intends to prepare an environmental impact statement (EIS) for the purchase of electricity generated by the proposed Hillsboro III Solar Project in Lawrence County, Alabama. The EIS will assess the potential environmental effects of constructing, operating, and maintaining the proposed 200-megawatt (MW) alternating current (AC) solar facility. The proposed 200 MW AC solar facility would occupy approximately 1,500 acres of the 3,761-acre Project Study Area. Public comments are invited concerning the scope of the EIS, alternatives being considered, and environmental issues that should be addressed as a part of this EIS. TVA is also requesting data, information, and analysis relevant to the proposed action from the public; affected federal, state, tribal, and local governments, agencies, and offices; the scientific community; industry; or any other interested party.

DATES: The public scoping period begins with the publication of this Notice of Intent in the **Federal Register**. To ensure consideration, comments must be postmarked, emailed, or submitted online no later than October 2, 2023.

ADDRESSES: Written comments should be sent to Elizabeth Smith, NEPA Specialist, Tennessee Valley Authority, 400 West Summit Hill Drive, WT 11B, Knoxville, Tennessee 37902. Comments may be submitted online at: *www.tva.gov/nepa,* or by email to *nepa@tva.gov.* Please note that TVA encourages comments submitted electronically.

FOR FURTHER INFORMATION CONTACT: Elizabeth Smith by email at *esmith14@tva.gov,* by phone at (865) 632–3053, or by mail at the address above.

SUPPLEMENTARY INFORMATION: This notice is provided in accordance with the Council on Environmental Quality's Regulations (40 CFR parts 1500 to 1508) and TVA's procedures for implementing the NEPA (18 CFR 1318). TVA is an agency and instrumentality of the United States, established by an act of Congress in 1933, to foster the social and economic welfare of the people of the Tennessee Valley region and to promote the proper use and conservation of the region's natural resources. One component of this mission is the generation, transmission, and sale of reliable and affordable electric energy.

Background

In June 2019, TVA completed the final 2019 Integrated Resource Plan (IRP) and associated EIS. The IRP is a comprehensive study of how TVA will meet the demand for electricity in its service territory over the next 20 years. The 2019 IRP recommends solar expansion and anticipates growth in all scenarios analyzed, with most scenarios anticipating 5,000–8,000 MW and one anticipating up to 14,000 MW by 2038. Customer demand for cleaner energy prompted TVA to release a Request for Proposal (RFP) for renewable energy resources (2022 Carbon-Free RFP).

TVA is considering entering into a Power Purchase Agreement (PPA) with Urban Grid Solar to purchase 200 MW AC of power generated by the proposed Hillsboro III Solar Project, hereafter referred to as the Project. The proposed 200 MW AC solar facility would occupy approximately 1,500 acres of the 3,761-acre Project Study Area which is located entirely in Lawrence County, Alabama. The project site is north of Wheeler, Alabama along US Highway 72 Alternate between Courtland and Hillsboro, Alabama. The project site is mostly farmland with areas of woody wetlands, deciduous forest, and hay/pasture. The land surplus is to accommodate relocating the array if any areas need to be avoided as a result of the NEPA review. A map showing the project site is available at *www.tva.gov/nepa.*

Preliminary Proposed Action and Alternatives

In addition to a No Action Alternative, TVA will evaluate the action alternative of purchasing power from the proposed Hillsboro III Solar Project under the terms of a PPA. In evaluating alternatives, TVA considered other solar proposals, prior to selecting the Hillsboro III site for further evaluation. Part of the screening process included a review of transmission options, including key connection points to TVA's transmission system. The Hillsboro site stood out as a viable option for connectivity. Environmental and cultural considerations are also included in TVA's screening. For the proposed site, the solar developer plans to consider the establishment of an alternative footprint so that impacts to cultural and/or biological resources could be avoided. The EIS will also evaluate ways to mitigate impacts that cannot be avoided. The description and analysis of these alternatives in the EIS will inform decision makers, other agencies, and the public about the potential for environmental impacts associated with the proposed solar facility. TVA solicits comments on whether there are other alternatives that should be assessed in the EIS.

Project Purpose and Need

The Hillsboro III Solar Project that was submitted as a result of TVA's 2022 Carbon-Free RFP will help TVA meet immediate needs for additional renewable generating capacity in response to customer demands and fulfill the renewable energy goals established in the 2019 IRP. To meet these goals, public scoping is integral to the process for implementing NEPA and ensures that (1) issues are identified early and properly studied, (2) issues of little significance do not consume substantial time and effort, and (3) the analysis of identified issues is thorough and balanced. This EIS will identify the purpose and need of the project and will contain descriptions of the existing environmental and socioeconomic resources within the area that could be affected by the proposed solar facility, including the documented historical, cultural, and environmental resources. Evaluation of potential environmental impacts to these resources will include, but not be limited to, air quality and greenhouse gas emissions, surface

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Appendix B – Public and Agency Comments

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

October 2, 2023

VIA ELECTRONIC MAIL ONLY
(esmith14@tva.gov)

Elizabeth Smith
Tennessee Valley Authority
400 West Summit Hill Drive, WT 11B-K
Knoxville, Tennessee 37902

RE: EPA Comments: Notice of Intent to Prepare an Environmental Impact Statement for Sugar Camp Energy LLC Mine Expansion (Significant Boundary Revision No. 8), Franklin, Jefferson, and Hamilton Counties, Illinois

Dear Ms. Smith:

The U.S. Environmental Protection Agency (EPA) has reviewed the Tennessee Valley Authority's (TVA) Federal Register Notice of Intent (NOI) regarding the forthcoming preparation of an Environmental Impact Statement (EIS) for the proposed Sugar Camp Mine Expansion – Significant Boundary Revision No. 8 in Franklin, Hamilton, and Jefferson Counties, Illinois. TVA is the lead agency under the National Environmental Policy Act (NEPA) and Sugar Camp Mine, LLC is the project proponent. This letter provides EPA's scoping comments on the proposal pursuant to NEPA, the Council on Environmental Quality's NEPA Implementing Regulations (40 CFR 1500-1508), and Section 309 of the Clean Air Act.

TVA is preparing a Draft EIS to consider whether to allow Sugar Camp Mine, LLC to expand mining operations to mine approximately 21,868 acres of TVA-owned coal reserves, as part of the existing Sugar Camp Mine – Revision No. 6. The full proposed mining expansion acreage is 22,414 acres; this land is owned by TVA and is under a coal lease agreement with the project proponent. A state mining permit application (Underground Coal Mine [UCM] Permit Number 382) is currently under separate review by the Illinois Department of Natural Resources (Illinois DNR). According to the NOI, the project proponent would extract approximately 122 million raw tons of TVA-owned coal over a 25-year period. Surface and underground disturbances would occur under the proposed mine expansion. Surface activities include construction of six bleeder ventilation shafts and associated infrastructure. Underground mining would be performed using both room-and-pillar mining and longwall mining and include planned subsidence under portions of the project area. The project proponent would use existing coal transfer and processing facilities. EPA previously provided comments on the EIS for Significant Boundary Revision (SBR) Number 6 in 2020.

TVA has identified four alternatives for evaluation in the forthcoming EIS; these include a No Action Alternative and three Action Alternatives. Alternatives are as follows:

- No Action: TVA would not approve the requested expansion to mine TVA-owned coal within the project area.
- Alternative A: TVA would implement the terms of the existing coal lease agreement, evaluate, and potentially approve the plan to mine 21,868 acres of TVA-owned coal.

- Alternative B: TVA would implement the terms of the existing coal lease agreement, evaluate, and potentially allow mining of the 21,868 acres of TVA-owned coal. Additionally, TVA would consider divesting the remaining TVA-owned mineral rights/reserves, including coal, oil, and gas in Illinois, and all associated surface rights.
- Alternative C: TVA would consider divesting all remaining TVA-owned mineral rights/reserves including coal, oil, and natural gas in Illinois, and all associated surface rights, and would not approve Sugar Camp's expansion request as detailed under UCM Permit No. 382.

EPA recognizes that current details regarding the proposed actions and potential impacts associated with the alternatives are limited. Based on our review of the available materials, including previous NEPA documentation, EPA recommends the forthcoming EIS provide clear information regarding potential impacts to surface waters, air quality, and human health. Our detailed comments, enclosed, focus on the project's purpose and need, range of alternatives, project description, and scope.

Our goal is to provide meaningful comments and recommendations that will improve the quality of the NEPA documentation, improve the permitting and NEPA processes, and better protect human health and the environment. Given this, EPA will continue to serve as a Cooperating Agency, providing consultation as TVA develops a comprehensive and defensible document, with the goal of efficiently resolving environmental issues early in the environmental review process.

Thank you in advance for your consideration of comments to help inform the Draft EIS and to better protect human health and the environment. If you have any questions regarding the contents of this letter, or if would like to discuss our comments in greater detail, please contact Elizabeth Poole at 312-353-2087 or via email at poole.elizabeth@epa.gov.

Sincerely,

Krystle Z. McClain, P.E.
NEPA Program Supervisor
Tribal and Multimedia Programs Office

Enclosure (3): Detailed Comments
USFWS Letter – August 4, 2017
Construction Emission Control Checklist

Cc (via email):
Robert Gramke, Chief, Regulatory Branch, U.S. ACE
Tyson Zobrist, Regulatory Project Manager, U.S. ACE
Matt Mangan, U.S. Fish and Wildlife Service
Jim Schafer, Illinois Department of Natural Resources
Brad Hayes, Illinois Department of Natural Resources
Bill Marr, Illinois EPA
Darin LeCrone, Illinois EPA
Darren Gove, Illinois EPA
Scott Twait, Illinois EPA

Enclosure 1: EPA's Detailed Comments on the Notice of Intent (Scoping) to Prepare an Environmental Impact Statement for the Sugar Camp Mine Expansion (No. 8) Franklin, Hamilton, and Jefferson Counties, Illinois

Background Documentation

EPA reviewed the following documents, referred to collectively hereafter as the "scoping package" in our comments:

- Notice of Intent (NOI) to Prepare an Environmental Impact Statement (EIS) for the project in the Federal Register (dated September 1, 2023);
- Illinois Department of Natural Resources (IDNR) draft mining permit - Number 382 (Significant Boundary Revision (SBR) Number 8);
- Illinois Environmental Protection Agency (Illinois EPA) previous Construction Permit 18050018, updated Construction Permit 22030011, and State Operating Permit 12070021.
- Previous NEPA documentation prepared by the Tennessee Valley Authority (TVA), including the 2020 Draft EIS and Final EIS for SBR Number 6.

Purpose and Need

NEPA regulations require that the Draft EIS "briefly specify the underlying purpose and need to which the agency is responding in proposing the alternatives including the proposed action" (40 CFR § 1502.13). The purpose and need statement should be specific enough to allow for a reasonable range of alternatives, but not so narrow as to pre-select a particular alternative. The statement should also justify the need for project impacts on the human and natural environment.

> **Recommendations:** The Draft EIS should articulate the purpose and need for the proposed action, which should include consideration of trends in coal demand and of alternative sources of energy production. If the need for a Clean Water Act (CWA) Section 404 permit application is triggered (see comments on Aquatic Resources – Streams and Wetlands below), the U.S. Army Corps of Engineers' (USACE) public interest review would also require review of "reasonable alternative locations and methods to accomplish the objective of the proposed structure or work."[1]

Project Description

Range of Alternatives

NEPA regulations require an EIS to "rigorously explore and objectively evaluate all reasonable alternatives" (40 CFR § 1502.14), whether or not they are within the jurisdiction of TVA. EPA commends TVA for already including alternatives that prioritize disinvestment in fossil fuels.

> **Recommendations:** Based on articulation of the purpose and need, as discussed above, the Draft EIS should consider a sufficient range of alternatives. EPA understands that coal resources are in a fixed location; however, alternatives may consider alternative site configuration, mining methods, mine locations, coal resources, or sources of energy,

[1] See "U.S. Army Corps of Engineers Permitting Process Information" at https://www.lrl.usace.army.mil/Portals/64/docs/regulatory/Permitting/PermittingProcessInformation.pdf

among other factors.

Description of Actions

The scoping package describes the following general activities as planned for the proposed project: room-and-pillar mining; continuous mining; longwall mining; associated planned subsidence (under a portion of the site); surface and underground disturbances; and both on-site and off-site infrastructure needs (such as six new bleeder ventilation shafts and use of the existing coal processing and transportation facilities, respectively).

> **Recommendations:** The Draft EIS should outline all specific proposed activities associated with each alternative to accurately assess potential impacts. This should include temporary staging of equipment, placement of fill or waste materials, temporary holding areas, planned subsidence, and locations of applicable on-site and off-site permanent facilities, among other potential proposed actions. The Draft EIS should include a description of any modifications, upgrades, or decommissioning activities related to the processing, transportation, and shipping facilities.

At this time, EPA comments on surface impacts are limited considering the proposed EIS is for an underground mine with unknown proposed surface impacts. The IDNR permit repeats a claim that there will be no surface impacts because it is an underground mine. However, the proposed underground longwall mining is anticipated to subside, potentially causing impacts to aquatic resources on the site and secondary impacts to upstream and downstream waters.

> **Recommendation:** The Draft EIS should disclose reasonably foreseeable surface-level impacts as a result of the underground mining process, particularly from planned subsidence.

Aquatic Resources

Wetlands and Streams Characterization

The expanded permit and shadow areas remain located in the glaciated upland area of northeastern Franklin County and western Hamilton County. These areas are situated within the reaches of multiple perennial streams, including, but not limited to, Sugar Camp Creek, Goose Creek, Carlton Branch and Taylor Branch and a large number of unnamed tributaries. National Wetlands Inventory (NWI) mapping indicates the likelihood of forested wetlands along Sugar Camp Creek and many other wetlands and ponds connected to streams within the proposed mining and subsidence areas.

> **Recommendation:** Include maps in the Draft EIS that show potential subsidence locations and the anticipated impacts to aquatic resources. The EIS should also include maps that depict full boundaries of wetland features and a delineation of all wetlands and streams (ephemeral, intermittent and perennial) within the project boundary. Further, if impacts to streams and wetlands are anticipated due to subsidence or any other reasons, it will be necessary to describe the baseline condition and quality of the resources that would be impacted using appropriate assessment methods. Collection of baseline conditions may be completed during the delineation of all wetlands and streams to ensure enough information is collected prior to review which may result in a request for

additional information by regulatory and coordinating agencies.

Secondary Impacts to Wetlands and Streams

Although no surface disturbance is proposed in this Revision, post-subsidence mitigation may be necessary to restore pre-existing drainage patterns as associated operations and bleeder shaft construction could impact regulated water resources. Subsidence may impact hydrology and wetland functional capacity and could also result in flooding or alteration of stream flow. Activities in the project area that would alter streams or wetlands may require a Section 404 permit from USACE. At a minimum, stream crossings have been noted on the provided maps which would trigger the need for a Section 404 CWA permit and a review of the overall project.

Recommendations: Assess the potential and expected impacts to wetlands and streams related to alterations from subsidence along with potential filling or dredging of wetlands or streams. The applicant should develop a plan for monitoring of stream and wetland resources post-construction. We recommend the applicant also assess whether adjacent, off-site water resources may be indirectly impacted. While the applicant suggests that the quality of streams and wetlands within the proposed permit shadow area will not likely change as a result of the proposed operations, those resources should be monitored to ensure there are no impacts. If impacts occur, appropriate remediation or mitigation should be required.

Clean Water Act Section 404(b)(1) Guidelines

Surface activities are anticipated through the construction of bleeder shafts and installation of associated utilities to operate the bleeder shafts to support the extraction of TVA-owned coal reserves. The exact location of these surface activities is unknown at this time, but they would occur within the project area.

Recommendations: EPA has the following recommendations related to the Clean Water Action Section 404(b)(1) guidelines:

- The exact location of the bleeder shafts should be mapped and provided for further review to determine if they will result in impacts to aquatic resources and require a Clean Water Act Section 404 permit.
- The EIS should clearly explain how the project would comply with the Clean Water Act Section 404(b)(1) Guidelines[2] if impacts to streams and wetlands are proposed. We strongly suggest the applicant exhaust all efforts at avoidance and minimization of stream and wetland impacts due to surface disturbance and the planned subsidence associated with longwall mining and to reduce cumulative impacts to regulated water resources in the project area. If surface impacts are anticipated, the Section 404 alternatives analysis will need to consider off-site alternatives as well as alternative mining methods rather than just the preferred site and the No Action alternative. The EIS should include a robust alternatives analysis which examines the use of other sites rather than just the site proposed.

[2] 40 CFR § 230

- EPA hereby reiterates comments previously made in the U.S. Fish and Wildlife Service's (USFWS) August 4, 2017, comment letter regarding Significant Boundary Revision Number 6 (letter enclosed) that impacts to streams and wetlands be avoided or that unavoidable impacts be minimized to the greatest extent possible. If a CWA Section 404 permit is required than an appropriate mitigation plan should be developed and coordinated with USACE, EPA, and the USFWS.
- If a CWA 404 permit application is required, the applicant must provide information to demonstrate project need, which should consider the current demand, market conditions, and currently available coal from other sources. The analysis should examine the applicant's current demand, the coal tonnage at current stockpiles, and the coal reserves at operating mines. These details are necessary to review the need for the project. Other publicly available sources indicate a steady downward trend in the consumption of coal, specifically by the electric power utilities.[3] We recommend the EIS include an analysis of current and future coal needs.

Water Quality

EPA is aware of per- and polyfluoroalkyl substances (PFAS) complaints made against the applicant at the Sugar Camp Mine based on use of fire-suppressant foam.

> **Recommendation:** The Draft EIS should include how PFAS-containing foam was used at the mine and provide details of any resultant investigations. Details should include whether there was any indication of PFAS in wastewater or runoff. The Draft EIS should also discuss if PFAS foam will continue to be used at the project site in the future.

Increasing the mine area would increase the quantity of wastewater needing treatment and disposal under the National Pollutant Discharge Elimination System (NPDES) program. The expanded operation would have an increase on the volume of water pumped from the underground mine works, which is a categorical wastestream. The coal and refuse removal from the operation would create additional wastewater volumes at the coarse refuse disposal sites and at the coal fine slurry disposal. All three of these wastestreams are categorical wastestreams under the NPDES program. Further, the existing NPDES permit contains water-quality-based effluent limits for chloride and sulfate.

> **Recommendation:** The scoping documents state that it is expected that no changes to the mine's existing NPDES permit will be required. The Draft EIS should evaluate pollutant loading limits to reflect increased production and provide additional documentation supporting this assertion.

Aerial photos of the current waste management facilities show deep red pools, which are consistent with the presence of acidic aquatic conditions. The NPDES categorical standards are determined based on the quality of water prior to treatment, and a deep red pool is an indication that the facility has an acid/ferruginous wastewater stream. The current NPDES permit only authorizes the facility to discharge Alkaline Mine Drainage, not Acid Mine Drainage.

> **Recommendations:** Verify that the facility has the appropriate authorization to dispose

[3] https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

of Acid Mine Drainage; and, if required, work to modify the current NPDES permit as needed. Document these actions in the Draft EIS.

Cumulative Impacts to Water Quality

In Indiana, similar mining operations have overlapped with historic oil and gas wells. Some of these wells were associated with Underground Injection Control Type II disposal and recovery operations.

Recommendations: The Draft EIS should identify whether there are historic oil and gas wells in the area. If historic wells exist, EPA recommends increased monitoring frequency to monitor for fluctuations in the qualtiy of wastewater, including having treatment and storage facilities which are capable of accommodating fluctuations in the quality of the wastewater.

Air Quality

Upon review of the provided information and previous permitted actions through the Illinois Environmental Protection Agency (IEPA), we have the following comments on the proposed expansion.

Recommendations:

- Any equipment that has the potential to emit air pollution may be required to obtain a Clean Air Act (CAA) permit before it is installed at the site. Prior to beginning actual construction of such equipment, the applicant should consult with IEPA to determine whether a CAA permit is required.
- A construction permit may be required if the coal mine expansion may lead to an "increased utilization" of the emission units at the surface level facility. Sugar Camp Energy may need to submit an application for a construction permit to the Illinois EPA if there will be any changes in the method of operation of the existing emission units at the surface level facility.
- Additionally, newly constructed emission units may need to be addressed within an operation permit. The applicant applied for a Federally Enforceable State Operating Permit (FESOP) in 2015, which was subsequently issued on May 12, 2022. It is not clear that any of the newly constructed emission units within construction permit #22030011 are incorporated into that FESOP permit.
- Any construction permit issued to address any new emission units or to address any changes in the method of operation to existing emission units will also need to be incorporated as part of an updated FESOP permit. The applicant will need to consult with the Illinois EPA to determine if an application to update the FESOP permit issued in 2015 will be necessary.
- Coal processing plant changes should be evaluated for applicability of CAA permitting requirements, including all federal requirements for New Source Performance Standards – specifically 40 CFR 60, Subpart Y. Any modifications to CAA permitting requirements should be disclosed in the Draft EIS.

Construction and operation of the proposed project would produce air emissions. Construction truck trips for material hauling, exhaust from heavy machinery, and generation of fugitive dust, are among anticipated air pollution sources. During operations, consider routine operations of the mine as well as maintenance and hauling activities.

> **Recommendations:** In the Draft EIS, identify all reasonably foreseeable sources of air emissions. Provide quantitative estimates of emissions totals and identify measures to minimize emissions.
>
> To minimize fugitive emissions during construction and operation, the fugitive coal dust emissions control plan may need to be updated. Specifically, when constructing surface equipment, the fugitive dust control plan, submitted to IEPA on July 27, 2018 and incorporated by reference into FESOP permit# 12070021, should be updated to incorporate the latest plant configuration and include equipment added after the 2018 fugitive dust control plan was submitted. Consider the enclosed Construction Emissions Control Checklist as a resource.

Based on the scoping package there would be construction of six bleeder shafts and installation of associated utilities to operate the bleeder shafts to support the extraction of coal. As provided above, any equipment that has the potential to emit air pollution may be required to obtain a CAA permit before installation at the site.

> **Recommendation:** Prior to beginning actual construction of such equipment, the applicant should consult with Illinois EPA to determine whether a CAA permit will be required.

It is unclear whether there would be increased throughput to the coal preparation plant due to Significant Boundary Revision Number 8 and whether that throughput would require revisions to construction and operating permits for this facility. Our review of the facility's IEPA Construction Permits suggest that the primary crushers and belt conveyers may experience increased use due to the project, which could lead to an increase in particulate matter emissions from the source.

> **Recommendations:** The Draft EIS should state whether there would be an increase in throughput to the coal preparation plant as a result of the project. The analysis should include whether Construction or Operating Permits would need to be revised to address the increased emissions or whether a new permit would be required.

Climate Change and Greenhouse Gas Emissions

Executive Order 14008: Tackling the Climate Crisis at Home and Abroad states, "*The United States and the world face a profound climate crisis. We have a narrow moment to pursue action…to avoid the most catastrophic impacts of that crisis and to seize the opportunity that tackling climate change presents*." The U.S. Global Change Research Program's National Climate Assessment provides data and scenarios that may be helpful in assessing trends in temperature, precipitation, and frequency and severity of storm events.[4]

[4] Information on changing climate conditions is available through the National Climate Assessment at: http://nca2018.globalchange.gov

All mining alternatives would directly release greenhouse gas (GHG) emissions during construction from trucks hauling materials, workers' vehicles, and operation of equipment. Downstream emissions from combustion are reasonably foreseeable. It is important for the Draft EIS to fully quantify and adequately disclose the impacts of the GHG emissions from the action alternatives and discuss the implications of long-term carbon lock-in in light of science-based policies established to avoid the worsening impacts of climate change.

Estimating upstream and downstream emissions would provide useful information to the public and decisionmakers as to the scale of the project's indirect impacts and the long-term public interests at stake. Omitting such emissions would result in an underestimation of the proposal's indirect impacts. In addition, estimates of the social cost of greenhouse gases (SC-GHG[5]) are informative for assessing the impacts of GHG emissions. SC-GHG estimates allow analysts to monetize the societal value of changes in GHG emissions from actions that have small, or marginal, impacts on cumulative global emissions. Estimates of the social cost of carbon (SC-CO_2) and other greenhouse gases (e.g., social cost of methane (SC-CH_4)) have been used for over a decade in Federal government analyses. Quantification of anticipated GHG releases and associated SC-GHG comparisons among all alternatives (including the No Action Alternative scenarios) within the Draft EIS would inform project decision-making and provide clear support for implementing all practicable measures to minimize GHG emissions and releases.

Recommendations:

- EPA recommends the Draft EIS include a discussion of reasonably foreseeable effects that changes in the climate may have on the proposed project, and what impacts the proposed project will have on climate change consequences. These considerations could help inform the development of measures to improve the resilience of the project.
- Incorporate practicable measures to address risks in the mine plan's design or alternatives. Consider project design elements to make the project resilient to climate change effects on the project. Consider designing all diversion features, processing facilities, dewatering plans, and associated infrastructure for a 500-year, 24-hour storm event as such events are expected to be more frequent under climate change scenarios.
- Include an estimate of the direct and indirect greenhouse gas emissions caused by the proposal and alternatives. The estimated indirect emissions should include emissions from end use combustion.
- Consider practicable mitigation of direct greenhouse gas emissions, such as using best practices to minimize construction emissions and use of alternative sources of energy to fossil fuels.
- In the affected environmental section, discuss projected future environmental trends (i.e., increasing flooding and severe precipitation events) that may impact the proposed project. Include consideration of future climate scenarios, such as those

[5] EPA uses the general term, "social cost of greenhouse gases" (SC-GHG), where possible because analysis of GHGs other than CO_2 are also relevant when assessing the climate damages resulting from GHG emissions. The social cost of carbon (SC-CO_2), social cost of methane (SC-CH_4), and social cost of nitrous oxide (SC-N_2O) can collectively be referenced as the SC-GHG.

provided by the National Climate Assessment[6]. If projected changes could exacerbate environmental impacts of the project, these likely changes should be considered in the Draft EIS.
- Pursue alternatives that disinvest in fossil fuels, contributing to the goals outlined in E.O. 14057, *Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability.*

Health and Safety

Adherence to occupational health and safety standards are part of the human environment under NEPA; NEPA calls on the Federal government to, "attain the widest range of beneficial uses of the environmental without degradation, risk to health or safety, or other undesirable and unintended consequences."[7] Information regarding human health protections are an important part of public disclosure and the decision-making process.

Recommendation: The Draft EIS should include information about how TVA and the project proponent ensure occupational health and safety onsite; this might be in the form of incorporation by reference. The Draft EIS should include clear and specific mitigation measures regarding human health and occupational safety.

Noise and Vibration

Health effects are associated with noise. "*Problems related to noise include stress related illnesses, high blood pressure, speech interference, hearing loss, sleep disruption, and lost productivity…[R]esearch has shown that exposure to constant or high levels of noise can cause countless adverse health effects*."[8]

Recommendations:
- Disclose the anticipated maximum noise level at the project site, particularly for miners.
- Analyze temporary and long-term (i.e., maintenance) noise impacts for all noise-sensitive receptors. Include residences, schools, day care centers, senior housing, community centers, and medical facilities. Disclose and compare noise and vibration impacts at specific noise sensitive locations for all project alternatives.
- Assess vibration impacts from mining and/or blasting at residences and other sensitive receptors.
- Include maps with noise contours to delineate the anticipated temporary and long-term noise impacts for all project alternatives. Indicate all sensitive receptors that may be impacted.

Children's Health

Children are more vulnerable to environmental exposure. According to EPA's publicly available

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[6] http://nca2018.globalchange.gov/
[7] Section 101(b)(3) [42 USC 4331]
[8] https://www.epa.gov/clean-air-act-overview/clean-air-act-title-iv-noise-pollution#:~:text=Health%20Effects,sleep%20disruption%2C%20and%20lost%20productivity

environmental and human health database *EJScreen*[9], there are several schools near the proposed project area.

> **Recommendation:** The Draft EIS should clarify whether identified places where children live, learn, and play would be impacted by the proposed project (if, for example, schools are located downwind of the ventilation shafts or near coal transportation routes). If TVA and the project proponent identify potential exposures, the Draft EIS should include outreach to impacted populations and mitigation measures to reduce potential harm.

Environmental Justice

Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations* (February 16, 1994), directs federal agencies to identify and address, as appropriate, disproportionately high and adverse human health or environmental effects of their actions on minority and low-income populations. It further directs agencies to develop a strategy for implementing environmental justice and providing minority and low-income communities access to public information and public participation. As such, we recommend that TVA address adverse environmental effects of the proposed project on these communities and outline measures to mitigate for impacts.

E.O. 12898 was supplemented by E.O. 14096, *Revitalizing Our Nation's Commitment to Environmental Justice for All* (April 26, 2023), which directs federal agencies to identify and address disproportionate and adverse human health or environmental burdens *and* risks, including those related to climate change and cumulative impacts, on communities with environmental justice concerns. It further directs agencies to provide opportunities in the NEPA process for early and meaningful involvement for communities with environmental justice concerns that may be potentially affected by a proposed action.

> **Recommendations:** We recommend implementation of the following environmental justice best practices before publication of the Draft EIS to better inform the potential impacts.
>
> - *Promising Practices for Environmental Justice Methodologies in NEPA Reviews*[10] may serve as a useful resource during the environmental review process. This document is a compilation of methodologies from current agency practices identified by the NEPA Committee of the Federal Interagency Working Group on Environmental Justice. The document focuses on the interface of EJ considerations through NEPA processes and provides recommendations on applying EJ methodologies that have been established in federal NEPA practice.
> - TVA should use EPA's EJScreen and/or the most recent American Community Survey from the U.S. Census Bureau for the Draft EIS to determine the presence of minority and low-income populations. In identifying minority populations, a 50 percent standard does not apply if "the minority population percentage of the affected

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[9] https://ejscreen.epa.gov/mapper/

[10] Available at: https://www.epa.gov/sites/production/files/2016-08/documents/nepa_promising_practices_document_2016.pdf.

area is meaningfully greater than the minority population percentage in the general population or other appropriate unit of geographic analysis."[11] To best illustrate the presence of a minority population, we recommend that TVA analyze block groups, the smallest geographical unit for which the U.S. Census Bureau publishes data.

- After TVA has determined if minority and low-income populations exist in the project area, we recommend that the Draft EIS discuss whether these communities would be potentially affected by individual or cumulative actions of the proposed action (e.g., the various SBRs). We also recommend addressing whether any of the alternatives would cause any disproportionate and high adverse impacts, such as higher exposure to toxins; changes in existing ecological, cultural, economic, or social resources or access; cumulative or multiple adverse exposures from environmental hazards; or community disruption.
- If it is determined that minority and low-income populations may be disproportionately impacted, describe in the Draft EIS the measures taken by TVA to fully analyze the environmental effects of the action on minority communities and low-income populations and identify potential mitigation measures. Clearly identify a monitoring and adaptive management plan to ensure that mitigation is effective and successful.
- EJScreen indicates broadband service gaps across this area. TVA should present varied opportunities for affected communities to provide input into the NEPA process, including non-digital access to information. The Draft EIS should include information describing what was done to inform these communities about the project and the potential impacts it will have on their communities (e.g., notices, mailings, fact sheets, briefings, presentations, translations, newsletters, reports, community interviews, surveys, canvassing, telephone hotlines, question and answer sessions, stakeholder meetings, and on-scene information), what input was received from the communities, and how that input was utilized in the decisions that were made regarding the project.

<u>Threatened and Endangered Species</u>

The proposed project area is within range of the Federally-listed endangered Indiana bat, endangered piping plover, and the threatened northern long-eared bat. There may be maternity roost(s) for the Indiana bat near the mine site. Changes to surface waters per CWA Section 404 permitting or water quality as a result of discharge may impact listed species.

Recommendations:

- Utilize the U.S. Fish and Wildlife Service's project planning tool (IPAC – Information for Planning and Conservation) to determine all federally listed endangered or threatened species that may be, or are, present within the boundaries of all project alternatives.
- Discuss whether project alternatives will have effects on migratory bird pathways in the project vicinity.

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[11] CEQ. Environmental Justice: Guidance Under the National Environmental Policy Act. December 1997. Available at https://www.epa.gov/sites/production/files/2015-02/documents/ej_guidance_nepa_ceq1297.pdf

- Ensure that project impacts on state and Federally-listed and candidate species are disclosed and assessed for all project alternatives in the Draft EIS.
- Ensure that the Draft EIS contains the assessments and conclusions from the USFWS and the Illinois Department of Natural Resources regarding the potential for impacts to state and Federally-listed species that would result from each project alternative.
- Summarize TVA's and the applicant's coordination with USFWS and IDNR related to listed species and include any correspondence from the agencies related to threatened, endangered, and candidate species in an appendix. Disclosing USFWS's and IDNR's recommendations and findings would clarify the scope of impacts.
- Include commitments by the applicant to adhere to all USFWS and IDNR recommendations to protect species, including, but not limited to, seasonal restrictions on tree clearing and in-water work.
- Require use of pollinator-promoting plants and/or native plant seed mixtures for restoration of disturbed areas associated with project construction activities.

Consultation and Coordination

- The Draft EIS should document consultation and coordination, for example with: USACE, USFWS, and EPA on impacts to Waters of the U.S.; USFWS and Illinois DNR regarding state- and federally- listed threatened or endangered species; the State Historic Preservation Office on historic resources; and applicable Tribal governments on historic tribal artifacts or other potential impacts.
- EPA recommends identification, inclusion, and integration of indigenous knowledge into the EIS analysis, as appropriate. Such anthropological work can include the collection of local and traditional knowledge concerning the affected environment, anticipated impacts from the project, and traditional hunting and land use patterns in the area. This information should be reviewed and included in the Draft EIS to the extent possible and used in the analysis of potential impacts.

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Enclosure 3: U.S. Environmental Protection Agency
Construction Emission Control Checklist

Diesel emissions and fugitive dust from project construction may pose environmental and human health risks and should be minimized. In 2002, EPA classified diesel emissions as a likely human carcinogen, and in 2012 the International Agency for Research on Cancer concluded that diesel exhaust is carcinogenic to humans. Acute exposures can lead to other health problems, such as eye and nose irritation, headaches, nausea, asthma, and other respiratory system issues. Longer term exposure may worsen heart and lung disease.[1] We recommend the Tennessee Valley Authority consider the following protective measures and commit to applicable measures in the Draft Environmental Impact Statement (EIS).

Mobile and Stationary Source Diesel Controls

Purchase or solicit bids that require the use of vehicles that are equipped with zero-emission technologies or the most advanced emission control systems available. Commit to the best available emissions control technologies for project equipment in order to meet the following standards.

- On-Highway Vehicles: On-highway vehicles should meet, or exceed, the EPA exhaust emissions standards for model year 2010 and newer heavy-duty, on-highway compression-ignition engines (e.g., long-haul trucks, refuse haulers, shuttle buses, etc.).[2]
- Non-road Vehicles and Equipment: Non-road vehicles and equipment should meet, or exceed, the EPA Tier 4 exhaust emissions standards for heavy-duty, non-road compression-ignition engines (e.g., construction equipment, non-road trucks, etc.).[3]
- Locomotives: Locomotives servicing infrastructure sites should meet, or exceed, the EPA Tier 4 exhaust emissions standards for line-haul and switch locomotive engines where possible.
- Marine Vessels: Marine vessels hauling materials for infrastructure projects should meet, or exceed, the latest EPA exhaust emissions standards for marine compression-ignition engines (e.g., Tier 4 for Category 1 & 2 vessels, and Tier 3 for Category 3 vessels).[4]
- Low Emission Equipment Exemptions: The equipment specifications outlined above should be met unless: 1) a piece of specialized equipment is not available for purchase or lease within the United States; or 2) the relevant project contractor has been awarded funds to retrofit existing equipment, or purchase/lease new equipment, but the funds are not yet available.

Consider requiring the following best practices through the construction contracting or oversight process:

- Establish and enforce a clear anti-idling policy for the construction site.
- Use onsite renewable electricity generation and/or grid-based electricity rather than diesel-powered generators or other equipment.

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[1] Carcinogenicity of diesel-engine and gasoline-engine exhausts and some nitroarenes. *The Lancet.* June 15, 2012
[2] http://www.epa.gov/otaq/standards/heavy-duty/hdci-exhaust.htm
3 https://www.epa.gov/emission-standards-reference-guide/epa-emission-standards-nonroad-engines-and-vehicles
[4] https://www.epa.gov/emission-standards-reference-guide/all-epa-emission-standards

- Use electric starting aids such as block heaters with older vehicles to warm the engine.
- Regularly maintain diesel engines to keep exhaust emissions low. Follow the manufacturer's recommended maintenance schedule and procedures. Smoke color can signal the need for maintenance (e.g., blue/black smoke indicates that an engine requires servicing or tuning).
- Where possible, retrofit older-tier or Tier 0 nonroad engines with an exhaust filtration device before it enters the construction site to capture diesel particulate matter.
- Replace the engines of older vehicles and/or equipment with diesel- or alternatively-fueled engines certified to meet newer, more stringent emissions standards (e.g., plug-in hybrid-electric vehicles, battery-electric vehicles, fuel cell electric vehicles, advanced technology locomotives, etc.), or with zero emissions electric systems. Retire older vehicles, given the significant contribution of vehicle emissions to the poor air quality conditions. Implement programs to encourage the voluntary removal from use and the marketplace of pre-2010 model year on-highway vehicles (e.g., scrappage rebates) and replace them with newer vehicles that meet or exceed the latest EPA exhaust emissions standards, or with zero emissions electric vehicles and/or equipment.

Fugitive Dust Source Controls

- Stabilize open storage piles and disturbed areas by covering and/or applying water or chemical/organic dust palliative, where appropriate. This applies to both inactive and active sites, during workdays, weekends, holidays, and windy conditions.
- Install wind fencing and phase grading operations where appropriate, and operate water trucks for stabilization of surfaces under windy conditions.
- When hauling material and operating non-earthmoving equipment, prevent spillage and limit speeds to 15 miles per hour (mph). Limit speed of earth-moving equipment to 10 mph.

Occupational Health

- Reduce exposure through work practices and training, such as maintaining filtration devices and training diesel-equipment operators to perform routine inspections.
- Position the exhaust pipe so that diesel fumes are directed away from the operator and nearby workers, reducing the fume concentration to which personnel are exposed.
- Use enclosed, climate-controlled cabs pressurized and equipped with high-efficiency particulate air (HEPA) filters to reduce the operators' exposure to diesel fumes. Pressurization ensures that air moves from inside to outside. HEPA filters ensure that any incoming air is filtered first.
- Use respirators, which are only an interim measure to control exposure to diesel emissions. In most cases, an N95 respirator is adequate. Workers must be trained and fit-tested before they wear respirators. Depending on the type of work being conducted, and if oil is present, concentrations of particulates present will determine the efficiency and type of mask and respirator. Personnel familiar with the selection, care, and use of respirators must perform the fit testing. Respirators must bear a National Institute for Occupational Safety and Health approval number.

NEPA Documentation

- Per Executive Order 13045 on Children's Health[5], EPA recommends the lead agency and project proponent pay particular attention to worksite proximity to places where children live, learn, and play, such as homes, schools, and playgrounds. Construction emission reduction measures should be strictly implemented near these locations in order to be protective of children's health.
- Specify how impacts to sensitive receptors, such as children, elderly, and the infirm will be minimized. For example, locate construction equipment and staging zones away from sensitive receptors and fresh air intakes to buildings and air conditioners.

[5] Children may be more highly exposed to contaminants because they generally eat more food, drink more water, and have higher inhalation rates relative to their size. Also, children's normal activities, such as putting their hands in their mouths or playing on the ground, can result in higher exposures to contaminants as compared with adults. Children may be more vulnerable to the toxic effects of contaminants because their bodies and systems are not fully developed and their growing organs are more easily harmed. EPA views childhood as a sequence of life stages, from conception through fetal development, infancy, and adolescence.

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United States Department of the Interior

U.S. FISH AND WILDLIFE SERVICE
Southern Illinois Sub-Office (ES)
8588 Route 148
Marion, Illinois 62959

FWS/SISO

August 4, 2017

Mr. Scott K. Fowler
Illinois Department of Natural Resources
Office of Mines and Minerals
Land Reclamation Division
One Natural Resources Way
Springfield, Illinois 62702-1271

Dear Mr. Fowler:

Thank you for your letter dated April 12, 2017, requesting review of significant revision No. 6 to permit 382 by Sugar Camp Energy, LLC (No. 1 Mine), for surface coal mining and reclamation operations in Hamilton and Franklin Counties, Illinois. The revision will add 37,971.9 acres of shadow area to existing permit No. 382. These comments are provided under the authority of and in accordance with the provisions of the Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 et seq.); the Endangered Species Act of 1973 (87 Stat. 884, as amended; 16 U.S.C. 1531 *et seq*.); the Migratory Bird Treaty Act (40 Stat. 755, as amended; 16 U.S.C. 703 *et seq*.) and, the National Environmental Policy Act (83 Stat. 852, as amended P.L. 91-190, 42 U.S.C. 4321 et seq.).

Threatened and Endangered Species

To facilitate compliance with Section 7(c) of the Endangered Species Act of 1973, as amended, Federal agencies are required to obtain from the Fish and Wildlife Service (Service) information concerning any species, listed or proposed to be listed, that have ranges which include the project area. As the State of Illinois has been delegated the responsibility of issuing mining permits by the Office of Surface Mining, we are providing the following list of threatened and endangered species to assist in your evaluation of the proposed permit. The list for the proposed permit area includes the endangered Indiana bat (*Myotis sodalis*), endangered piping plover (*Charadrius melodus*), and threatened northern long-eared bat (*Myotis septentrionalis*). There is no designated critical habitat in the project area at this time.

Information provided in the permit application indicates that there is no surface disturbance proposed in this revision and therefore no impacts to listed species are anticipated. Based on the information provided in the permit application, the Service concurs that the proposed permit actions are not likely to adversely affect any federally listed species. Although no surface disturbance is proposed in this revision, post-subsidence mitigation may be necessary to restore pre-existing drainage patterns which could result in impacts to forested riparian areas.

- The Service recommends that any tree clearing be minimized or avoided if possible to reduce impacts to potential habitat for the Indiana bat and northern long-eared bat. If tree clearing is necessary, it should not occur during the April 1 thru October 14 time frame. Also, any forested areas impacted by post-subsidence mitigation should be restored.

Fish and Wildlife Resources

Although no surface disturbance is proposed in this revision, post-subsidence mitigation may be necessary to restore pre-existing drainage patterns which could result in impacts to streams and wetlands. Activities in the project area that would alter these streams or wetlands may require a Section 404 permit from the US Army Corps of Engineers.

- The Service recommends that impacts to streams and wetlands be avoided or impacts minimized to the greatest extent possible. If a permit is required than an appropriate mitigation plan should be developed and coordinated with the Service.

Migratory Birds

Although the bald eagle has been removed from the threatened and endangered species list, it continues to be protected under the Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act (BGEPA). The Service developed the National Bald Eagle Management Guidelines to provide landowners, land managers, and others with information and recommendations regarding how to minimize potential project impacts to bald eagles, particularly where such impacts may constitute "disturbance," which is prohibited by the BGEPA. A copy of the guidelines is available at:

http://www.fws.gov/midwest/eagle/pdf/NationalBaldEagleManagementGuidelines.pdf

- The Service is unaware of any bald eagle nests in the permit area; however, if a bald eagle nest is found in the permit area or vicinity of the permit area then our office should be contacted and the guidelines implemented.

Thank you for the opportunity to comment on the proposed surface mining permit and provide information concerning threatened and endangered species. If you have any questions, please contact me at (618) 997-3344, ext. 345.

Sincerely,

/s/ Matthew T. Mangan

Matthew T. Mangan
Fish and Wildlife Biologist

October 2, 2023

Elizabeth Smith, NEPA Specialist
Tennessee Valley Authority
400 West Summit Hill Drive, #WT 11B
Knoxville, TN 37902
NEPA@tva.gov

Submitted e-mail to NEPA@TVA.gov

Re: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8

Dear Ms. Smith:

Sierra Club and Prairie Rivers Network submit the following comments on the scope of Tennessee Valley Authority's ("TVA's") upcoming environmental review of the proposed expansion at the Sugar Camp Coal Mine No. 1 in Illinois. According to TVA's Scoping Notice published in the Federal Register, the proposed expansion would allow the Sugar Camp coal mine to expand onto approximately 22,414 acres of land, mine 21,858 acres of TVA-owned coal reserves, and extract 122 million tons of TVA-owned coal over a 25-year period.[1]

Given the state of this climate crisis, it would be irresponsible for TVA to approve any action alternative that entailed mining and burning an additional 122 million tons of TVA-owned coal. As a federal entity, TVA should be part of the climate solution and ensure its decisions align with President Biden's national climate goals. Doing so requires that TVA-owned fossil fuels, including the 122 million tons of coal at issue here, remain in the ground. TVA should not sell its mineral rights to Sugar Camp Energy, nor should it divest itself of the coal reserves in a way that leaves them open to development by others.

Moreover, given the facts relating to how this coal will be mined and its impacts on water quality in the Big Muddy Basin, the mine operator's irresponsible use of toxic substances, mine subsidence, and worker safety it would be particularly irresponsible to approve mining of this coal by the Sugar Camp coal operator.

[1] Tennessee Valley Authority, Sugar Camp Energy LLC Mine NO. 1 Significant Boundary Revision 8 Environmental Impact Statement, 88 Fed. Reg. 60527, 60528, (Sept. 1, 2023).

In its upcoming environmental impact statement ("EIS"), TVA must directly address the climate crisis and the role that federally-managed fossil fuels play in exacerbating that crisis. The climate crisis is at a key juncture: extreme weather events are becoming more common and increasingly destructive, greenhouse gas emissions continue to rise, and yet we remain within a narrowing window of opportunity for meaningful climate action. Americans are already feeling impacts of climate change in ways that are immediate and expensive. According to the National Oceanic and Atmospheric Administration ("NOAA"), through September, in 2023 there have been 23 weather/climate disasters that with losses exceeding $1 billion in the United States, and in total these climate disasters caused 253 deaths.[2] Moreover, these events are getting more frequent and more destructive: the 1980–2022 average was 8.1 billion-dollar climate events per year; but the average for the most recent 5 years (2018–2022) is 18 such events per year.[3]

A recent Tyndall Center study analyzing phase out pathways for fossil fuel extraction globally concluded that, to preserve a 50 or 67 percent chance of limiting temperature rise to 1.5°C, developed countries, including the United States, must immediately begin phasing out coal production, and end production entirely by 2030.[4] This conclusion extends beyond *new* fossil fuel investments; the committed carbon emissions from *existing* fossil fuel leases and infrastructure in the energy and industrial sectors already exceed the carbon budget for limiting warming to 1.5°C. This means that no new fossil infrastructure can be built, and much existing infrastructure must be retired to avoid catastrophic climate harms.[5] While President Biden committed the U.S. to reducing greenhouse gas emissions to 50 percent below 2005 levels by 2030, and to net zero by 2050,[6] the United States remains far off track to meet these commitments.

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[2] https://www.ncei.noaa.gov/access/billions/. Attached as Exhibit 1.
[3] *Id.*
[4] Calverley and Anderson, Phaseout Pathways for Fossil Fuel Production Within Paris-compliant Carbon Budgets, Table 6 (2022), available at https://pure.manchester.ac.uk/ws/portalfiles/portal/213256008/Tyndall_Production_Phaseout_Report_final_text_3_.pdf ("Tyndall Report"). Attached as Exhibit 2.
[5] Dan Tong et al., Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target, 572 Nature 373 (2019), available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6697221/. Attached as Exhibit 3. Alexander Pfeiffer et al., Committed emissions from existing and planned power plants and asset stranding required to meet the Paris Agreement, 13 Environmental Research Letters 054019 (2018), available at https://iopscience.iop.org/article/10.1088/1748-9326/aabc5f/meta. Attached as Exhibit 4.
[6] White House, Fact Sheet: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies (Apr. 22, 2021), https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-

The latest report of the Intergovernmental Panel on Climate Change ("IPCC") starkly describes the consequences of indecision or inaction.[7] "Continued greenhouse gas emissions will lead to increasing global warming, with the best estimate of reaching 1.5°C in the near term in considered scenarios and modelled pathways. Every increment of global warming will intensify multiple and concurrent hazards."[8] Incremental additions of greenhouse gases bring us closer to "tipping points," which carry "abrupt and/or irreversible changes in the climate system."[9] The path to avoiding the most catastrophic impacts is clear. "Deep, rapid, and sustained reductions in greenhouse gas emissions would lead to a discernible slowdown in global warming within around two decades, and also to discernible changes in atmospheric composition within a few years."[10]

The United States—and governments of wealthy nations across the world—must immediately begin to phase out mining and burning coal to stay within 1.5°C temperature rise and avoid new weather extremes, rising seas, animal and plant extinctions, and death, especially for the poorest and most vulnerable people.[11] The window for avoiding these harms is narrowing. This is why U.N. Secretary-General Guterres conditioned participation in the September 2023 Climate Ambition Summit on participants' commitment to ending permitting for new fossil fuel production, prohibiting the expansion of existing fossil fuel reserves, and phasing out fossil fuel production.[12] A new study, published June 8, 2023, using the same methods as the IPCC's AR6 Working Group 1 report (2021), concludes that the remaining global carbon budget to maintain a 50% chance of keeping temperatures within 1.5℃ of pre-industrial levels has been cut in half since 2021.[13]

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reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/. Attached as Exhibit 5.

[7] Intergovernmental Panel on Climate Change, Synthesis Report of the IPCC Sixth Assessment Report, Summary for Policy Makers (Paola Arias et al. (eds.) 2023), *available at* https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf. Attached as Exhibit 6.

[8] *Id.* at 12.

[9] *Id.* at 18.

[10] *Id.* at 12

[11] *Id.* at 10 (explaining current "gap" between emissions are reductions required to limit warming, which "make it likely that warming will exceed 1.5 C").

[12] United Nations, "Secretary-General's Video Message for Press Conference to Launch the Synthesis Report of the Intergovernmental Panel on Climate Change" (March 20, 2023), https://www.un.org/sg/en/content/sg/statement/2023-03-20/secretary-generals-video-message-for-press-conference-launch-the-synthesis-report-of-the-intergovernmental-panel-climate-change. Attached as Exhibit 7.

[13] Piers Forster, et al., Indicators of Global Climate Change 2022: annual update of large-scale indicators of the state of the climate system and human influence, Earth Syst. Sci. Data, 15, 2295–2327 at 2313, T. 7 (June 8, 2023), available at

We are at a critical juncture in national and international efforts to prevent the worst effects of climate disruption. Rather than commit to using our federally-owned lands and minerals to further the fossil fuel industry's agenda, we must ensure public resources are managed to benefit all Americans. Sierra Club and Prairie Rivers Network request that TVA reject the proposed lease of TVA-owned coal reserves in favor of the No Action alternative. While we appreciate TVA's stated plan to analyze alternatives that entail divesting TVA's fossil fuel resources in this EIS, those fossil fuels must be kept in the ground to help avoid a climate catastrophe. Any planned TVA fossil fuel divestment that allows a private coal company to mine this coal is not an environmentally beneficial alternative.

Sierra Club is America's largest grassroots environmental organization, with more than 3 million members and supporters nationwide and more than 30,000 members in Illinois. Sierra Club is dedicated to exploring, enjoying, and protecting the wild places of the Earth; to practicing and promoting the responsible use of the Earth's resources and ecosystems; to educating and enlisting humanity to protect and restore the quality of the natural and human environment; and to using all lawful means to carry out these objectives.

Prairie Rivers Network is a non-profit organization that strives to protect the rivers, streams and lakes of Illinois and to promote the lasting health and beauty of watershed communities. Many of our members live near and recreate on the Big Muddy River, where the Sugar Camp mine will discharge its wastewater, and are adversely affected by the discharge of pollutants that degrade water quality.

TVA stated in its scoping notice that it will evaluate, at a minimum, "air quality and greenhouse gas emissions, surface water, groundwater, wetlands, floodplains, vegetation, wildlife, threatened and endangered species, land use, natural areas and parks and recreation, geology, soils, prime farmland, visual resources, noise, cultural resources, socioeconomics and environmental justice, solid and hazardous waste, public and occupational health and safety, utilities, and transportation. The EIS will analyze measures that would avoid, minimize, or mitigate environmental effects."[14] For each resource, TVA must analyze and disclose direct, indirect, and cumulative impacts, including impacts associated with mining, transportation (disclosing the likely truck, rail, and/or barge routes and impacts along the route), and combustion of the coal. In addition to the quantifiable climate impacts, discussed in detail below, burning Sugar Camp coal will also result in serious non-climate public health effects. BLM recently disclosed the effects of burning coal, oil, and gas in its Draft EIS/Resource Management Plan Amendments for the Buffalo and Miles City Resource Management Plans. TVA should use this analysis as a starting point to analyze and disclose the public health effects of the proposed Sugar Camp expansion.

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https://essd.copernicus.org/articles/15/2295/2023/essd-15-2295-2023.pdf. (Reducing remaining carbon budget from 500 GtCO2e under AR6 to 250 GtCO2e.) Attached as Exhibit 8.
[14] 88 Fed. Reg. 605208.

On behalf of our members and supporters, we urge TVA to deny Sugar Camp's proposed expansion into TVA-owned coal reserves in favor of the No Action alternative. This alternative should entail TVA adopting a policy of keeping its remaining reserves of coal, oil, and gas in the ground rather than being sold or leased to fossil fuel corporations.

I. TVA MUST ADDRESS IMPACTS TO WATER RESOURCES.

As explained in detail in the attached comments submitted by Sierra Club in April 2019 regarding TVA's Supplemental Assessment at Sugar Camp Mine, the proposed expansion poses a serious threat to water resources that has not been previously analyzed.[15] The occurrences at the mine since April 2019 have made the threats even more severe.

Sierra Club and Prairie Rivers Network members are concerned and potentially affected by pollutant discharges from the Sugar Camp Mine into the Middle Fork Big Muddy River and creeks in Franklin County, including an unnamed tributary to Middle Fork Big Muddy River, an unnamed tributary to Akin Creek. Further, our members are concerned with the growing levels of chloride and other water pollutants in the Middle Fork Big Muddy River and Big Muddy River, which are Waters of the State as part of the Mississippi River Basin. The Middle Fork Big Muddy River is listed on the draft 2016 303(d) list of impaired waters for reasons that may include pollutants from coal mining.

At a minimum, TVA's upcoming Environmental Impact Statement ("EIS") for the 122 million ton expansion must address the following issues regarding impacts to water resources:

Repeated history of water discharge violations at Sugar Camp: The repeated history of violations and non-compliance on record for the Sugar Camp Mine clearly shows this mine has consistently failed to remove coal in an environmentally sound manner as evidenced by its repeated quarters in non-compliance with basic permit levels, including 125 state and federal violations from 2015 to 2018.[16] There have been at least two formal enforcement actions in recent years, and unpermitted construction activities, including creation of two deep underground injection wells before being permitted to do so. According to the EPA ECHO database, Sugar Camp has a repeated history of contaminated water releases and coal slurry releases to area waterways. The mine has a history of failing to maintain its waste containment

[15] Sierra Club, Letter to Tennessee Valley Authority, "Comment Regarding Sugar Camp Coal Mine Expansion Viking District #2 Draft Supplemental Environmental Assessment, Franklin and Hamilton Counties, Illinois," (April 11, 2019). Attached as Exhibit 9.

[16] *Id.* at 2. For a summary of water discharge violations and enforcement actions, see attachment 1 to Sierra Club's April 2019 letter, which shows the Sugar Camp data posted on the U.S. Environmental Protection Agency's ECHO (Enforcement and Compliance History Online) database.

structures, to the detriment of area creeks and discharging to the Middle Fork Big Muddy River. There are also recorded instances of coal waste overflowing mine containment structures.[17]

In the forthcoming EIS, TVA must analyze and disclose the environmental impacts of the mine's water pollution and its struggles to keep discharges within permitted levels. Given the fact that the applicant has been discharging chloride at high concentrations (higher even than its current permit allows), the EIS must also consider impacts from chloride toxicity and other effects on the environment.

Cumulative impacts of pollution loading on the Big Muddy River: TVA must analyze and disclose the cumulative impacts to the Big Muddy River that would result from this massive expansion when combined with past, present, and future mining at Sugar Camp and other nearby projects. For example, the Williamson Energy Pond Creek No. 1 Mine, located near Johnston City, Williamson County, but also with shadow area in Franklin County, has constructed a 12.5-mile pipeline to pump contaminated mine water for direct discharge into the Big Muddy River. The proposal would entail discharges of up to 2,700,000 to 3,500,000 gallons per day of high chloride and sulfate contaminated water. The cumulative impacts of mine discharges to the Big Muddy River and its tributaries must be analyzed and disclosed.

Impacts to Rend Lake: The Sugar Camp Mine obtains water from Rend Lake and TVA must analyze impacts to water quantity and water quality at Rend Lake based on the proposed and past withdrawals, both from Sugar Camp and other projects.[18] For example, a contract signed in 2007 with Adena Resources, LLC for direct withdrawal of water from Rend Lake to supply Sugar Camp and Pond Creek mines, states that the daily withdrawal quota will initially be set at 6 million gallons per day. That amount is likely to be higher now. Rend Lake provides public water for all or part of seven counties in Southern Illinois. A water main break in 2018 put 60 communities at risk due to lack of water and resulted in school and business closures and extended boil orders for the water users. In 2007, drought conditions caused a significant drop in Rend Lake water levels and restrictions on lake use. According to the latest data we have obtained, the Sugar Camp Mine can use up to 4.3 million gallons per day of Rend Lake water. The EIS must disclose these prior impacts and address cumulative withdrawals on the lake when evaluating the proposed expansion.

Since April 2019, there have been numerous developments which also much be considered in relation to the environmental effect of development of this property. First, in August 2019, a fire broke out in a portion of the mine. The operator responded to this fired by discharging

[17] *Id.*
[18] *Id.* at 3.

large amounts of PFAS containing substances into the mine before ultimately have to close a portion of the mine.[19] A fire at the mine in 2021 burned for more than a month.[20]

Further, the Illinois Environmental Protection Agency and the Illinois Pollution Control Board have made clear that they will not require discharges to the Big Muddy to meet federal water quality criteria for at least chloride. Sierra Club and Prairie Rivers Network v. Illinois Environmental Protection Agency and Williamson Energy LLC, https://pcb.illinois.gov/documents/dsweb/Get/Document-108194 at least until the arduous process of changing Illinois water standards is completed. Thus, it is virtually certain that mining this coal will result is serious degradation of the Big Muddy River from chloride and other toxic pollutants.

II. TVA MUST ADDRESS SUBSIDENCE-RELATED IMPACTS.

Room and pillar mining can cause subsidence, resulting in massive costs to the public and governmental entities. Coal mine subsidence insurance is mandatory in Franklin County, where this Sugar Camp Mine expansion is located, and is also mandatory in other near-by counties.[21] Thirty four counties in Illinois require mine subsidence insurance because of subsidence risks.[22] Indeed, news reports have documented concerns of farmers and landowners due to subsidence at the Sugar Camp mine.[23] The EIS should consider eventual subsidence and potential societal harm to the public, as well as private costs that will be incurred. The EIS must also consider the applicant's specific plans to determine whether the risk of subsidence has been minimized.

III. TVA MUST ADEQUATELY ADDRESS THE CLIMATE IMPACTS OF THE PROPOSED COAL MINE EXPANSION.

A. TVA Must Provide the Public with a Thorough, Objective, and Transparent Accounting of the Climate Impacts of Expanded Mining at Sugar Camp.

[19] Leanne Fuller, "Company faces nearly $1.2 million in federal penalties for failing to evacuate miners after fire broke out in southern Illinois coal mine," (June 17, 2022). Attached as Exhibit 10.

[20] James Marshall, "Fire Shuts Down Major Ill. Coal Mine," Politico Pro (Sept. 22, 2021). Attached as Exhibit 11.

[21] Illinois Mine Subsidence Insurance Fund, "Should I Purchase Mine Subsidence Insurance?" at p. 6. Available at Why_Should_I_Buy.pdf (imsif.com). Attached as Exhibit 12.

[22] *Id*.

[23] Kari Lyderson, "Illinois mine expanding despite safety, environmental concerns," Energy News Network, (Mar. 21, 2018). Available at https://energynews.us/2018/03/21/illinois-mine-expanding-despite-safety-environmental-concerns/. Attached as Exhibit 13.

In evaluating a proposal that would result in the mining and burning of 122 million tons of federally-managed coal, TVA must do more than simply quantify carbon dioxide (CO_2) and methane (CH_4) emissions that will result from burning the TVA reserves at Sugar Camp.

Climate scientists' understanding of climate disruption has increased significantly in recent years, and we have clear scientific consensus that we must quickly and dramatically reduce greenhouse gas ("GHG") emissions in the U.S. if we are going to avoid the most damaging effects of climate change.

Specifically, we request TVA analyze and disclose the following issues, which must be accounted for in the forthcoming Environmental Impact Statement:

1) Acknowledge the robust scientific consensus on the need to drastically cut global CO_2 emissions;

2) Assess whether the proposed mining and related burning of approximately 122 million tons of federal coal are inconsistent with President Biden's national climate commitments to greenhouse gas emissions to 50 percent below 2005 levels by 2030 and to net zero by 2050;

3) Use the social cost of carbon and social cost of methane protocol to analyze and disclose the climate impacts of the proposal and the mining of other TVA-managed coal reserves; and

4) Use carbon budgets to analyze the climate impact of mining and burning 122 million tons of coal reserves.

5) Acknowledge the environmental justice impacts of continued coal extraction.

6) Incorporate assessments of emissions from fossil fuels mined from and other exploitations of Sugar Camp in the EIS as well as in TVA's ongoing Integrated Resource Planning process, including impacts on TVA's ability to decarbonize by 2035.

B. Further Coal Mining and Burning by TVA Conflicts with National Climate Goals.

President Biden committed to a fast, equitable transition to renewable energy in order reduce greenhouse gas emissions to 50 percent below 2005 levels by 2030 and to net zero emissions by 2050.[24] "It is the policy of my Administration to organize and deploy the full capacity of its agencies to combat the climate crisis to implement a Government-wide approach that reduces

[24] White House Fact Sheet, *supra*.

climate pollution in every sector of the economy."[25] Meeting those goals requires rapidly phasing out federal coal production. TVA cannot effectively "combat the climate crisis" while continuing to fuel that crisis by leasing its mineral rights to benefit fossil fuel companies.

As summarized by dozens of renowned climate scientists in 2016 in comments to BLM on the scope its planned (and ultimately cancelled review of the federal coal program): "We are scientists writing to urge the Department of the Interior to take meaningful action to fight climate change by ending federal coal leasing, extraction, and burning. The vast majority of known coal in the United States must stay in the ground if the federal coal program is to be consistent with national climate objectives and be protective of public health, welfare, and biodiversity."[26]

Given this strong and clear signal from leading climate scientists, as well as the ever-growing body of research demonstrating the need to keep fossil fuels in the ground in order or avoid the work effects of climate change, it is imperative that TVA analyze whether the continuation of the developing its existing fossil fuel reserves, including those at issue here, is consistent with our international climate commitments and the need to keep global warming within tolerable levels.

Given the state of scientific consensus around climate change, it is clear that efforts to meet our national and international climate commitments are compatible with leasing and burning federally-owned coal well into the future.

As the Council on Environmental Quality explained as early as 2014 in Draft NEPA climate guidance, (which is the subject of shifting political winds and has subsequently been finalized, revoked, replaced with new draft guidance, revoked again, and replaced with Interim Guidance that is immediately effective), federal agencies evaluating the climate impacts of their decisions should "incorporate by reference applicable agency emissions targets such as applicable Federal, state, tribal, or local goals for GHG emission reductions to provide a frame of reference *and make it clear whether the emissions being discussed are consistent with such goals*."[27] In its climate analysis, TVA must follow CEQ's Interim *National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions and Climate Change* 88 Fed. Reg. 1196 (Jan. 9, 2023).

One recent paper in the scientific journal *Nature*, estimates that to align with a 1.5°C scenario (with 50% probability of limiting warming to 1.5°C), 97 percent of U.S. coal reserves would have

[25] EO 14008, sec. 201.
[26] Letter from Ken Caldeira. et al., to Secretary Sally Jewell, "Scientists Support Ending Coal Leasing on Public Lands to Protect the Climate, Public Health, and Biodiversity" (July 27, 2016).
[27] Council on Environmental Quality, "Revised Draft Guidance on the Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in NEPA Reviews," 79 Fed. Reg. 77,802, 77,826 (Dec. 24, 2014) (emphasis added).

to remain in the ground by 2050.[28] The study rightly concludes that "[c]entral to pushing this transition forwards will be the domestic policy measures required to both restrict production and reduce demand."[29]

C. TVA Must Disclose Scientific Consensus on the Urgent Need to Cut U.S. Greenhouse Gas Emissions.

Based on an overwhelming amount of climate evidence published in recent years, TVA must acknowledge the findings of recent climate reports, including the Fourth National Climate Assessment of 2018 and those prepared by the Intergovernmental Panel on Climate Change ("IPCC") and U.S. Geological Survey. Additionally, information published in January 2019 by Oil Change International specifically highlights the urgent need for federally-managed fossil fuels to remain in the ground in order to effectively combat climate change. The findings of these recent and important climate reports are summarized below.

1. <u>Fourth National Climate Assessment</u>

Prepared by the U.S. Global Change Research Program and published in 2018, the Fourth National Climate Assessment, Volume II ("NCA4") identifies and evaluates the risks of climate change that threaten the U.S., and how a lack of mitigation and adaptation measures will result in dire climate consequences for the U.S. and its territories. This report builds upon the foundational physical science set out in the first volume of NCA4, the 2017-released *Climate Science Special Report*, which analyzed how climate change is affecting geological processes across the U.S.[30] Volume II focuses on national and regional impacts of human-induced climate change since the Third National Climate Assessment in 2014, as well as highlighting the future of global warming that will jeopardize human health, economy, and the environment.

The report affirms that it is no longer reliably true that current and future climate conditions will resemble the recent past. Due to human activities that produce greenhouse gas emissions, the atmospheric concentration of carbon dioxide has increased approximately 40 percent since the beginning of the industrial era in the 19th century.[31] In fact, USGCRP concludes that evidence of anthropogenic climate change is staggering, and that the impacts of climate change are intensifying across the U.S. and its territories. These impacts are multiplying climate risks to Americans' physical, social, and economic well-being.[32] Climate risks threatening the U.S. and its territories include: impacts to the economy, such as property losses up to $1 trillion in

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[28] Dan Welsby, et al., *Unextractable fossil fuels in a 1.5*°C *world*, 597 Nature 230, 233 (Sept. 9, 2021). Attached as Exhibit 14.
[29] *Id.*
[30] USGCRP, *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: Report-in-Brief* (2018), 1. Attached as Exhibit 15.
[31] *Id.* at 30.
[32] *Id.* at 26.

coastal property destruction; loss of reliable and affordable energy supplies and damaged energy infrastructure; declines in agricultural productivity; loss of two billion labor hours annually by 2090 due to temperature extremes; recreational and cultural losses of wildlife and ecosystems such as coral reefs; decreased water quality and security; diminished snowpack, sea level rise, and frequent flooding; increase in droughts, wildfires, and invasive species; and rise in deaths across vulnerable populations due to extreme weather events and heat waves.[33] To avoid these grave scenarios, the U.S. public and private sectors must invest in and implement mitigation actions to reduce greenhouse gas emissions, as well as adopt adaptation plans to prepare for future impacts.

Furthermore, while cutting carbon dioxide production is most efficient in reducing greenhouse gas emissions and limiting global warming, the report also mentions the need to reduce other climate pollutants such as methane. Methane (CH_4) is removed naturally from the atmosphere at a faster rate than carbon dioxide, and can help slow the global rise in temperature.[34] In terms of methane reduction, NCA4 specifically calls for the replacement of coal with other sources of energy, like wind and solar renewables, in order to mitigate greenhouse gas emissions.[35] As mentioned previously in this letter, fossil fuel combustion accounts for approximately 85 percent of total U.S. greenhouse gas emissions, of which methane from fossil fuel extraction and processing accounts for most of the remainder.[36] NCA4 demonstrates how it is essential to phase-out fossil fuel extraction in favor of more renewable energy sources. Renewable energy will not only create less greenhouse gas emissions, but will provide other economic and societal benefits including improving air quality and public health and increasing energy independence and security through increased reliance on domestic sources of energy.[37]

These findings are significant in regards to TVA moving forward with the proposed coal lease expansion, since no matter the amount of methane and carbon dioxide produced from fossil fuel extraction and end-source combustion, NCA4 unequivocally states that we must immediately reduce U.S. greenhouse gas emissions. TVA must take into account this updated climate report, and explicitly acknowledge its findings. We urge TVA to consider the report's conclusions and not move forward with the proposed federal coal lease expansion at Sugar Camp.

2. IPCC SR 1.5

In October 2018, the Intergovernmental Panel on Climate Change ("IPCC") released a special report on the impacts of global warming, commissioned by the Paris Agreement of 2016. *Global*

[33] *Id.* at 36-48.
[34] *Id.* at 31.
[35] *Id.* at 51.
[36] *Id.*
[37] *Id.* at 53.

Warming of 1.5°C, finds greenhouse gas emissions produced by human activity have significantly contributed to global warming since the industrial revolution of the 19th century, increasing the rise in global temperature by 0.2°C per decade at present.[38] The report forecasts the state of climate at 1.5°C and 2°C, describing the devastating consequences continued warming has for our earth – destroying ecosystems, disrupting global economy, and jeopardizing public health. The report is a stark warning that delayed actions to cut greenhouse gas emissions, as well as the implementation of other mitigation and adaptation measures to climate change, will be extremely costly.

The IPCC report assessed scientific, technical, and socio-economic literature to compare the impacts of global warming at 1.5°C to 2.0°C above pre-industrial levels of greenhouse gas emissions, and the results are severe. At 2.0°C warming, as compared to 1.5°C, the following will be even more certain to occur: heavy precipitation and flooding; loss of ice sheets in Antarctica and Greenland triggering multi-meter sea level rise; heat waves, heat-related morbidity and mortality, and spread of vector-borne diseases; species loss and extinction, including doubling the number of insects, plants, and invertebrates losing over half of their geographic range; increased risks of forest fires and the spread of invasive species; increase in ocean temperature, acidity, and deoxygenation; risks to marine biodiversity, fisheries, and the near extinction of coral reef ecosystems; climate-related risks to health, livelihoods, food security, and freshwater supply; and risks to economic growth and the increase of poverty by several hundred million by 2050.[39]

Global Warming of 1.5°C concludes that anthropogenic CO_2 emissions must decline approximately 45 percent from 2010 levels by 2030 in order to stay within the range of 1.5°C, reaching net zero emissions around 2050.[40] In addition to cutting carbon emissions, the IPCC reports other non-CO_2 emissions, including methane, must be deeply reduced to achieve limiting global warming to 1.5°C with no or limited overshoot.[41] To progress in reducing global greenhouse gas emissions, rapid and transformative changes must be made to our global economy, particularly energy infrastructure. For instance, the IPCC suggests the complete phase-out of coal, explaining "the use of coal, with no or limited overshoot of 1.5°C, shows a steep reduction in all pathways and would be reduced to close to 0% (0-2%) of electricity (*high confidence*)."[42]

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[38] IPCC, *Global Warming of 1.5°C*, An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty, Summary for Policymakers at SMP-4 (2018) (hereafter "IPCC "). Attached as Exhibit 16.
[39] *Id.* at 8-14.
[40] *Id.* at 15.
[41] *Id.* at 16.
[42] *Id.* at 21.

In summary, the lower the greenhouse gas emissions in 2030, the less challenging it will be to limit global warming to 1.5°C. Far-reaching climate mitigation and adaptation efforts are needed to both slow the rise in global temperature as well as prepare the planet for climate change impacts that are already in place, due to past and ongoing greenhouse gas emissions. The report specifically notes that "the challenges from delayed actions to reduce greenhouse gas emissions include the risk of cost escalation, lock-in carbon-emitting infrastructure, stranded assets, and reduced flexibility in future options in the medium- and long-term (*high-confidence*)."[43] Therefore, collective, international cooperation on all levels is needed to limit global warming to 1.5°C.

Given this report from the IPCC and its strong evidence of the rise in global temperature and severity of future climate change impacts, TVA should deny the proposed coal mine expansion and instead take steps to ensure that its decisions do not further exacerbate the climate crisis.

3. Oil Change International: Drilling Towards Disaster

In January 2019, Oil Change International in collaboration with another 17 not-for-profit organizations published a report called *Drilling Towards Disaster: Why U.S. Oil and Gas Expansion is Incompatible with Climate Limits* ("Report").[44] In addition to discussing why further oil and gas expansion must be halted to avoid climate crisis, the Report discusses the dire need of saying "no" to additional coal reserve development. Already with all developed reserves of coal, gas, oil, and cement combined, we have surpassed the threshold of a 50 percent chance of only a 1.5°C global temperature increase.[45] In fact, we have surpassed this threshold by so much that we are now on the doorstep of a 66 percent chance of a 2°C increase with developed reserves alone.[46] Approving this proposed coal expansion at Sugar Camp for mining an additional 105 million tons of coal would only further lock us into an unsustainable and catastrophic climate trajectory.

To date, the U.S. is still the world's third-largest coal producer, behind China and India.[47] Federally leased coal is a huge player as "[a]round 40% of all U.S. coal production comes from federally leased land."[48] Existing U.S. mines already contain far more coal than the U.S. can extract under a coal phase-out timeline that is consistent with the Paris Agreement goals.[49] Based on both economic efficiency and equity, the U.S. should phase out coal much faster than

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[43] *Id.* at 24.
[44] Oil Change International, *Drilling Towards Disaster: Why U.S. Oil and Gas Expansion is Incompatible with Climate Limits* (January 2019). Attached as Exhibit 17.
[45] *Id.* at 5.
[46] *Id.*
[47] *Id.* at 21.
[48] *Id.* at 22.
[49] *Id.*

the global average to meet responsibilities under the Paris goals.[50] To be consistent with Powering Past Coal Alliance's (an alliance that include 28 national governments) coal mining phase out of 2030, more than 70 percent of coal reserves in existing mines need to remain in the ground.[51]

Although U.S. coal mining is currently in decline, it is not being managed in a way that is fast enough for climate or fair for workers. Again, "[i]f U.S. coal production is phased out over a timeframe consistent with equitably meeting the Paris goals, at least 70 percent of coal reserves in already-producing mines would [need] to stay in the ground."[52] Federal agencies as well as policymakers need to focus on accelerating the phase out of coal by 2030 or sooner, while ensuring a just transition for communities and workers.

Based on the overwhelming scientific consensus that we must drastically reduce GHG emissions as quickly as possible in order to avoid a climate catastrophe, TVA should reject further mining of TVA-owned coal reserves at Sugar Camp Mine.

D. TVA Must Evaluate the Significance of Greenhouse Gas Emissions by Using Available Methodologies, Including the Social Cost of Greenhouse Gases and Carbon Budgets.

i. Social costs

The social cost of carbon and social cost of methane tools are based on sound science; have already been used by federal agencies to evaluate the impacts of agency policy proposals; and help put climate impacts into a context that is easily understood by both the public and decision-makers.

Recently the White House directed federal agencies to use the social cost of greenhouse gases in NEPA reviews.

> The President is directing agencies to consider the SC-GHG in environmental reviews conducted pursuant to the National Environmental Policy Act (NEPA) as appropriate.
>
> This is consistent with the Council on Environmental Quality's (CEQ) January 2023 guidance on how agencies should consider greenhouse gas emissions in their NEPA analysis. Under NEPA, before agencies take major federal actions, such as permits, approvals, financial assistance, and resource planning, they must identify, disclose, and consider in their decision making the reasonably

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[50] *Id*.

[51] *Id*.

[52] *Id*. at 7 (emphasis in original).

> foreseeable effects of those proposals. Agencies already often quantify greenhouse gas emissions in their environmental reviews and when they do so, it is a relatively simple — yet tremendously informative — step to also apply the SC-GHG estimates to those emissions to provide context about their climate change impacts.[53]

Federal agencies evaluating climate impacts of their proposals have frequently claimed that science has not developed the tools to analyze climate impacts of individual proposals. This is not accurate. The social cost of carbon and social cost of methane are a reliable tool that is available and should be utilized by TVA in the upcoming EIS process. Under NEPA's implementing regulations, where information relevant to reasonably foreseeable significant adverse impacts cannot be obtained because the overall costs of obtaining it are exorbitant or the means to obtain it are not known, NEPA regulations direct agencies to evaluate a project's impacts "based upon theoretical approaches or research methods generally accepted in the scientific community." 40 C.F.R. § 1502.21(c)(4). The social cost of carbon and social cost of methane are based on generally accepted research methods and years of peer-reviewed scientific and economic studies. As the D.C. Circuit recently explained in invalidating the Federal Energy Regulatory Commission's review of a fossil fuel infrastructure project, 40 C.F.R. § 1502.21 requires federal agencies to evaluate the social cost of carbon as one potentially available, scientifically accepted tool for analyzing climate impacts. *Vecinos para el Bienestar de la Comunidad Costera v. Fed. Energy Regul. Comm'n*, 6 F.4th 1321, 1329 (D.C. Cir. 2021).

The social cost of carbon, updated in February 2021, was created by an interagency working group ("IWG") in 2010 that consisted of scientific and economic experts from a dozen federal agencies and offices, including EPA, and the Departments of Agriculture, Commerce, Energy, Transportation, and the Treasury.[54] The working group's primary goal was to help federal agencies engaged in rulemaking to quantify the economic benefit of federal actions that reduce CO_2 emissions. The result of their efforts was the social cost of carbon – a schedule of estimates of the global economic harm caused by each ton of CO_2 emissions in a given year, expressed as

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[53] White House, FACT SHEET: Biden-Harris Administration Announces New Actions to Reduce Greenhouse Gas Emissions and Combat the Climate Crisis (Sept. 21, 2023). Available at https://www.whitehouse.gov/briefing-room/statements-releases/2023/09/21/fact-sheet-biden-harris-administration-announces-new-actions-to-reduce-greenhouse-gas-emissions-and-combat-the-climate-crisis/. Attached as Exhibit 18.

[54] Interagency Working Group, Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates Under Executive Order 13990 (Feb. 2021), https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf. Attached as Exhibit 19.

$/ton.[55] These values encompass damages from decreased agricultural productivity as a result of drought, human health effects, and property damage from increased flooding, among other factors.[56] The IWG updated the social cost of carbon and methane with interim values in February 2021, and plans to further update the figures.[57]

Although it was initially developed to help agencies craft regulatory impact assessments of proposed rules, the social cost of carbon need not and should not be limited to this application. Secretarial Order 3399, signed by Secretary Haaland in April, acknowledges that the social cost of carbon and methane "can be a useful measure to assess the climate impacts of GHG emission changes for Federal proposed actions, in addition to rulemakings."[58] The Secretarial Order further instructs, "[f]or instance, when a Bureau/Office determines that a monetized assessment of socioeconomic impacts is relevant, the SC-GHG protocol is an essential tool to quantify the costs and benefits associated with a proposed action's GHG emissions and relevant to the choice among different alternatives being considered."[59] The guiding principle of NEPA is that the public is entitled to a clear understanding of the likely impacts of federal agencies' decisions. The U.S. Supreme Court has called the disclosure of impacts the "key requirement of NEPA," holding that agencies must "consider and disclose the actual environmental effects" of a proposed project in a way that "brings those effects to bear on [an agency's] decisions." *Baltimore Gas & Elec. Co. v. Nat. Res. Def. Council, Inc.*, 462 U.S. 87, 96 (1983). The social cost of carbon and social cost of methane provide decision makers and the public with an informative, accessible mechanism for both analyzing and understanding the climate impacts of a proposed decision.

ii. <u>Carbon budgets</u>

In evaluating its decisions for its vast mineral reserves, TVA has the opportunity to stanch the flow of greenhouse gases into our atmosphere to help avoid a climate catastrophe. As part of the upcoming review, TVA should use carbon budgets to assess and compare the impacts of various program alternatives. Carbon budgets essentially work backward from a desired temperate threshold (say, 1.5°C) and desired confidence at limiting warming to that temperature increase (say, 50% confidence level), to arrive at an amount of greenhouse gases that the world's economies can emit – forever – while likely staying within the desired temperature increase. Based on equitable principles, individual country's contributions can be articulated. Thus, federal proposals can be understood as a percentage of the remaining U.S. carbon budget as one means of analyzing the magnitude of the proposal's climate impact. In order to stay within planetary carbon budgets to avoid worst-case climate change scenarios, additional mining and burning of U.S. federal coal is simply untenable. At a minimum, TVA must

[55] *Id.*
[56] *Id.*
[57] *Id.*
[58] SO 3399 (April 16, 2021).
[59] *Id.*

examine whether the proposed mining, shipping, and burning of 122 million tons of TVA reserves that are part of the proposed Sugar Camp proposed expansion are consistent with a 1.5 carbon budget. The Tenth Circuit Court of Appeals recently invalidated a Department of Interior NEPA review of oil and gas drilling permits in the Chaco region of New Mexico for failing to use carbon budgets or explain why it could not use this tool to evaluate climate impacts. *Dine Citizens Against Ruining Our Env't v. Haaland*, 59 F.4th 1016 (10th Cir. 2023)

Indeed, carbon budgets are not a new or novel tool. A 2016 analysis found that the carbon emissions that would be released from burning the oil, gas, and coal in the world's currently operating fields and mines would fully exhaust and exceed the carbon budget consistent with staying below 1.5°C.[60] The reserves in currently operating oil and gas fields alone, even excluding coal mines, would likely lead to warming beyond 1.5°C.[61] An important conclusion of the analysis is that no new fossil fuel extraction or infrastructure should be built, and governments should grant no new permits for extraction and infrastructure. Furthermore, many of the world's existing oil and gas fields and coal mines will need to be closed before their reserves are fully extracted in order to limit warming to 1.5°C.[62] In short, the analysis established that there is no room in the carbon budget for new fossil fuel extraction or infrastructure anywhere, including in the United States, and much existing fossil fuel production must be phased out to avoid the catastrophic damages from climate change.[63]

A 2019 Oil Change International analysis underscored that the United States must halt new fossil fuel extraction and rapidly phase out existing production to avoid jeopardizing our ability to meet the Paris climate targets and avoid the worst dangers of climate change.[64] The analysis

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[60] Oil Change International, *The Sky's Limit: Why the Paris Climate Goals Require a Managed Decline of Fossil Fuel Production*, (September 2016), http://priceofoil.org/2016/09/22/the-skys-limit-report/ at Table 3. Attached as Exhibit 20. According to this analysis, the CO_2 emissions from developed reserves in existing and under-construction global oil and gas fields and existing coal mines are estimated at 942 Gt CO_2, which vastly exceeds the 1.5°C-compatible carbon budget estimated in the 2018 IPCC report on *Global Warming of 1.5°C* at 420 $GtCO_2$ to 570 $GtCO_2$.

[61] The CO_2 emissions from developed reserves in currently operating oil and gas fields alone are estimated at 517 Gt CO_2, which would likely exhaust the 1.5°C-compatible carbon budget estimated in the 2018 IPCC report on *Global Warming of 1.5°C* at 420 $GtCO_2$ to 570 $GtCO_2$.

[62] *Id.* at 7, 13.

[63] This conclusion was reinforced by the IPCC Fifth Assessment Report which estimated that global fossil fuel reserves exceed the remaining carbon budget (from 2011 onward) for staying below 2°C (a target incompatible with the Paris Agreement) by 4 to 7 times, while fossil fuel resources exceed the carbon budget for 2°C by 31 to 50 times. *See* Bruckner, Thomas et al., 2014: Energy Systems *in* Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press (2014), at Table 7.2.

[64] Oil Change International, *supra*.

showed that the U.S. oil and gas industry is on track to account for 60 percent of the world's projected growth in oil and gas production by 2030—the time period over which the IPCC concluded that global carbon dioxide emissions should be roughly halved to meet the 1.5°C Paris Agreement target.[65] Between 2018 and 2050, the United States is poised to unleash the world's largest burst of CO_2 emissions from new oil and gas development—primarily from shale and largely dependent on fracking—estimated at 120 billion metric tons of CO_2 which is equivalent to the lifetime CO_2 emissions of nearly 1,000 coal-fired power plants. Based on a 1.5°C IPCC pathway, U.S. production alone would exhaust nearly 50 percent of the world's total allowance for oil and gas by 2030 and exhaust more than 90 percent by 2050.

Research on the United States' carbon budget and the carbon emissions locked into U.S. fossil fuels similarly supports the conclusion that the U.S. must halt new fossil fuel production and rapidly phase out existing production to avoid the worst dangers of climate change. A 2015 analysis of U.S. fossil fuel resources demonstrated that the potential carbon emissions from already leased fossil fuel resources on U.S. federal lands would essentially exhaust the remaining U.S. carbon budget consistent with the 1.5°C target.[66] This analysis estimated that recoverable fossil fuels from U.S. federal lands would release up to 349 to 492 $GtCO_2eq$ of carbon emissions, if fully extracted and burned. Of that amount, already leased fossil fuels would release 30 to 43 $GtCO_2eq$ of emissions, while as yet unleased fossil fuels would emit 319 to 450 $GtCO_2eq$ of emissions. A 2016 study found that carbon emissions from already leased fossil fuel resources on federal lands alone (30 to 43 $GtCO_2eq$) would essentially exhaust the U.S. carbon budget for a 1.5°C target (25 to 57 $GtCO_2eq$) if these leased fossil fuels are fully extracted and burned.[67] The potential carbon emissions from unleased federal fossil fuel resources (319 to 450 $GtCO_2eq$) would exceed the U.S. carbon budget for limiting warming to 1.5°C many times over.[68]

More recent scholarship affirms these findings, and concludes that even steeper reductions in GHG emissions are necessary to keep emissions within the remaining available carbon budget associated with 1.5℃ warming. One such study used a global energy system model to assess the amount of coal, oil, and gas that would need to remain in the ground both regionally and globally, to allow for a 50 percent change of limiting warming to 1.5℃.[69] Globally, the study

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[65] IPCC, AR 6, Summary for Policy Makers at SPM-15. Supra note 7.
[66] EcoShift Consulting, The Potential Greenhouse Gas Emissions of U.S. Federal Fossil Fuels, (2015). Attached as Exhibit 21.
[67] Robiou du Pont, Yann et al., Equitable mitigation to achieve the Paris Agreement goals, 7 Nature Climate Change 38 (2017), at Supplemental Table 1. Attached as Exhibit 22.
[68] EcoShift Consulting, *supra* at 4.
[69] Dan Welsby, et al., Unextractable Fossil Fuels in a 1.5℃ World, *supra* at 230. Welsby notes that in 2015 McGlade and Elkins estimated that one-third of oil reserves, nearly half of methane gas, and 80 percent of global coal reserves would need to stay in the ground to limit warming to 2℃, with the updated figures a marked increase in the cuts required under prior carbon budgets.

concluded, 60 percent of the world's oil, 60 percent of its methane gas, and 90 percent of coal "must remain unextracted to keep within a 1.5℃ carbon budget."[70] Thus, "very high shares of reserves considered economic today would not be extracted under a global 1.5℃ target,"[71] which, for the U.S., meant that 97 percent of U.S. coal reserves must remain undeveloped in order to meet our national goal of limiting global warming to 1.5℃ or less.[72]

E. TVA Must Analyze Environmental Justice Impacts

As CEQ's proposed Phase II NEPA regulations recognize, climate change is an environmental justice issue that must be addressed in NEPA reviews. In addressing the environmental justice impacts of the proposed Sugar Camp mine expansion, TVA should incorporate the requirements set out in CEQ's proposed Phase II regulations. These requirements reflect existing NEPA obligations, and the CEQ Phase I regulations, finalized earlier in the Biden Administration, make it clear that the current NEPA regulations are a floor, not a ceiling, on agency NEPA analyses.

In January 2021, White House National Climate Advisor Gina McCarthy acknowledged that, "[c]limate change is a racial justice issue because it exacerbates the challenges in the communities that have been left behind. It goes after the very same communities that pollution has held back and racism has held back. And it's our opportunity to serve those communities -- to elevate them."[73] As TVA evaluates the climate impacts of its coal-related decisions, it must recognize that climate impacts in the United States are not and will not be felt evenly. Should TVA recognize this fact, as it must, and still decide to continue to develop its coal reserves anyway, that would amount to a deliberate choice to inflict climate harms most acutely on environmental justice communities within the U.S. in this century. That unnecessary human suffering can and should be avoided. But if TVA refuses to align its choices with the Biden Administration's climate priorities, TVA must at a minimum own the impacts of its choices on low-income and communities of color.

A recent EPA report, released in September 2021, *Climate Change and Social Vulnerability in the United States*, concluded that climate change will disproportionately affect people of color and low-income communities.[74] The report examined six impacts of climate change (air quality and health, extreme temperature and health, extreme temperature and labor, coastal flooding and traffic, coastal flooding and property, inland flooding and property) affect four "socially

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[70] *Id.*

[71] *Id.* at 231.

[72] *Id.* at 233.

[73] Gina McCarthy Talks About the Intersectionality of Climate Change (Jan. 30, 2021), Gina McCarthy Talks About the Intersectionality of Climate Change - YouTube.

[74] U.S. Environmental Protection Agency, *Climate Change and Social Vulnerability in the United States* (Sept. 2021), *available at* https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf. Attached as Exhibit 23.

vulnerable" groups based on income, education, race, and age. EPA analyzed whether members of socially vulnerable groups currently live in areas that are projected to be most severely impacted by climate change, as compared to non-socially vulnerable groups.[75]

Of the four identified socially vulnerable groups, EPA found that racial minorities are most likely to currently live in areas that are at the highest risk for climate change related impacts such as increased mortality because of extreme temperatures, childhood asthma, labor hour losses, traffic delays, and land loss due to higher sea levels.[76] EPA concluded that racial minorities are projected to be impacted significantly more than non-minorities by the extreme weather, air pollution, and ocean level rise that would be caused by a 2°C global warming. Notably, black and African American individuals are 40% more likely to currently live in areas with the highest projected increase in mortality due to extreme temperatures.[77]

IV. CONCLUSION

For all of the reasons explained above, we request that TVA reject the proposed Sugar Camp expansion in favor of the No Action alternative. That is the only responsible choice. Should you have any questions about the information presented in this letter or the attached exhibits, please feel free to contact us at a phone number or email address listed below.

Sincerely,

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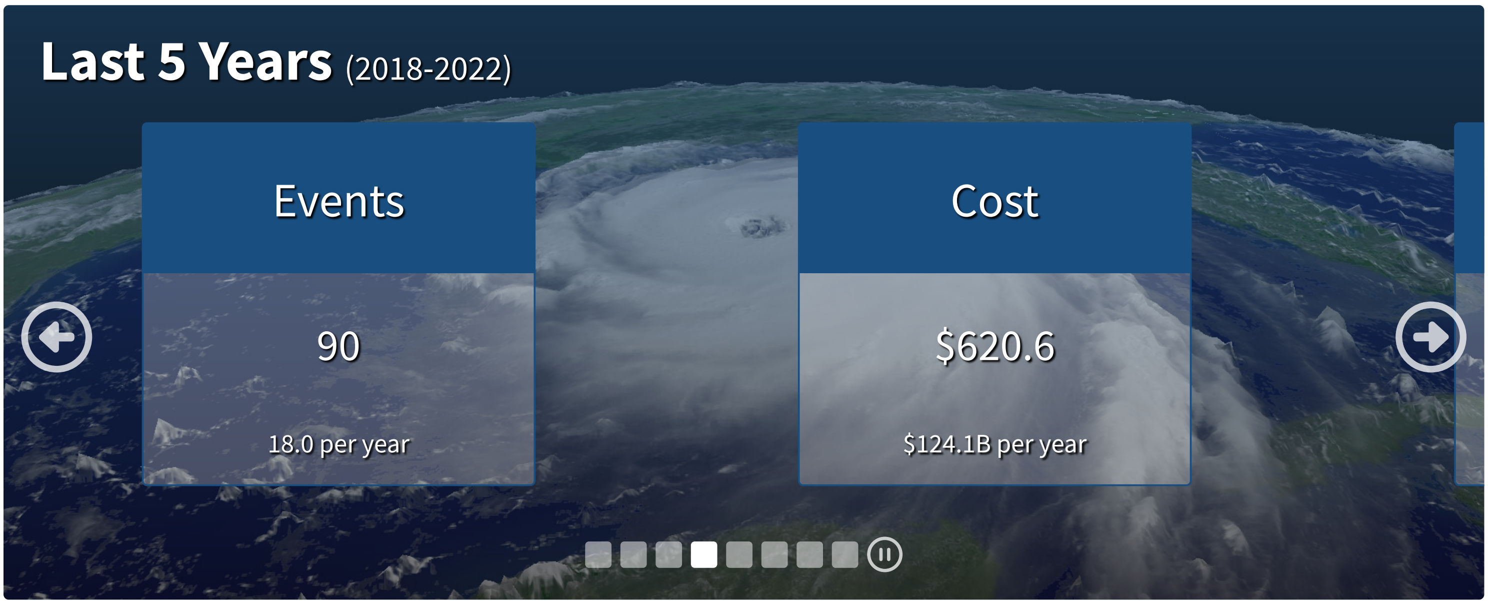
[75] *Id.* at 6.
[76] *Id.*
[77] *Id.*

Overview

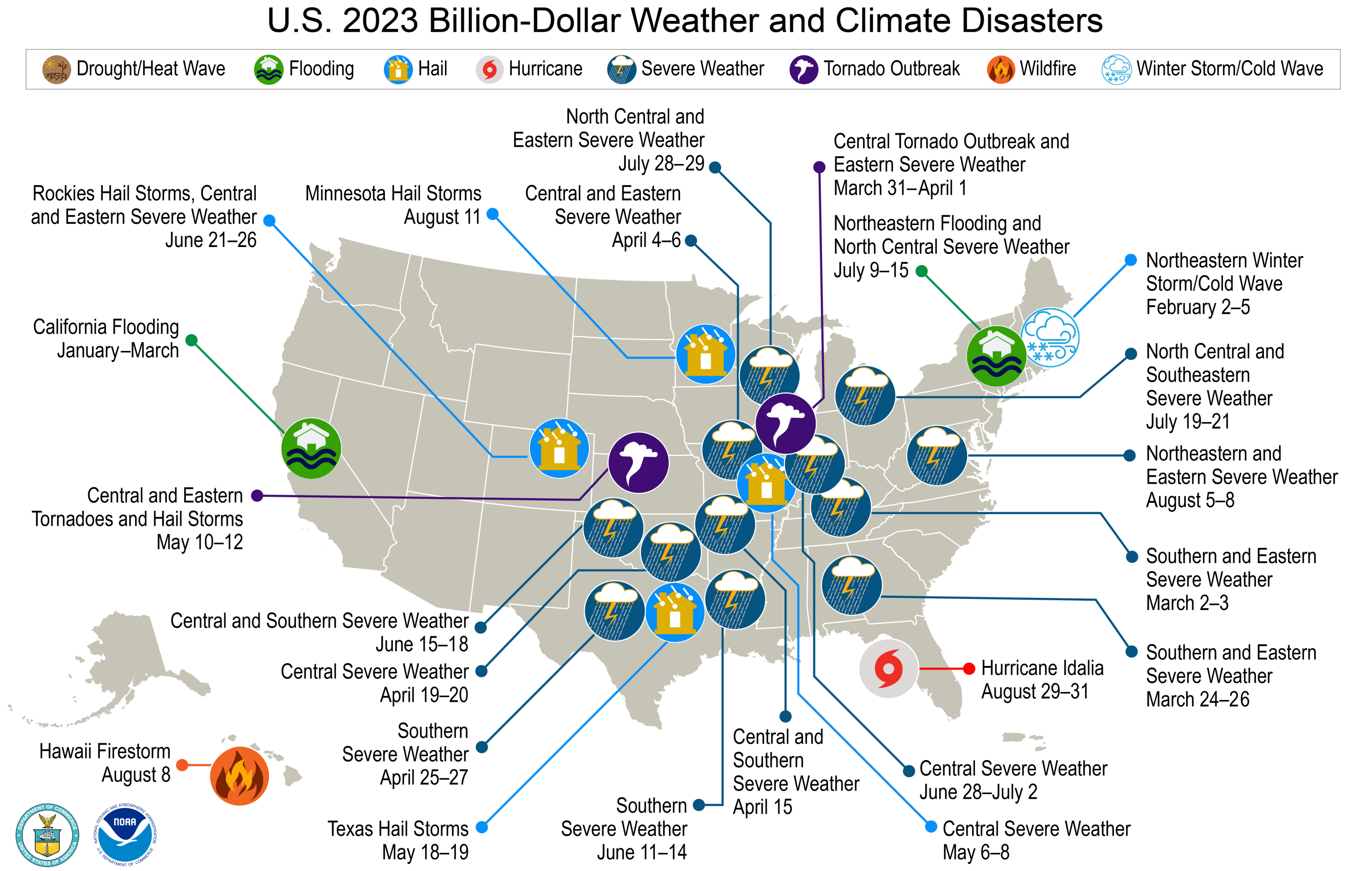
The U.S. has sustained 371 weather and climate disasters since 1980 where overall damages/costs reached or exceeded $1 billion (including CPI adjustment to 2023). **The total cost of these 371 events exceeds $2.615 trillion**.



View summary data in Summary Stats

2023 in Progress...

In 2023 (as of September 11), there have been 23 confirmed weather/climate disaster events with losses exceeding $1 billion each to affect United States. These events included 2 flooding events, 18 severe storm events, 1 tropical cyclone event, 1 wildfire event, and 1 winter storm event. Overall, these events resulted in the deaths of 253 people and had significant economic effects on the areas impacted. The 1980–2022 annual average is 8.1 events (CPI-adjusted); the annual average for the most recent 5 years (2018–2022) is 18.0 events (CPI-adjusted).



This map denotes the approximate location for each of the ***23 separate billion-dollar weather and climate disasters that impacted the United States through August 2023.***

Potential Billion-Dollar Events

The following is a compilation of events in which damage costs potentially exceed the $1 billion-dollar threshold. This is only a **preliminary list** *as calculations are not yet finalized and total costs have not been determined (as of September 11, 2023).*

- Tropical Storm Hilary (August 2023): *Tropical Storm Hilary caused a first-ever tropical storm watch to be issued for southern California, as it brought record-breaking rainfall and flooding across parts of the Southwest.*
- Southern and Midwest Drought (Spring-Fall 2023): *Drought conditions were present across numerous Midwestern states (KS, MO, NE, IL, IN, IA, WI, LA and TX). The agriculture sector has been impacted across the affected states including damage to field crops from lack of rainfall. Ranchers have also been forced to sell-off livestock early in some regions due to high feeding costs.*

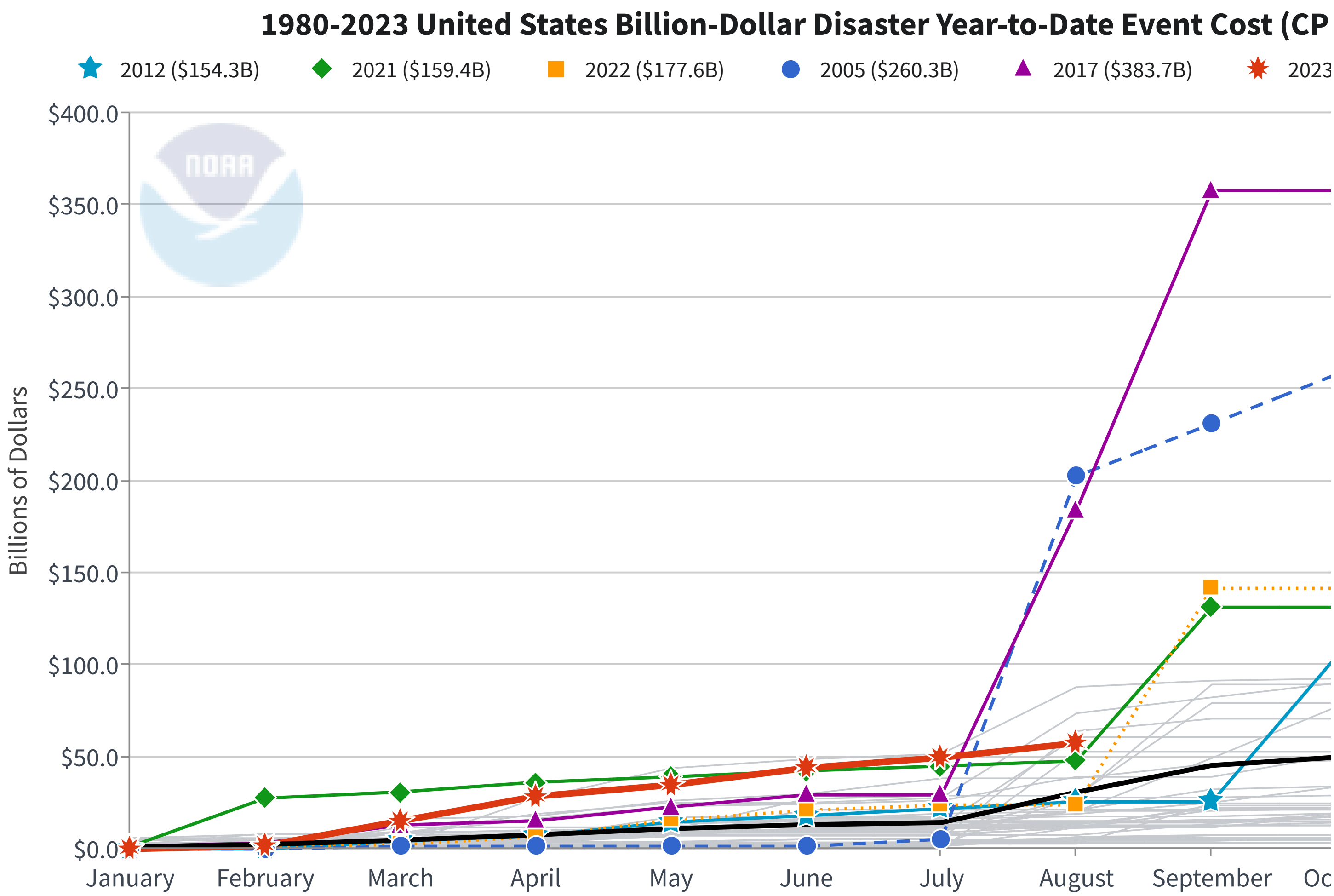
All Disasters | Drought | Flooding | Freeze

Severe Storm | Tropical Cyclone | Wildfire | Winter Storm

United States

Cost

Update | CPI-Adjusted | Unadjusted



Updated: September 11, 2023 *Event statistics are added according to the date*

**Costs not included for Hurricane Idalia (August 2023)*

US Summary

Methodology and Data Sources

The National Centers for Environmental Information (NCEI) is the Nation's Scorekeeper in terms of addressing severe weather and climate events in their historical perspective. As part of its responsibility of monitoring and assessing the climate, NCEI tracks and evaluates climate events in the U.S. and globally that have great economic and societal impacts. NCEI is frequently called upon to provide summaries of global and U.S. temperature and precipitation trends, extremes, and comparisons in their historical perspective. Found here are the weather and climate events that have had the greatest economic impact from 1980 to 2023.

In 2012, NCEI -- then known as National Climatic Data Center (NCDC) -- reviewed its methodology on how it develops Billion-dollar Disasters. NCEI held a workshop with economic experts (May, 2012) and worked with a consulting partner to examine possible inaccuracy and biases in the data sources and methodology used in developing the loss assessments (mid-2013). This ensures more consistency with the numbers NCEI provides on a yearly basis and give more confidence in the year-to-year comparison of information. Another outcome is a published peer-reviewed article "U.S. Billion-dollar Weather and Climate Disasters: Data Sources, Trends, Accuracy and Biases" (Smith and Katz, 2013). This research found the net effect of all biases appears to be an underestimation of average loss. In particular, it is shown that the factor approach can result in an underestimation of average loss of approximately 10–15%. This bias was corrected during a reanalysis of the loss data to reflect new loss totals.

It is also known that the uncertainty of loss estimates differ by disaster event type reflecting the quality and completeness of the data sources used in our loss estimation. In 2019, six of the fourteen billion-dollar events (i.e., three inland floods events, California/Alaskan wildfires, tropical cyclones Dorian and Imelda) have higher potential uncertainty values around the loss estimates due to less coverage of insured assets and data latency. The remaining eight events (i.e., the severe storm events producing tornado, hail and high wind damage) have lower potential uncertainty surrounding their estimate due to more complete insurance coverage and data availability. Our newest research defines the cost uncertainty using confidence intervals as discussed in the peer-reviewed article "Quantifying Uncertainty and Variable Sensitivity within the U.S. Billion-dollar Weather and Climate Disaster Cost Estimates" (Smith and Matthews, 2015). This research is a next step to enhance the value and usability of estimated disaster costs given data limitations and inherent complexities.

In performing these disaster cost assessments these statistics were developed using the most comprehensive public and private sector sources and represent the estimated total costs of these events -- that is, the costs in terms of dollars that would not have been incurred had the event not taken place. More than one dozen public and private sector data sources help capture the total, direct costs (both insured and uninsured) of the weather and climate events. These costs include: physical damage to residential, commercial, and municipal buildings; material assets (content) within buildings; time element losses such as business interruption or loss of living quarters; damage to vehicles and boats; public assets including roads, bridges, levees; electrical infrastructure and offshore energy platforms; agricultural assets including crops, livestock, and commercial timber; and wildfire suppression costs, among others. However, these disaster costs do not take into account losses to: natural capital or environmental degradation; mental or physical healthcare related costs, the value of a statistical life (VSL); or supply chain, contingent business interruption costs. Therefore, our estimates should be considered conservative with respect to what is truly lost, but cannot be completely measured due to a lack of consistently available data. Sources include the National Weather Service, the Federal Emergency Management Agency, U.S. Department of Agriculture, National Interagency Fire Center, U.S. Army Corps, individual state emergency management agencies, state and regional climate centers and insurance industry estimates, among others. Please see Calculating the Cost of Weather and Climate Disasters for more information.

Or download a recent presentation: Smith, A., 2022: 2021 U.S. Billion-dollar weather and climate disasters in historical context and new hazard and socioeconomic risk mapping. *April 2022, AMS Washington Forum*, Washington, DC.

For more in-depth analysis, the following report offers the latest summary on the 2022 U.S. billion-dollar weather and climate disasters in historical context.

Citing this information:

NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2023). https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73

Phaseout Pathways for Fossil Fuel Production Within Paris-compliant Carbon Budgets

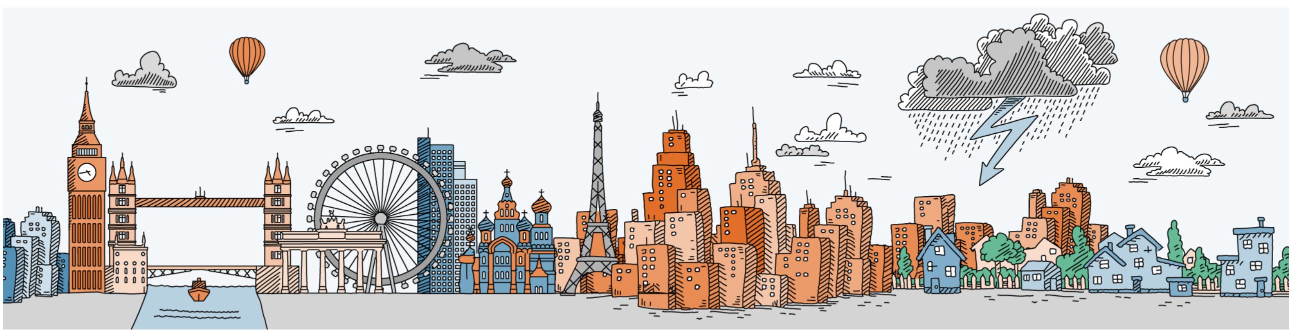
Tyndall°Centre
for Climate Change Research

Phaseout Pathways for Fossil Fuel Production

within Paris-compliant carbon budgets

Research Report

Client: International Institute for Sustainable Development
Document ref: Tyndall Production Phaseout Report
Version: Final Text
Date: 11 March 2022
Prepared by: Dr Dan Calverley and Professor Kevin Anderson



About the Tyndall Centre for Climate Change Research

The Tyndall Centre is a partnership of universities bringing together researchers from the social and natural sciences and engineering to develop sustainable responses to climate change. We work with leaders from the public and private sectors to promote informed decisions on mitigating and adapting to climate change. The Tyndall Centre was founded in 2000 to conduct cutting edge, interdisciplinary research, and provide a conduit between scientists and policymakers. With approximately 200 members across career stages, the Tyndall Centre represents a substantial body of the UK's climate change research expertise. Since 2000, the Tyndall Centre has significantly advanced various areas of climate change research and policymaking including: the development of emission reduction pathways for major energy consuming sectors, the understanding of climate impacts, risks and adaptation options, public perceptions of climate change, and the governance of climate negotiations and policymaking. The partnership institutions are: University of East Anglia, University of Manchester, Cardiff University and Newcastle University.

For further information please see www.tyndall.ac.uk.

Acknowledgement:
This research was commissioned by the International Institute for Sustainable Development (IISD). The authors are grateful to Greg Muttitt of IISD for discussion and comments on earlier drafts; likewise to multiple reviewers from international civil society organisations for their feedback and comments. However, all views contained within this report are attributable solely to the authors and do not necessarily reflect the views of IISD, the wider Tyndall Centre or the authors' other affiliated institutions.

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Cite as: Calverley, D. and Anderson, K. (2022), Phaseout pathways for fossil fuel production within Paris-compliant carbon budgets. Tyndall Centre, University of Manchester.

MANCHESTER 1824 The University of Manchester CEMUS UPPSALA UNIVERSITET CET UNIVERSITAS BERGENSIS

Contents

List of Figures & Tables

Headline finding

To comply with the carbon budget for a 50:50 chance of not exceeding 1.5°C of warming requires immediate and deep cuts in the production of all fossil fuels. There are no exceptions; all nations need to begin a rapid and just phaseout of existing production. The report makes absolutely clear that there is no capacity in the carbon budget for opening up new production facilities of any kind, whether coal mines, oil wells or gas terminals. A transition based on principles of equity requires wealthy, high-emitting nations to phase out all oil and gas production by 2034 while the poorest nations have until 2050 to end production.

Key messages

1. The carbon budgets associated with “keep 1.5°C alive” and “stay well below 2°C” imply much more urgent cuts in emissions than any government is considering, and require the rapid and complete phaseout of all fossil fuel production. The maths are clear: for a 50:50 chance of not exceeding 1.5°C, the carbon budget equates to ten years of current emissions. For a 67% or better chance of 1.5°C this falls to just seven years. For a 50% chance of 1.7°C it only increases to eighteen years.
2. There is widespread recognition that coal production must be phased out urgently and that wealthy countries must act first. However, quantifying such a shift in relation to a 50% chance of 1.5°C, with an emphasis on equity, makes clear just how stark this ‘urgency’ really is. For developed nations, coal production needs to fall by 50% within five years and be effectively eliminated by 2030. For developing nations coal production must halve within a decade with all extraction ceased by 2040.
3. The UN’s equity framing of ‘common but differentiated responsibility’ requires those wealthier nations with economies less dependent on oil and gas revenues lead the way with high rates of closure and early phase-out dates. Poorer nations have a little leeway, with both slower rates of closure and slightly later phaseout dates.
4. The IPCC’s headline carbon budget for a 50% chance of 1.5°C places very tight constraints on the production of oil and gas. For the wealthiest group of ‘producer nations’, with the highest capacity to achieve a ‘just transition’, output of oil and gas needs to be cut by 74% by 2030, with complete phase out by 2034. For the middle-income group with medium capacity for a just transition, the timeframe extends a little, with a 28% cut by 2030, and a zero-production year of 2043. For the poorest group with lowest capacity, a 14% cut is required by 2030, with all production ended by 2050.
5. There is no practical emission space within the IPCC’s carbon budget for a 50% chance of 1.5°C for any nation to develop any new production facilities of any kind, whether coal mines, oil wells or gas terminals. This challenging conclusion holds across all nations, regardless of income or levels of development.
6. From a mitigation perspective alone, it is no longer possible to deliver an equitable division of the small and rapidly shrinking carbon budgets. Although poorer countries have longer to phase out oil and gas production, many will be hit hard by the loss of revenue with an attendant risk of political instability. An equitable transition will require wealthy high-emitting nations make substantial and ongoing financial transfers to poorer nations to facilitate their low-carbon development, against a backdrop of dangerous and increasing climate impacts.

How confident are we in our findings?

It is certainly possible to 'fine tune' some of the assumptions that underpin the quantitative analysis within this report. However, within the tight IPCC carbon budgets for 1.5–2°C, and with serious attention paid to the UN framing of equity, the key messages outlined here are sufficiently robust to provide a strong guide to mitigation policy.

A potential exception to this is whether it is considered appropriate or not to expand the IPCC's carbon budgets through future 'carbon dioxide removal', deployed at planetary scale and principally in the second half of the century. This issue receives careful attention within the report. Specifically, in relation to emissions of carbon dioxide from the energy sector, the inclusion of highly-speculative-at-scale CDR is judged inappropriate, as it works against the tenets of precaution. Moreover, whilst CDR is now ubiquitous in mitigation analyses, the IPCC's estimates of additional feedbacks, potentially reducing carbon budgets, are seldom if ever included. For this analysis, a conservative approach is adopted, neither easing the mitigation burden through CDR nor increasing it through additional feedbacks.

1 Introduction

This section provides the key context and landscape from which the report's analysis is subsequently developed.

The Paris Agreement commits us, as a minimum, to acting to hold global warming to well below 2°C, and in doing so to strive for no more than 1.5°C of warming.

1.1 Commitments, temperatures and probabilities

The 2015 Paris Agreement undertakes to hold "the increase in the global average temperature to well below 2°C … and to pursue efforts to limit the temperature increase to 1.5°C." [1]. The temperature goals of the Paris Agreement are themselves proxies for suites of climate impacts (more accurately, for the rate of change of impacts) and their attendant consequences for people and the wider biosphere[1].

In the years since Paris, evidence has accumulated that the impacts of 1.5°C of warming will likely be more severe and occur much earlier than previously anticipated [2]. The Working Group I (WGI) contribution to the IPCC's Sixth Assessment Report (AR6) published in August 2021 gives a best-estimate of when mean global surface temperature will surpass 1.5°C [3]. This is now expected to fall between 2030 and 2035, in the absence of stringent and rapid mitigation policies.

While the Paris Agreement places an unambiguous obligation on its signatories to limit warming to 'well below 2°C', the language of 'pursue…1.5°C' is rather less imperative. Nevertheless, anticipating the findings of AR6 and recognising the serious threats to life and wellbeing from impacts at 1.5°C, in May 2021 the council of environment ministers of the G7 group of nations published a communiqué explicitly pledging to hold warming to 1.5°C [4].

Since Paris, the case for limiting warming to 1.5°C has strengthened considerably.

The undertaking in the G7 communiqué arguably suggests a higher than 50% probability of restricting warming to no more than 1.5°C. In a similar vein, the November 2021 COP26 event had as its strapline "keep 1.5°C alive" [5]; multiple previous COP events also had a strong focus on 1.5 rather than 2°C. Notwithstanding these clear scientific and political precedents for fortified efforts to limit warming to 1.5°C, the magnitude and rapidity of mitigation action needed to deliver such a target cannot be overstated. The window of opportunity is fast closing for the transformative system-wide decarbonisation needed to achieve even a reasonable chance of not exceeding 1.5°C of warming.

1.2 The logic of addressing production

To achieve the reductions in emissions necessary for staying within 1.5–2°C of warming, fossil fuel use must be urgently curtailed [2], [6], [7]. Clearly, mitigating the consumption of fossil fuels at the downstream level will have direct and clear implications for the upstream production of those fuels[2]. Without the ability to store significant surpluses of fossil fuels, supply (production) corresponds with demand (consumption).

At the global level, then, annual fossil fuel production and consumption are effectively in lockstep (see §4.1 for more detail). At the level of individual nations, however, there are important differences in the relationship of production to consumption across the three primary fossil fuel types: coal, oil and gas.

1.3 Focus on oil and gas

Oil is used by all countries – regardless of whether they produce it or not.

Oil is currently used in significant quantities by virtually every nation of the world, developed and developing, almost irrespective of each nation's level of oil production. Its prevalence can be attributed to a combination of high energy density, inherent portability and versatility, and an extensive legacy of production and distribution infrastructure. As a highly traded commodity, oil is moved around the world by tanker and pipeline, with production and consumption typically occurring in geographically separated locations, i.e. in different countries, often on different continents.

This is less the case with gas, which although increasingly traded via both pipeline and in the form of LNG (liquefied natural gas), is more costly to move from point of production to distant points of consumption. While gas is used by many countries that do not produce it, these tend to be wealthier, developed countries with long-term sale and purchase agreements with producer nations, and with well-established and high capital cost gas infrastructures.

Coal, as the least energy dense, bulkiest fossil fuel, is far less traded than either oil or gas, hence its consumption is more geographically tied to production. That is to say, coal is not widely used by countries that do not produce it (see §4.3.1 for details on the differences in coal consumption and production patterns across developing and developed nations).

Coal is being targeted for urgent phaseout by international climate organisations.

As a consequence of its lower energy density, coal has much higher CO_2 emissions per unit of useful energy produced[3]. Coal combustion is also responsible for much higher levels of particulate air pollution than other fossil fuels, which are directly hazardous to human health[4]. Thus, ending coal-fired power generation has become the focus of international mitigation efforts, with the Secretary General of the United Nations emphatically calling for its urgent phaseout [8], and many countries declaring moratoria on coal consumption under the banner of the Powering Past Coal Alliance (PPCA) [5].

In this report, we take the growing consensus on coal phaseout as a given. Assumptions about coal are key to establishing the starting position for oil and gas, so are treated early in the analysis (see §4.3). Thereafter, we turn our attention specifically to oil and gas. Less than half of the nations of the world have oil and gas extractive industries of any consequence – a disparity that arises both from the uneven distribution of hydrocarbon deposits in the Earth's crust and centuries of geopolitical wrangling over access rights to those deposits. The world's oil and gas production is therefore highly concentrated and supplied by a minority of nations.

95% of global oil and gas production takes place in just thirty-three countries; 99.7% in eighty-eight. nations.

1.4 Equity in production phaseout pathways

Oil-and-gas-producing nations (hereafter 'producer nations' or simply 'producers') have economies that are, to a greater or lesser extent, dependent on revenue from the extraction and sale of that oil and gas. While mitigation of fossil fuel use must be pursued by all nations (with universal acknowledgement that wealthy, high-emitting nations must make the deepest and most urgent cuts[5]), the economic consequences of diminishing production will be experienced primarily by producer nations.

Ending consumption of oil and gas will economically and socially impact the minority of nations that produce those fuels.

Importantly, within the top eighty-eight producer nations, major disparities exist across a range of indices of economic prosperity, wellbeing and internal inequality. This in turn reveals a wide discrepancy in the capacities of different producer nations to transition away from fossil fuels in as fair a way as possible to those who are currently dependent on fossil fuel production for their livelihoods (a 'just transition') .

These disparities will see some producer countries face much greater difficulty than others in ensuring both a just transition for their extractive workers and the funding of basic development needs of their wider citizenries as they phase out fossil fuel production. These difficulties are most likely to arise in nations where revenue from fossil fuel extraction dominates the economy, and hence where the functioning of much of society is dependent on that revenue. Such precarious positions are exacerbated where there is already a low level of underlying economic development and high internal inequality (expressed as a low IHDI score), or both. These vulnerabilities, and their implications for political stability and the provision of basic needs, must remain a key consideration when detailing specific national phaseout schedules.

Producer nations differ widely in their:

- *dependency on revenue from fossil fuels;*
- *ability (or capacity) to ensure fair treatment for their extractive workers as the world ends its use of fossil fuels.*

In adopting this approach, we remain cognisant of wider equity concerns. For example, the processes of extraction may violate the rights and indeed safety and security of those living nearby. Or, more simply, the benefits of fossil fuel revenue may be confined to a relatively small proportion of a country's population. Such localised aspects of equity are beyond the scope of this report. Consequently, it is important to understand that the analysis presented here provides 'provisional' phase-out schedules for oil and gas production, and that these may need to be accelerated or delayed depending on country-specific circumstances.

Precisely because of the considerable variation in the capacities of producer nations to deliver a real-world[6] and, preferably, just transition, one phaseout pathway patently does not fit all.

1.5 Why use a production-emissions budget methodology?

Fossil fuels, once extracted, are inevitably burned. Using fuel-specific emissions factors allows conversion of a quantity of fossil fuel produced into its ultimate CO_2 emissions outcome. Note that in this analysis, production emissions refers to the emissions from the ultimate combustion of the fossil fuel at point of end-use, not just the emissions incurred in extracting or processing it (see §4.1 for more details on this approach).

Tonnes of coal, oil or gas produced can be expressed as the amount of CO_2 that will be emitted when the fuel is burned.

Translating fossil fuels into CO_2 emissions allows us to determine the amount of production that would 'fit' into an agreed global carbon budget. Thus, 'production budgets' are simply the amount of fossil fuels, expressed as their CO_2 equivalent, that can be extracted (and subsequently combusted) within a given carbon budget.

Production budgets are fuel-specific and will vary according to the assumptions made about the relative split of coal to oil to gas within the global primary energy mix. Such budgets can be disaggregated to groups of producer nations according to their relative capacity to make a just transition. Finally, national production budgets can be transposed into plausible production phaseout pathways and, ultimately, end dates.

Plausible production phaseout pathways reveal what would have to change in the annual outputs of producer nations if we are to keep within a temperature-derived global carbon budget, while respecting the equity principles of the Paris Agreement.

Our approach differs notably from the majority of contemporary analyses of production in that it proceeds from transparent and sequentially reasoned assumptions about key determinants. For example, we make clear our reasoning and treatment of: coal production, uncertainties around earth systems feedbacks, emissions from land use change, forestry and agriculture, and the presumption of still speculative-at-scale carbon dioxide removal techniques.

Such transparency and wider accessibility is arguably lacking from analyses that utilise integrated assessment models (IAMs) [10]. Most IAMs are complex, cost-optimised models that use assumptions about rising carbon prices, elasticities of demand, discount rates, etc, to drive changes away from fossil fuels and towards renewables and other forms of low-carbon energy supply. Almost all incorporate (often uncritically) unprecedented amounts of negative emissions technologies (NETs) and/or 'nature-based solutions' (NbS) to remove CO_2 from the atmosphere after it has been released. The majority of IAMs use embedded algorithms designed to deal with marginal (i.e. relatively small) changes near to economic equilibrium and typically informed by historical norms (e.g. existing elasticities of demand and discount rates). They are not constituted to model the immediacy, depth or pace of profound transformation required to stay within the 1.5 °C or even "well below 2°C" carbon budgets.

Most IAMs invoke 'carbon dioxide removal' to capture huge quantities of CO_2 from the atmosphere, after it has been emitted from burning fossil fuels.

Another important point of divergence is that central to our approach is the consideration of equity. IAMs, by contrast, are not configured in a way that can cope with the nuanced reasoning and weighing of contextual factors required to ascertain the 'least unfair' outcomes for disparate constituencies[7].

IAMs do not deal with complex, nuanced issues of equity or fairness.

1.6 The core concepts of precaution and equity

This report takes the precautionary principle as a guide to the development of its methodology and assumptions, recognising that for the past thirty years the collective global response to climate change has been the opposite of this. Disturbingly, reliance on speculative negative emissions technologies and the uncertain manipulation of nature still pervade much of the mitigation debate today. The ubiquitous adoption of carbon dioxide removal (CDR) and carbon capture and storage (CCS) to weaken the rapid phaseout of fossil fuels implied by 1.5°C carbon budgets (see §3.2 below) demonstrates a clear and ongoing rejection of precaution in favour of minimising disruption to the status quo.

1.7 The case for financial transfers

While evoking the precautionary principle, it is important to acknowledge that, to a significant degree, our application of it has necessarily been weakened by our judgement of what is now, in 2022, achievable. This judgement call similarly is played out when considering the fossil-fuel phaseout schedules between the different country groups.

It is the view of the authors that 1.5 to 2°C carbon budgets (see §2.3) are now so depleted that equity between nations cannot be delivered through differential mitigation alone. In this regard, and with practicality still guided by principles of equity, the best that can be achieved is the 'least unfair distribution' of the remaining carbon budget.

It is now too late to deliver equity simply through later phaseout dates for developing countries – financial transfers will be essential.

This is a highly inequitable and far from satisfactory position. In large part this situation has come about because the nations with greatest historical emissions have so far abdicated their "common but differentiated responsibility" to rapidly cut their emissions. The upshot of this failure is that substantial levels of financial assistance [11] and reparations [12] are now required, if poorer nations are to deal with the climate impacts knowingly imposed on them while simultaneously developing their societies without recourse to ongoing revenue from fossil fuel production.

1.8 Key question for this research

Building on the foregoing context, this research report addresses the following question.

> "How, within a given **global emissions budget** aligned with the Paris Agreement goals, could **oil and gas production be differentially phased-out** in producer nations, while taking account of the principle of **equity** as embedded in principle of common but differentiated responsibilities and respective capabilities (CBDR-RC)?"

In so doing, we develop phaseout pathways appropriate for countries with higher capacities that are able to make a rapid and just transition at one end of the scale (phasing out production faster), and for countries with lower capacities to transition at the other (phasing out production more slowly – or perhaps more accurately, "not as fast").

The pathways are informed by careful consideration of issues of equity (as captured in CBDR-RC), and all comply with the remaining carbon budgets for given probabilities of specific temperatures consistent with the Paris Agreement goals. We identify what these pathways tell us about the phaseout schedules and the required end dates for production of oil and gas in producer countries. All this is guided by nations' respective dependence on oil and gas revenues and their capacity to rapidly transition away from fossil fuel production.

This analysis uses science-based budgets, carefully reasoned and transparent assumptions about mitigation and a careful consideration of equity.

SECTION FOOTNOTES

[1] While mitigating impacts of climate change is the primary concern of both this report and the Paris Agreement, it is worth noting that the temperature goals of the treaty are situated in the context of wider sustainable development, equity and poverty eradication goals.

[2] It has been argued that from a mitigation perspective it is simpler to deal with a smaller number of supplying entities (whether they be nationalised industries or private companies) than a much larger number of consuming entities (individual end-users). While such arguments may be compelling, this work does not seek to advance nor contradict them.

[3] Both in direct combustion and still more so when used for electricity generation

[4] Historically, the phase out of coal in many wealthy nations has been driven as much by clean air directives as by climate change mitigation. The impact of coal on air quality is now also a serious concern for many rapidly industrialising nations, particularly China and India.

[5] Agreed as part of the 1992 UNFCCC [20] and the attendant principle of CBDR-RC, with the latter remaining central in all subsequent United Nations COPs.

[6] For some nations, oil and gas revenue forms such a large part of the economy that rapidly removing it could destabilise what are sometimes fragile governments.

[7] For example, from a technical perspective, this would require embedding concepts such as the 'marginal value of money' (determined not by modelers in the global north, but by sociological/anthropological analyses of diverse populations in 'poorer' nations) and compensation principles (e.g. Kaldor-Hicks-Scitovsky, including the thorny issue of whether such compensation should actually be paid or simply theoretically possible). These would then need to be considered in relation to key factors in GE models, not just as technical adjustments, but rather informed by much deeper cultural and philosophical considerations of nations where the tenets of GE modelling are far removed from the functioning of such societies. Ultimately, IAMs and GE models are constructs of a particular and highly technocratic worldview, and as such are unable to embed the diverse political economies that comprise and inform the multi-layered process and dialogues feeding into the COP negotiations and agreements.

2 Global carbon budget framing

This section addresses the question: what CO_2 emissions space (expressed as a carbon budget range) is left for global energy use if the temperature and equity goals of the Paris Agreement are to be delivered?

2.1 Cumulative carbon budgets

Carbon budgets delimit the total additional quantity of CO_2 that can be released into the atmosphere for a named probability of not exceeding a given temperature threshold. The WGI contribution to AR6 updates the carbon budgets associated with a range of temperature stabilisation levels from those published in the IPCC's previous major report, SR1.5 [2].

For this research report, three scenarios based on AR6 carbon budgets[8] have been selected to represent:

(i) A 50% chance of staying within 1.7°C. This budget also gives a greater than 83% chance of staying within 2°C, as per the Paris Agreement.
(ii) A 50% chance of staying within (or stabilising at) 1.5°C.
(iii) A 67% chance of staying within (or stabilising at) 1.5°C.

This report revolves around three core scenarios, based on different probabilities of not exceeding 1.5°C and 1.7°C.

The 'headline' budgets in AR6 are for all global CO_2 emissions from the start of 2020 onwards, to cover the rest of the twenty-first century and beyond[9].

2.2 Adjustments to the headline budgets

From the headline AR6 budgets, we now make a series of deductions to identify how much is available for emissions from fossil fuels.

2.2.1 Earth system feedbacks

Earth system feedbacks (ESFs) include positive and negative climate responses to rising temperatures, for example, they may trigger the release of naturally stored greenhouse gases through thawing permafrost, increased frequency and extent of forest fires, or methane released from wetlands [13]. Whereas the budgets presented in SR1.5 did not include ESFs in their headline numbers[10], the AR6 budgets already account for 26 $GtCO_2$ (±97 $GtCO_2$) of ESFs per degree Celsius of warming.

Feedbacks within the climate system have the potential to make the AR6 carbon budgets considerably smaller.

For the purposes of this research, no adjustment has been made to the headline budgets for ESFs. That is, we use the AR6 headline budgets, which have already been reduced by 26$GtCO_2$ per degree for ESFs, with no further adjustment for the ±97 $GtCO_2$ per degree uncertainty range.

However, the scale of these potential feedbacks must always be borne in mind when considering the potential for overshooting the budget and temperature target. This sobering point is all the more important to recall whenever unproven-at-scale methods of carbon dioxide removal (CDR, see §3, below) are proposed as a means of extending the budget space available for a given temperature and probability.

Though different in character, both CDR and the additional ESFs share high levels of uncertainty. Consequently, from a precautionary perspective, it would be reasonable to expect a family of emission scenarios with carbon budgets reduced in line with the estimates of additional ESFs (97 $GtCO_2$ per °C)[11]. Instead, the four headline scenarios in AR6 all assume the huge roll-out of CDR: three reliant on NETs and one that adopts very significant levels of afforestation. None of the four headline scenarios takes account of the significantly reduced carbon budgets from including the additional ESFs.

In keeping with AR6, we do not adjust the global carbon budgets for possible additional feedbacks within the climate system.

Set within the context of high levels of uncertainty associated with both CDR and additional ESFs, the analysis developed for this report adopts a conservative approach. As such, it uses the AR6 headline budgets, not increasing them through the inclusion of CDR (see section 3) nor reducing them through additional ESFs.

2.2.2 Recent emissions

The Global Carbon Project [5, 6] reports that global CO_2 emissions from fossil fuels (energy and processes) in 2020 were 34 $GtCO_2$, with CO_2 from land use change and forestry (LUCF) adding a further 3.2 $GtCO_2$. Data analysis for 2021 emissions is not yet finalised, but it is expected that 2021 will see a slight rebound of the COVID-19-induced downturn, resulting in total emissions of around 36.7 $GtCO_2$ from fossil fuels and 3.8 $GtCO_2$ from LUCF. We remove this combined 78.5 $GtCO_2$ of emissions in 2020 and 2021 from the AR6 budgets to give values commencing in 2022.

Adjustments are made to the global budgets to account for recent emissions and global cement process emissions.

2.2.3 Global cement production

Following the logic elaborated in Anderson et al's 2020 Climate Policy paper, *A Factor of Two* [16] (hereafter *Factor of Two*), process CO_2 emissions from global cement production is treated here as a 'global overhead'. That is to say, process emissions from cement production are treated as the responsibility of all nations, rather than purely of those developing nations from which the majority of these emissions will arise as they continue to expand and upgrade their infrastructure.

Cement process emissions are a largely unavoidable consequence of creating new infrastructure. We treat them as a global overhead, i.e. the collective responsibility of all nations.

Treating cement process emissions in this way recognises that the remaining carbon budget for all nations has already been affected by the cement-related emissions from previous infrastructure development in wealthy nations. It also applies pressure to innovate and reduce emissions from cement manufacture for all nations, since all bear the consequences (less emissions space for energy) of ongoing high emissions from cement anywhere.

Acknowledging the very high level of optimism in applying the IEA's Cement Technology Roadmap [17] estimate of growth in global cement production in *Factor of Two*, in our 1.7°C scenario here we adopt a slightly more conservative (but still ambitious) value of 100 $GtCO_2$ to account for cement-based process emissions out to 2075 (the point at which the IEA roadmap posits elimination of all cement process emissions). However, AR6 budgets for a 50% and 67% chance of staying within 1.5°C are too small to admit of this precaution without severely constraining the energy pathways of developing countries. Therefore, in the 1.5°C scenarios a global overhead of 60 $GtCO_2$ is assumed for cement, as in *Factor of Two*, and removed from the post-2022 budgets[12].

Our assumed pathway for cement manufacture is ambitious and will be highly challenging for the industry to deliver.

Note that 100$GtCO_2$ assumes a growth rate in cement production that corresponds to the lowest recorded period of growth in recent years (following the 2008 international financial crisis), while the 60$GtCO_2$ assumes annual growth in cement production at a rate that is an order of magnitude lower than any value recorded since the 1950s. Clearly both are optimistic assumptions. To comply with the much tighter budgets for 1.5°C, all systems, energy and processes alike, are pushed as hard as can be practically conceived, hence we use the highly optimistic 60$GtCO_2$ overhead. In the 1.7°C budget there is a little more space for energy and process emissions alike, so it was deemed appropriate that some of that flexibility should accrue to the cement sector. Hence 100$GtCO_2$ was judged the more suitable overhead.

2.2.4 Global iron and steel production

Steel is a vital construction material, which will inevitably play a large role in expanding the renewable energy networks of all countries. As such, it might be argued that iron and steel production should be treated as a global overhead in the emissions budget, in much the same way as cement process emissions. The explicit focus in this project on fossil fuel production also suggests that metallurgical coal, which is used to make coke for the iron and steel industries, might be considered a global overhead.

High levels of process emissions are not inevitable for iron- and steelmaking, so we do not treat those industries like cement manufacture.

Coke is both a fuel source and a reducing agent in the blast furnace–basic oxygen furnace (BF-BOF) method of primary steelmaking. Process emissions from iron and steelmaking are 12% of direct emissions in the BF-BOF method, specifically 0.3 $GtCO_2$ of 2.6 $GtCO_2$ total direct[13] emissions in 2019 [18].

However, there exist proven, viable alternatives to BF-BOF that do not require the use of coke either as a fuel source or as the carbon-based reducing agent. These include as direct reduced iron (DRI) furnaces and electric arc furnaces

(EAF), with renewable-produced ("green") hydrogen as the reducing agent. Both DRI and EAF are currently in use in several countries and being upscaled. Thus even accepting that BF-BOF is the most common method of primary steelmaking today, its process emissions are (i) a much smaller proportion than in cement making, and (ii) mitigable with readily available, existing technology. For these reasons, process emissions from metallurgical coal for the iron and steelmaking industries is not treated as a global overhead. No further distinction is drawn between thermal and metallurgical coal in this project.

2.2.5 Emissions from global land use change and forestry

In the same way that cement process emissions are treated as the joint responsibility of all the nations of the world, so too we consider emissions from deforestation as a 'global overhead' within the carbon budget. The reasons for this are threefold.

First, wealthy countries have to a large extent already deforested their territories during the process of industrialising their economies. By making land available for agriculture and industry, they have already economically benefited from their own programme of deforestation (much as they have already benefited from emissions from cement for their own infrastructure).

Emissions from deforestation are also treated as the collective responsibility of all nations.

Second, treating deforestation emissions as a global overhead better encourages all nations to assess their own influence on global deforestation activities, such as through finding alternatives to meat-based diets that require large areas of cleared land for cattle ranches.

Third, this approach denies any claim by wealthy, long-deforested nations, to emissions 'credit' – effectively additional budget for energy emissions – from reforestation and afforestation projects, whether in their own territories or abroad. Treating the balance of deforestation emissions as a global overhead, therefore prevents a possible weakening of mitigation in wealthy high-emitting countries that would seek such offset credits.

However, in keeping with *Factor of Two*, it is also assumed that a global mitigation programme compliant with temperature-derived carbon budgets would have to include a vigorous development of forest-based carbon sequestration practices, in tandem with an urgent suppression of deforestation emissions themselves. It is therefore assumed that over the period 2022 to 2100 emissions from deforestation are balanced out by an equivalent quantity of carbon dioxide sequestered from LUCF[14].

We assume that CO_2 emissions from deforestation are balanced out over the century by sequestration from the wider land use sector.

While we consider this zero-sum balancing an optimistic assumption, we note that many mitigation modellers invoke considerably higher levels of optimism in assuming that forests will remove huge quantities of carbon dioxide from the atmosphere over the course of the century (see §3 for discussion of why we adopt a more precautionary approach to carbon dioxide removal). Note that no such assumption about balancing out is made for emissions of non-CO_2 greenhouse gases from LUCF or agriculture, which must be considered the prime candidates for technology-based CDR if and when such technologies become viable and deployed at scale.

We assume that non-CO_2 emissions from the wider land use sector (including agriculture) will remain largely unavoidable during the rest of the century, and must be compensated for.

2.3 Global budgets for scenarios in this project

Taking account of the adjustments to AR6's headline temperature-derived budgets described in section 2.2, we can determine the following range of global budgets for CO_2 emissions from energy only from January 2022 onwards.

Scenario	Headline global budget in AR6, i.e. from start of 2020	Less 2020-21 emissions (budget from start of 2022)	Less cement process emissions (fossil fuel budget)	Years at current emission rate
50% 1.7°C	850	771	**671**	18.3
50% 1.5°C	500	421	**361**	9.8
67% 1.5°C	400	321	**261**	7.1

Table 1: Global emissions budgets and key adjustments under three scenarios.

There is less than ten-years'-worth of current emissions remaining for a 50:50 chance of limiting global warming to 1.5°C.

NB: All budget values in billion tonnes of CO_2 ($GtCO_2$). The budget for 50% chance of 1.7°C is the same as for 83% chance of 2°C.

SECTION FOOTNOTES

[8] AR6, Table SPM.2

[9] CO_2 is atmospherically stable (chemically unreactive), so accumulates and exerts a warming effect for centuries, potentially millennia, to come. The budgets in AR6 are therefore effectively 'forever' budgets, unless and until direct air capture and permanent sequestration of CO_2 is developed and successfully implemented at the global scale.

[10] Table 2.2 of SR1.5 specifies a reduction to the budgets of $100GtCO_2$ over the century to reflect climate feedback uncertainties.

[11] Scenarios could also be developed for an increase in the budgets by 97GtCO_2/°C (as the per the IPCC estimate of additional ESFs), however this would work directly against a more precautionary perspective. In addition, it could be argued that given *all* the IPCC's headline mitigation scenarios adopt significant levels of highly uncertain CDR (effectively expanding the carbon budget), then indirectly at least, the effect of increasing the budget through ESFs should be considered.

[12] For more detail on how the various estimates of growth in global cement production in the IEA Cement Technology Roadmap were applied to real world data on cement production, see *Factor of Two* (section 3.1.1 and Appendix B–Cement in Supplemental Material).

[13] Direct emissions in this case refers to the emissions only from the steelmaking process itself, not the emissions from producing the electricity and heat consumed by the sector.

[14] *Factor of Two,* written in 2019 and published in early 2020, assumed that LUCF emissions would balance out over the course of the century from the start of 2020 onwards. As there is no evidence of emissions from this sector declining in the interim, here we remove LUCF emissions in 2020 and 2021 (see §2.2.2) and assume that the sector is zero-sum over the remainder of the century.

3 What role for Carbon Dioxide Removal and Carbon Capture and Storage?

3.1 The case for CDR and CCS

Since the IPCC's first major report in 1990 and the UNFCCC entering into force in 1994[15] [19], the rates of mitigation needed to *"prevent dangerous anthropogenic interference with the climate system"* [11, p.4] have increased substantially. From 2013 the IPCC's reports began to include explicit carbon budgets for various probabilities of different temperatures [2], [6], [7]. These budgets have provided a means to robustly quantify the widening gulf between real action to reduce emissions on the one hand, and political commitments on climate change on the other.

Mitigation modelling has only started to widely embrace CDR and CCS relatively recently, prompted by rapidly depleting carbon budgets and improved understanding of the severity and onset of likely impacts of 1.5°C.

Coincident with the rapid decline in the remaining carbon budgets, improvements in climate science have led to a reduction in the temperature at which 'dangerous' impacts are forecast to occur [21]. This combination of dwindling budgets and a focus on lower temperatures (i.e. a stronger emphasis on 1.5°C) has prompted many mitigation scenario modellers to include increasing levels of future 'carbon dioxide removal' (CDR) and the deployment of 'carbon capture and storage' (CCS) technologies. Within a given carbon budget, the adoption of CDR reduces the necessary rates of mitigation by effectively increasing the available emissions space. The inclusion of CCS has the effect of reducing the carbon intensity of fossil fuel energy (e.g. the grams of CO_2 emitted per kWh of energy produced) and thereby increase the total quantity of fossil fuels that may be combusted for any given carbon budget.

3.2 Why we do not expand the carbon budgets through CDR

Within this report, CDR, both in the form of 'negative emissions technologies' (NETs) and 'nature-based solutions' (NbS), is not used to increase the size of the remaining carbon budgets. This position reflects several key concerns arising from the almost ubiquitous adoption of CDR within high-level emission scenarios. The following subsections provide a succinct account of why, within this analysis, CDR is not used to expand the emission space available for fossil fuel combustion.

3.2.1 NETs: too speculative for inclusion

As of today, NETs are either in the form of small pilot demonstrators capturing just a few thousand tonnes of carbon dioxide[16] [22], [23] or remain in the imagination of modelers and engineers. Despite this, virtually all high-level mitigation analyses assume that in coming decades NETs will be deployed at huge, planetary scale, increasing significantly post-2050 and extending well beyond the end of the century. Certainly, there is merit in a well-funded research and development programme on NETs. Moreover, provided any promising designs meet stringent ecological and social sustainability criteria, a rapid process of large-scale testing and subsequent deployment should commence.

Negative emissions technology schemes remain at the scale of small pilot schemes. Their deployment at planetary-scale is as yet hard to envisage.

Such deployment of NETs in a small suite of more exotic scenarios would add an important family of model outputs to complement those using existing technologies and understood processes of social change. However, and despite the fledgling state of NETs, their 'unproblematic' use to remove many hundreds of billions of tonnes of carbon dioxide across the century is now pervasive.

3.2.2 BECCS: ecological and sustainability implications

Within existing models and scenarios, the approach that dominates the NETs assumption is bioenergy with carbon capture and storage (BECCS). In this approach the growing of organic material (biomass) absorbs atmospheric CO_2, with the biomass subsequently combusted as fuel in a conventional thermal power station from which the CO_2 is captured and stored rather than emitted.

BECCS is not invoked in this report because of its serious ecological and societal risks.

Ostensibly BECCS confers considerable advantages to models seeking to cost-optimise their responses to climate change, as it substitutes for other mitigation options deemed to have higher marginal costs. However, the scale of mono-cropped[17] biomass necessary to deliver the billions of tonnes of removal through BECCs imposes considerable ecological and societal risks. In important respects, the cure could be as bad if not worse than the disease. One estimate puts the *"loss of terrestrial species* (from high levels of BECCS) *perhaps worse than the losses resulting from a temperature increase of about 2.8°C above pre-industrial levels."* [24]. Another estimate puts the land take associated with the levels of BECCS in many models at between 380 and 700 million hectares [25], equivalent to one-and-a-half times the combined area of the EU's twenty-seven countries, or up to twice the area of India. Further to such high-profile impacts, BECCS at scale also has major implications for water use, land-rights, global shipping and wider transport demands, as well as those associated with the integrity of carbon dioxide storage.

From the perspective of this analysis, the particular details of returning to a global economy powered, in significant part, by the combustion of plant material with the emissions subsequently captured and buried, is largely beside the point. As noted in §3.2.1, this analysis does not explicitly adopt any form of NETs as a means for directly expanding the available carbon budget space for fossil fuels. Nevertheless, as discussed in §3.2.4 below, some form of CDR is indirectly assumed to compensate for warming arising from those residual agricultural emissions that cannot be eliminated.

3.2.3 Forestry as a 'nature-based solution' to rising emissions

Another approach increasingly mooted as having potential to expand the available carbon budget, and thereby reduce the rates of immediate and early mitigation, is the adoption of high levels of forestry. This typically takes the form of afforestation and reforestation, but in analyses that draw on specialist forestry expertise, notably extends to include the regeneration of degraded forests [26].

While there is certainly significant potential for the uptake of carbon dioxide into additional forestry cover, what is critical for this report is that "*the rates and amounts of net carbon uptake are slow and low compared to the rates and amounts of carbon dioxide we release by fossil fuel combustion. Hence, removal of carbon dioxide from the atmosphere does not compensate for the release of fossil fuel emissions*" [26, p. 10]. This key point was reiterated at COP26. Based on the publication of the 'New Insights in Climate Science 2021' [27], Professor Rockström (one of the report's authors) stated clearly "*we need nature-based solutions, but we cannot use them to slow down the pace of emission reductions from fossil fuels*" [28].

Forestation as a 'nature-based solution' to climate change is not invoked in this report because biospheric carbon is not interchangeable with fossil carbon.

Further to this, the simple reduction of the myriad complexities of trees and forests to one of carbon risks missing a much more nuanced suite of climate-related issues that remain, to an important degree, unsettled[18] [29].

For this report the breadth of forestry-related issues – from how terrestrial carbon is always vulnerable to re-emission (i.e. issues of permanence), through to temporal differences in land and fossil-fuel carbon cycles – are considered sufficient reason to exclude NbS from compensating directly for fossil fuels emissions.

3.2.4 CDR to balance residual emissions from agriculture

A key caveat to the role of CDR in relation to carbon dioxide budgets and fossil fuels is that emissions of all long-lived greenhouse gases need to reduce to zero, or warming from any residual emissions must be compensated for. In this regard, the report's authors acknowledge the vital role of some form of CDR in balancing ongoing warming from residual agricultural emissions of nitrous oxide (N_2O) and methane (CH_4). While such emissions can be significantly reduced from their current rate, they cannot be entirely eradicated. With a rising global population, alongside changes in the climate, rainfall patterns, etc, there will very likely be additional demand for fertiliser use to maintain and potentially increase yields. Overall, a combination of much improved agricultural practices and a fundamental shift away from meat consumption is here assumed to result in total global agricultural emissions in

Ongoing emissions of non-CO_2 greenhouse gases (nitrous oxide and methane) cannot be eliminated from agriculture, even with better technology and practices and shifts in diets.

the order of 4 to 7 $GtCO_2e$/year [30], [31] – not too dissimilar to estimates of future CDR.

Acknowledging the need for significant levels of CDR to address those emissions impossible to eliminate (in contrast to just 'difficult' to decarbonise) highlights the jeopardy of 'double-counting' such removals to offset emissions from fossil fuels. Thus, the fossil fuel phaseout schedules in this report are developed without recourse to future CDR for the energy system.

This report assumes that CDR has a vital role to play in balancing residual (unavoidable) non-CO_2 emissions from agriculture – but not CO_2 from fossil fuels.

3.3 Why do we not expand the use for fossil fuels through CCS ?

The prospect of CCS has, since the late 1970s [32], been proposed as a potential means for reducing the emissions per kilowatt hour of fossil-fuel-fired power generation. More recently, it has also been offered as a technology with the potential to unlock the production of 'blue hydrogen'. However, while CCS has remained central to most orthodox system-level mitigation scenarios, in practice the fossil fuels industries have demonstrated very little belief in its long-term prospects, having constructed just a few small pilot schemes over the past two decades.

In 2010 the IEA's CCS Roadmap (as part of its low carbon 'Blue' scenario) [33] envisaged sixty large scale CCS projects by 2020, rising to around 500 by 2030 and over 1800 by 2050. In its 2021 report, the Global CCS Institute noted there were twenty-seven plants operational, with four more currently under construction [34]. Total capture was estimated at a little under 37 $MtCO_2$, or less than 0.1% of total fossil-fuel CO_2 emissions. If those future plants designated by the Global CCS Institute as in a stage of "advanced development" were all to proceed to construction and then full operation, capture rates could rise by an additional 47 $MtCO_2$, bringing the total to a little over 0.2% of current annual fossil fuel emissions. However, these values include both geological storage and the use of captured CO_2 for 'enhanced oil recovery'. Considering only CO_2 actually stored geologically reduces the 37 $MtCO_2$ to a little over 7 $MtCO_2$, or under 0.02% of energy-related CO_2 emitted in 2021. As for the future projects, and again assuming they are proceed to full operation, then in terms of storage, by 2030 the total is set to rise to around 45 $MtCO_2$, or a little over 0.1% of current emissions [35].

Despite bold promises of its potential, CCS on fossil fuels has yet to deliver more than a few million tonnes of CO_2 actually stored.

All of this is far-removed from the long-standing enthusiasm for CCS as a cornerstone of the decarbonisation agenda. Yet, and despite the long history of over-promising and under-delivering [36], this enthusiasm remains unchecked.

3.3.1 CCS: too little too late

The primary remit of this report is reducing emissions in line with not exceeding 1.5°C. This entails rapid decarbonisation, beginning now and being all but complete within one to two decades. Such a tight timeframe is inconsistent with any realistic interpretation of the roadmaps of CCS-based power generation or blue hydrogen production.

The remaining carbon budget for 1.5°C is too small to allow time for CCS to make an impact on fossil fuel emissions.

Furthermore, power generation is the one area of energy supply where very low or zero carbon alternatives actually exist, and at prices that are already competitive. Adding both the significant capital cost of CCS to existing or even new facilities, alongside the major energy penalty of CCS-based generation (i.e. much higher costs/kilowatt hour), further reinforces the cost-competitiveness (and energy security benefits) of renewables.

As such, bolting on what is in effect an inefficient and expensive filter to prolong the life of fossil fuels is very much an 'end-of-pipe' approach, more reminiscent of the last century than the system-level considerations of this century.

3.3.2 The very high lifecycle emissions of CCS

While it may be possible to reduce operational emissions of CO_2 by around 90%, this still leaves a significant residue of CO_2 released to the atmosphere[19] [37]. Given the need for all GHGs to be eliminated globally, with only residual emissions from agriculture remaining, then the high lifecycle emissions associated with CCS (typically 100–300 gCO_2e/kWh [38]) make it unsuitable for all but very marginal roles.

3.3.3 A tonne emitted from CCS is a tonne that cannot be emitted elsewhere

A further consideration in terms of CCS within the energy system is how low- or zero-CO_2 options for power generation are far more advanced than are the alternatives for fossil fuels in other sectors, particularly transport. Consequently, every tonne of CO_2 emitted from a power station (even with CCS) is a tonne that cannot be emitted from transport or industry. Since electricity generation has many more options for easier and earlier decarbonisation, this misappropriation of the scarce carbon budget works against a system-level transition to zero carbon energy.

CCS will be needed to mitigate ongoing process emissions from cement, for which there is no ready alternative.

3.3.4 The potential merits of CCS on cement

The role of CCS in eliminating process emissions from industry, particularly cement manufacture, is subject to different conditions to that for power generation. As it stands, CCS looks set to be a key technology in addressing the 4% of global CO_2 emissions released from the chemical reactions in cement production.

3.4 CDR and CCS: summary

In short, this report eschews the substitution of deep cuts in emissions today for CDR and CCS tomorrow. Rather, it faces the mitigation challenges head on, navigating the highly constrained space between an equitable and practical distribution of the rapidly dwindling carbon budgets.

SECTION FOOTNOTES

[15] The UNFCCC was adopted at the UN in New York in May 1992, opened for signatures in Rio in June 1992 and finally entered into force in March 1994.

[16] For example, the new (Sept 2021) Orca power plant in Iceland, which captures around 4000 tonnes of CO_2, or the equivalent of around 0.00001% of global CO_2 emissions from fossil fuels. Ostensibly higher levels of actual removal occur at the ADM bioethanol plant in Illinois in the USA. Here in the region of 0.5MtCO_2/yr have been successfully captured and stored, with the operational capacity to increase to 1MtCO_2/yr [60]. However, there is little full life-cycle information available to determine the net levels of CO_2 removal, with the plant's total CO_2 emissions actually rising in recent years (to over 4MtCO_2/yr), likely due in part to the wider activities it undertakes, but also the energy required for the capture and storage. The ADM plant certainly demonstrates how, when rich CO_2 streams exist from biomass processing, it is possible to capture and store the CO_2. However, the application of CCS on the *combustion* of biomass (or indeed fossil fuels) presents a very different engineering challenge (with much lower concentrations of CO_2 and more contaminants), yet it is this approach that dominates the high-level mitigation models.

[17] Or at least a crop with very limited biodiversity.

[18] For example, issues of albedo and 'volatile organic compounds' (VOCs). See [29] for more details.

[19] Sustained capture rates above 90% are theoretically possible, but would very likely go along with a significant increase in both indirect greenhouse emissions and cost.

4 Splitting the global carbon budget between fossil fuel types

This section explains the key methodological assumptions and reasoning used in this analysis to estimate production-specific emissions budgets.

4.1 Rationale for 'production budgets'

This project is primarily concerned with the production side of the emissions equation. At the global level, annual production is in lockstep with annual consumption of fossil fuels. That is to say, fuel is extracted in quantities more or less equal to the market consumption of that fuel. This is largely because of physical and economic limits on storage, whereby there is simply not capacity to store significant surpluses of fossil fuels over and above the national capacity buffers that are held as a matter of course. What limited additional storage facilities exist are filled to capacity by as little as a few months' surplus production for oil and gas [39], or a few weeks for coal [40]. Oversupply therefore leads to falling prices and rapidly scaled down production volumes. The empirical data on annual production and consumption volumes neatly bear out this one-for-one relationship[20].

Fossil fuels cannot be stored in large quantities, so annual production and consumption globally are closely related.

At the global level then, for all practical purposes, fossil fuel production and consumption are equivalent. It is therefore taken as a premise of this work that whatever quantity of fossil fuels is produced in a given year is consumed in that same calendar year[21]. By applying an appropriate emissions factor to each fuel type, one can then calculate the amount of CO_2 that will be released into the atmosphere when the relevant quantity of produced fuel is combusted. Physical restrictions on storing excess production are again relevant here. Since significant surplus production cannot be stored, and apart from the very small fraction of fossil fuels that is diverted to non-energy end uses (and, importantly, that are not combusted at end of life – see §4.1.1 below), it is a matter of inevitability that, once extracted, a fossil fuel will be combusted.

Once extracted, fossil fuels are inevitably combusted.

This being so, the global budgets for CO_2 (Table 1) from fossil-based energy use can be straightforwardly applied to fossil fuel *production* at the global level just as well as to consumption. By translating production volumes into their inevitable emissions outcome using appropriate fuel-specific emissions factors, one can quantify the maximum amount of fossil fuels that may be extracted globally while respecting given temperature-derived carbon budgets [41]–[44].

Global CO_2 budgets for consumption can easily be applied to production.

A complete dataset of the total quantities of each fuel type produced and consumed, in thousands of tonnes of oil equivalent (ktoe), for two-hundred-and-thirteen countries was compiled from the IEA's World Summary Energy Balances 2020 [45]. The most recent year for which a complete dataset was available for both production and consumption of fossil fuels was 2018. It is this year, therefore, that forms the baseline for all subsequent comparisons and pathway development in this project, unless otherwise stated. The energy equivalent values from the IEA were then converted into their emissions equivalent using IPCC emissions factors[22].

Fossil fuel production is usually expressed in units of energy or volume. Using appropriate emissions factors, these quantities can be converted into their equivalent CO_2 emissions.

4.1.1 Non-energy end uses of fossil fuels

Non-energy use refers to those fossil fuels used as raw materials in the manufacture of physical products rather than direct combustion for energy generation (as heat, electricity or motion). Globally, non-energy use averages around 6.4% of total energy supply [46], with the non-energy percentage of oil and gas being slightly higher and coal substantially lower than the aggregate. While this is a non-negligible fraction of the total quantity of fossil fuels extracted each year, it would be misleading to suppose that 'non-energy use' (or sometimes 'non-combustion end use') means that the feedstocks do not ultimately result in CO_2 and other GHG emissions.

It is an open question exactly what portion of non-energy end use fossil fuels are sequestered in stable form as physical products, buildings or infrastructure (such as roads). However, a large proportion of non-energy fossil fuel use is ultimately incinerated at the end of the useful life of the products[23]. Around one quarter of plastics produced annually is incinerated, which releases embedded carbon to the atmosphere[24]. Even the heavy hydrocarbons in road materials such as asphalt and bitumen undergo slow biodegradation in situ, which also gives rise to CO_2 emissions.

As a general principle, this project adopts a pragmatic but precautionary approach to uncertainty, which is appropriate in view of the high uncertainties around earth system feedbacks in the AR6 carbon budgets, and around the consequences of short-term overshoot of given temperature thresholds. Therefore, at the global level, we assume the total quantity of fossil fuel production to be equivalent to the emissions from combusting that same quantity of fossil fuel in any given year. In any case, the proportion of non-energy use fossil CO_2 that remains permanently locked up in durable products is considered too small to materially affect the outcome of the analysis here.

The amount of fossil fuels diverted to non-energy end uses and which remain unburned is negligible from a global carbon budget perspective.

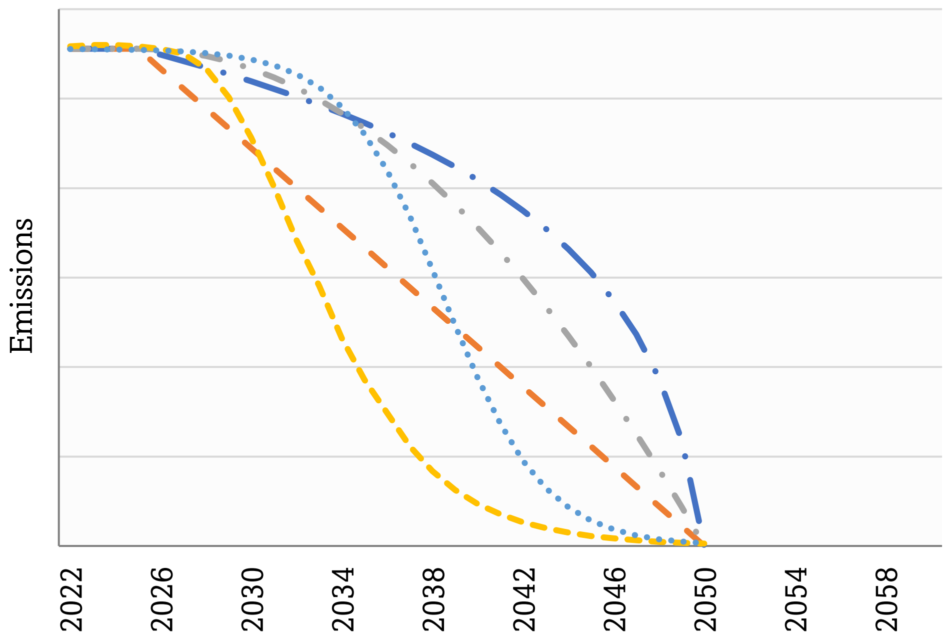
4.2 Phaseout schedules, end dates, pathways and budgets

The remit of this research was to identify appropriate phaseout schedules for oil and gas production in order to comply with specific temperature-constrained emissions budgets. While the concept of an 'end date'[25] can be useful for policymaking, it must be treated with a degree of caution. Put bluntly: the climate is indifferent to the end year for production (or indeed consumption) of fossil fuels; it takes notice only of the cumulative quantity of carbon added to the atmosphere over and above pre-industrial levels. As such, whether fossil fuels end in 2030 or 2080, what matters is not the end date *per se*, but the total emissions released into the atmosphere up to that point.

End dates for production (or consumption) mean little without an accompanying budget and pathway.

When we plot annual emissions associated with production or consumption of fossil fuels on a graph, the line or curve that joins the yearly amounts is known as the emissions pathway (sometimes, emissions trajectory). The pathway is how annual emissions vary (ideally decline) over time until they reach the final zero date, or some other specified end point. In this regard, end dates are a function of the available carbon budget and the rate at which it is depleted over time.

There is a wide variety of emissions pathways that can lead to the same end date or zero year (see Figure 1 below), but they describe very different cumulative emissions burdens, which in turn have very different consequences for global warming. Thus, the production end dates assessed in this study are relevant to a given climate outcome *only if* the stated pace of emissions reductions (expressed as the pathway) between now and that year is adhered to. If mitigation were to lag in the short term, then the 'end date' would have to come earlier to stay within the overall carbon budget.



Strikingly different budgets and pathways can have the same end date. The climate is sensitive only to the cumulative emissions, or budget.

Figure 1: Example of five stylised emissions pathways with the same end year, but with markedly different cumulative emissions.

Nevertheless, given the constraints of small and dwindling carbon budgets for desirable probabilities of 1.5°C and 2°C, the variety of *plausible* pathways for emissions from fossil fuel production is limited. That is to say, there is virtually no scope for increasing emissions in the short term without requiring overnight cessation of emissions at the 'eleventh hour'. For the smaller budgets, there is no scope for anything but immediate deep and rapid reduction in emissions from all forms of production, without bringing the world's energy system to a socially devasting 'hard stop' once the budget is all too quickly consumed.

There are few plausible pathways that are still compatible with 1.5°C. Since we can't end fossil fuel emissions overnight, pathways must show year-on-year reductions.

Thus, the envelope of viable pathways for a given budget with a given zero year is effectively constrained by the imperatives of:

(i) ensuring an ecologically sustainable energy supply for the post-fossil era; and

(ii) ensuring a just transition for those whose livelihoods currently depend on fossil fuel extraction; and

(iii) ensuring viable and ecologically sustainable pathways broadly consistent with the tenets of CBDR-RC.

How these considerations feed into the formation of plausible pathways for ending fossil fuel production is discussed in more detail in section 6 below. There we look at fundamental principles of equity and methods for estimating the differing capacities of producer nations to facilitate a just transition away from fossil fuel production for their societies. For now, it is sufficient to remember that when we get to zero production matters less than how we get there.

4.2.1 Heuristic, not predictive, pathways

Another important point to note about all the pathways presented in this report is that they serve as heuristic tools to understand the relationship between annual emissions (associated with a specified activity) and the global emissions budgets associated with given temperature targets. They are not intended to prescribe precise budgets or pathways for specific nations, but rather to explore the consequences of certain trends and policies.

The pathways in this report are illustrative rather than precisely prescriptive for individual nations.

A key advantage of such relatively simple heuristic pathways is that they render transparent both the problem of fitting production within the remaining global emissions budget, and the assumptions involved in robustly addressing that problem. This stands in contrast to highly complex and inaccessible bottom-up system models.

4.3 Coal budgets – a necessary first step

A key assumption for this analysis was that coal, as the most carbon intensive and least energy efficient fossil fuel type, should be phased out as a higher priority than oil and gas. Coal-fired electricity generation has already been phased out in a number of industrialised, wealthy countries that once relied on it. Building on this, there is now a growing political consensus that in order to address the climate emergency coal must be phased out as a priority in all countries that continue to use it [8].

To estimate how much emissions budget there is left for oil and gas, we first looked at how quickly coal production could realistically be phased out .

While the main focus of this analysis is oil and gas production, establishing implications of possible phaseout schedules for coal was an important preliminary step in determining the carbon budgets and functional end dates for oil and gas.

4.3.1 Coal production in Developed and Developing Countries

It is important to note that coal is both produced and consumed disproportionately by the poorer countries of the world. Using the categorisation developed in *Factor of Two* for classifying countries as 'Developed' or 'Developing'[26], 72% of coal *production* occurred in the group of Developing nations in our baseline year (2018), with 28% in Developed.

Coal is both produced and consumed disproportionately by developing countries.

As a side-note, this analysis also showed that 74% of coal energy was *consumed* in Developing countries. The small net transfer of coal from Developed to Developing countries notwithstanding, levels of domestic coal production and consumption are closely related for most countries that have any significant proportion of coal in their primary energy mix. Put simply, countries that use a lot of coal tend to be those that have a lot of coal reserves. Coal is much less traded internationally than oil or gas – a simple consequence of its comparatively greater bulk and mass (and hence higher transport costs) than for the quantity of oil or gas with equivalent energy content.

Developing countries' favouring of coal consumption as a 'fuel of choice' may be attributed a range of factors, including: the lack of available and affordable alternatives to coal-fired power generation; limited access to capital for new technology; and the urgent need to increase energy consumption to address issues of poverty.

4.3.2 Coal pathway assumptions

For each of the three temperature-constrained scenarios in this report (§2.3), a pragmatic judgement was made as to the fastest phaseout pathway for coal production in both Developed and Developing country groups. A number of key constraints and considerations that fed into the iterative process of developing the phaseout pathways are described in the following subsections.

Coal phaseout was pushed as hard as we judged it possible to deliver.

4.3.2.1 Relevance of consumption to coal production phaseout schedule

While the explicit focus of this work is on production, in the case of coal the aforementioned close connection between domestic production and consumption was an important factor to consider in developing plausible phaseout pathways. That is to say, because Developing countries with coal reserves tend to use them principally for their own energy supply, the phaseout pathway has direct and immediate implications for energy *consumption* in those countries and hence their ability to meet the basic development needs of their citizens.

In our analysis, coal is phased out faster for developed countries than for developing countries.

Conversely, very few Developed countries rely heavily on coal production for their domestic energy consumption needs (Poland being a notable exception). The greater economic capacity of Developed countries to implement alternatives to coal to supply their energy needs means that a faster pace of shutdown for coal production in those countries is deemed appropriate.

4.3.2.2 Powering Past Coal Alliance declaration

Members of the Powering Past Coal Alliance (PPCA) have adopted a phaseout timeline for coal power generation in OECD and EU countries by 2030 and in the Rest of the World by 2050[27]. This was based on Rocha et al's [47] estimate of Paris-compatible timelines for ending coal use (Rocha et al also proposed a 2040 phaseout date for China).

Our assumptions about coal production phaseout schedules and end dates track the growing international consensus on phasing out coal's use for power generation.

The PPCA timelines provide a useful backdrop against which to situate the coal production phaseout pathways developed here. However, there are several important methodological differences between the present research and that by Rocha et al, (underpinning the PPCA declaration) that make direct comparison problematic. The foremost divergence is that Rocha et al's analysis and the PPCA itself relates to coal *use* with the main focus being, understandably, on power generation, whereas the focus of this project is explicitly on production.

Second, Rocha et al define the 'phaseout year' as the year in which the reduction in emissions from coal consumption is 90% or more against a baseline year of 2015. This differs subtly but importantly from our 'functional zero year', defined as the first year in which coal (or oil and gas, as the case may be) *production* is less than or equal to 5% of 2018 production. Noting that OECD coal production fell by 10% between 2015 and 2018, the Rocha et al baseline (transposed to production) is around 11% greater than the 2018 one used here[28].

Finally, China, notwithstanding its crucial role as the world's biggest producer and consumer of coal, sits squarely in the Developing countries category and is therefore treated as such in our present analysis, rather than being placed in a separate 'category of one' as in Rocha et al.

4.3.2.3 Sectoral share as a constraint on coal phaseout pathways

Recalling that the climate responds only to cumulative emissions, in developing the phase-out pathway for coal close attention was paid to its share of the global carbon budget, as well as to the remaining budget space for oil and gas. A key constraint was that in no temperature scenario was coal allowed to take up more than its current proportion of production emissions.

For each scenario, we do not allow coal to consume more of the global emissions budget than its current annual share.

	Share of total emissions in 2018	50% 1.7°C scenario	50% 1.5°C scenario	67% 1.5°C scenario
Coal	41%	37%	40%	41%
Oil	38%	41%	39%	38%
Gas	21%	22%	21%	21%

Table 2: Share of global emissions budget by fossil fuel type at baseline and under three temperature-based scenarios.

4.3.2.4 Developing Countries' peak coal production year

Accepting the close correspondence between coal consumption and production for Developing countries, pathway development for that group included a sensitivity analysis of the effect of delaying the year of peak production. Delaying the peak of Developed countries' coal production was found to be an option only in the 1.7°C scenario, with production held constant at 2018 levels until 2025. Under the much tighter constraints of 1.5°C scenarios, any delay in the year of peak production saw coal exceed the limit of 42% of the global budget (4.4.2.3), and by extension substantially reduce the remaining proportion of emissions space for oil and gas. Therefore our coal phaseout pathways in both of the 1.5°C scenarios have peak coal production in 2022 for Developing and Developed country groups alike.

The slightly larger budget for a 50% chance of 1.7°C allows a few more years before developing countries must start winding down their coal production. This is not an option for a 50% or better chance of 1.5°C – reductions must begin immediately.

Once plotted, the coal phaseout pathways rendered 'emergent budgets' for both Developed and Developing country groups (i.e. the cumulative emissions from coal production), as represented by the areas under the curves in Figure 2 below.

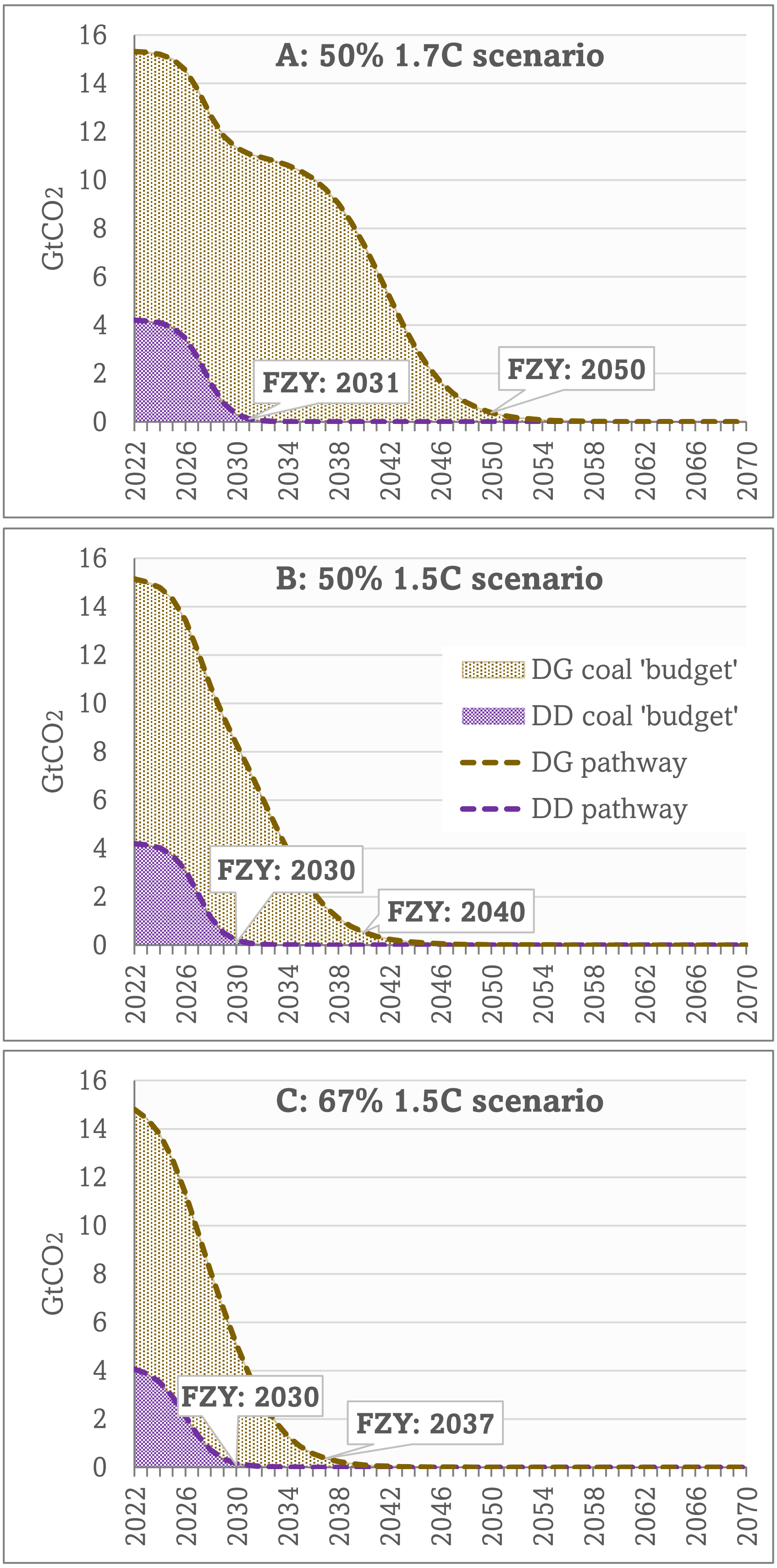


Figure 2: Coal production phaseout pathways and respective 'budgets' for Developed (DD) and Developing (DG) countries under three temperature scenarios.

NB: FZY = Functional Zero Year (<5% of 2018 baseline). See endnote 29 for note on the distinctive pathway shape in panel A (50% 1.7°C scenario).

4.4 Oil and gas budgets

The cumulative emissions totals from the coal phaseout pathways were then subtracted from the global carbon budgets (for the respective temperature scenarios) leaving a budget for oil and gas production combined.

Global budgets for oil and gas production over the rest of the century were obtained by subtracting coal emissions from the overall global budgets (based on IPCC AR6).

Further disaggregation into oil and gas separately was not undertaken in this analysis, because:

(i) most producer nations with one fuel (oil or gas) also have the other, and it was not deemed sensible to be prescriptive about which fuel type producer nations should prioritise.

(ii) it was decided to limit the number pathways and variables to ensure clarity of presentation and communication.

(iii) compelling reasons for favouring one fuel over the other, relative to their current shares, could not be found. See Appendix 1: Key sensitivities for more details of limitations and alternative assumptions.

Oil and gas are therefore treated in combination (summing to the non-coal emissions budget) in all scenarios in this report.

	Budget ($GtCO_2$) : 50% 1.7°C scenario	**Budget ($GtCO_2$): 50% 1.5°C scenario**	**Budget ($GtCO_2$): 67% 1.5°C scenario**
Coal	249	145	108
Oil & Gas	422	215	154

Table 3: global CO_2 production budgets for coal and oil & gas (combined) in three core scenarios.

NB: budgets as of January 2022.

These oil and gas budgets are then taken as the starting point for the disaggregation to groups of producer nations (§6).

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[20] For this project's baseline year of 2018, the amount of each of the three primary fossil fuel types produced was within 1% of the amount consumed globally, according to the IEA's World Summary Energy Balances 2019. Specifically, global coal production was 1.2% *below* consumption; global oil production was 0.6% above consumption; and global natural gas production was 1.1% above consumption.

[21] This is an expedient simplification: clearly a barrel of oil or tonne of coal extracted in say mid-December of one year may not enter the fuel supply chain and reach its final point of end use (combustion) until the following year. However, from one year to the next this 'carry over' simply cancels out, as the historical records on global production and consumption show.

[22] IPCC default emission factors for stationary combustion in the energy industries (tCO_2 / toe): bituminous coal 3.96; crude oil 3.07; natural gas 2.35 [61].

[23] Combustible non-energy products include plastics, lubricants, waxes, solvents, adhesives, paints, paper coverings and packaging [41].

[24] The amount of plastics recycled worldwide is low at around one fifth of annual production, while just over half ends up in municipal landfills or as litter. Most plastics do not break down in nature, so landfilled plastic is unlikely to release CO_2 directly [46].

[25] The terms 'end date', 'end year', 'phaseout year' or 'zero year' are used variously throughout the literature and dialogue on decarbonisation. They are treated synonymously in this report, except where otherwise specified.

[26] Countries were assigned to either 'Developed' (DD) or 'Developing' (DG) categories firstly according to their status as Annex 1 or non-Annex, with a refinement and subsequent reallocation from DG to DD of a small number of oil-rich, wealthy, non-Annex 1 nations whose HDI score exceeded the mean value for Annex 1 nations. This reallocation produced the new categories 'DD2' and 'DG2' in *Factor of Two*, which are the categories adopted here. Appendix C of *Factor of Two* contains the full country list; the categories of the producer countries relevant here can be found in Appendix 2: key data at the end of this report.

[27] In a post-SR1.5 update to the 2016 Rocha et al study, Yanguas Parra et al [62] found that, for compatibility with 1.5°C goals, coal use must be ended by 2030 in OECD (basically Developed) countries and by 2040 at the latest in non-OECD (Developing) countries. The 10-year earlier end date for Developing countries has yet to be adopted into the PPCA declaration.

[28] The coal phaseout pathways developed in this analysis reached functional zero years not later than the Rocha et al / PPCA phaseout years in all but one case. The exception was the Developed countries' coal pathway under the 67% chance of 1.7°C scenario, which reaches functional zero in 2031. However, against a 2015 baseline and 90% reduction phaseout threshold as per Rocha *et al*'s analysis, that pathway's phaseout year would be 2030.

[29] The coal pathways for a 50% chance of 1.7°C are slightly different from the pathways for the 1.5°C budgets, in that Developing countries' emissions from coal production are held constant from 2022 until 2025, when they begin their decline – essentially a delayed peak year. This gives the characteristic 'humped' shape of the stacked area chart of the budgets in Panel A of Figure 2. Under 1.5°C global budgets there was insufficient leeway to allow this delayed peak year for Developing countries' coal.

5 Dividing the global carbon budget between producer nations

Summary: this section explains the rationale and the methodology for grouping countries, before going on to present the five groups.

5.1 'Location independence': international trade of oil and gas

Whereas §4.4 identified the typically close correspondence between the country of production and country of consumption in the case of coal, national energy data demonstrates this is not true of oil or gas. Oil in particular is a widely-traded global commodity and is relatively cheap to move from port to port. Gas is traditionally more costly to move across and between continents, since pipelines are expensive to construct, in significant part because of the high capital cost of constructing pipelines and associated infrastructure. However, the growth of liquefied natural gas (LNG) production and marine transportation by tanker have led to increasing 'commodification' of the international gas market. International trade in gas has grown as a consequence, although it remains a markedly less traded fuel than oil.

Oil and gas are more widely traded than coal. Constraining a country's production need not mean a corresponding immediate constraint on their use of oil and gas.

For these reasons, production of oil and gas is taken to be largely independent of consumption. This is important when considering access-to-energy and the development implications of the phaseout pathways presented here[30]. Since oil and gas are widely traded (more so oil than gas), a country's energy needs are effectively indifferent to where the oil or gas is produced. This 'location independence' forms an important premise of this analysis. Countries will still be able to access oil and gas on the international market, at least to the extent that oil and gas continues to be available (ultimately constrained by the oil and gas budgets and the accompanying phase-out pathways). In short, constraining production of some nations more than others does not lead, necessarily, to a corresponding limitation on their access to oil and gas[31].

5.2 Oil and gas phaseout pathways and equity

The principle of 'common but differentiated responsibilities and respective capabilities' (CBDR-RC) makes plain that Developed Countries, with greater socio-economic capacity to mitigate, should make both bigger and earlier steps to decarbonise than Developing Countries (with less capacity) Moreover, the principle requires that Developed Countries provide financial support to enable Developing Countries to implement effective mitigation while continuing to pursue sustainable development and poverty eradication.

The principle of equity dictates that developed countries, with the greatest abilities to decarbonise, should make both bigger and sooner emissions reductions than developing countries.

While usually applied to the consumption or energy use side of the equation, CBDR-RC can reasonably be taken to apply to the production side too. The key difference in applying CBDR-RC to production is that, whereas all countries are consumers of fossil fuels (therefore have emissions associated with energy use), only a minority of countries are producers of fossil fuels.

Considering only producer countries, CBDR-RC can be reasonably interpreted as requiring those nations with the greatest capacity for a just transition away from oil and gas production doing so earlier and more rapidly than those nations with less capacity to make a just transition.

Equity can be applied to production phaseout schedules, to reflect differing abilities or capacities to make a just (or fair) transition for oil and gas industry workers.

With this as a guiding principle, we quantify the 'capacity' to make a just transition for oil and gas producing nations and to classify them accordingly. It may also be noted that much of the production in the 'Global South' is carried out by 'Northern' multinational corporations, such that many of the benefits accrue outside the country of extraction. While our analysis focuses on managing the transitional impacts in-country, further research could usefully differentiate between production by foreign companies, domestic private sector and state-owned companies [48], [49].

Of total global oil and gas production, 95% takes place in just thirty-three producer nations. However, there are many developing countries lower down the list of producers, in which oil and /or gas production makes an important contribution to their national economy, while not being internationally significant in quantity. It was therefore decided to extend the list to capture the top eighty-eight producer nations, thereby accounting for 99.97% of all oil and gas production.

95% of global oil and gas production occurs in just 33 countries.

5.3 Quantifying capacity to make a just transition

Seeking to quantify countries' capacities to make a just transition away from oil and gas production, several approaches were explored. Muttitt and Kartha compared producer countries along dimensions of overall capacity to fund a just transition (expressed as GDP per capita) and their level of dependence on income from oil and gas production (expressed as the share of government spending budget derived from oil production) [50].

A similar approach was considered here, but data on the second metric was lacking for the full list of producer countries in this analysis. In addition, government spending alone was considered to capture only part of the full extent of a country's 'dependence' on production, and one that was largely contingent on individual country's tax regimes and structuring of their national oil companies.

Hence, the net was cast wider in seeking a metric that would capture a fuller picture of how intrinsic oil and gas production are to a country's present economy, taking into account jobs supported in auxiliary sectors as well as those directly employed in the upstream extraction industry itself. Since no such comprehensive dataset was found to exist, it was determined to obtain from scratch country by country values for the percentage share of GDP contributed by the oil and gas production sector. This was done by structured web-search, whereby reputable internet sources for each producer country's share of GDP from oil and gas were sought and, where possible, cross referenced.

5.3.1 'Non-oil GDP per capita' – a useful metric of capacity

For our analysis we developed a new measure of countries' capacities to transition away from oil and gas production, based on the contribution of oil and gas to national GDP.

Ultimately, values for GDP from oil and gas were found or inferred for sixty of the eighty-eight producer nations in this study. The remaining twenty-eight nations, for which no useful data could be found, collectively comprise only 1.7% of global oil and gas production. In each case where no useful quantitative data could be obtained, there was sufficient reason to consider the relevance of extraction to the economy in question to be very minor indeed (less than 1%). As such, a generous allowance of 1% contribution to GDP from oil and gas was applied to each country for which no data was recorded.

See column 8 of Table 7 in Appendix 2: Key data for the complete list of values. See §10.1.6 in Appendix 1: Key sensitivities for details of the caveats relating to this dataset.

The percentages of GDP from oil and gas production were then applied to each nation's GDP per capita (purchasing power parity, current USD) to give the share of GDP per capita that effectively is independent of a country's production industries. This value, which we refer to as 'non-oil (and gas) GDP per capita', is adopted here as the metric of a country's capacity to fund a just transition even without benefit of its production related national income. As a per capita figure, in essence it represents each country's relative 'net-capacity' to fund a just transition once its entire GDP share from oil and gas production is discounted.

Table 4 shows the top thirty-three countries according to production volumes as a share of the global total oil and gas production in our baseline year (i). This is juxtaposed against the thirty-three countries with the highest proportion of GDP from oil and gas (ii) and the thirty-three countries with the highest non-oil GDP per capita at PPP, 2019, current international dollars (iii). This partial snapshot of the full list of eighty-eight nations represents all producer nations with non-oil GDP per capita above the mean. The right-hand two columns (iv and v) indicate whether a country in the list of non-oil GDP per capita (iii) also appears in the lists (i) and (ii), and if so its ranking in those lists.

Rank	**(i) Top 33 producers by share of global oil & gas production**[32]		**(ii) Top 33 producers by share of national GDP from oil & gas (dependence)**[33]		**(iii) Top 33 producers by non-oil GDP/capita, PPP, 2019, current $ (capacity)**[34]		**(iv) Top 33 by % of global production?**	**(v) Top 33 by dependence on O&G?**
1	United States	17.9%	Iraq	65%	Ireland	$90,894	No	No
2	Russia	14.8%	Congo	65%	United States	$60,098	Yes (1)	No
3	Saudi Arabia	8.5%	Brunei	60%	Denmark	$59,139	No	No
4	Canada	5.4%	Equatorial Guinea	60%	Netherlands	$58,922	No	No
5	Iran	5.1%	Libya	60%	Austria	$58,098	No	No
6	China	4.1%	South Sudan	60%	Qatar	$57,065	Yes (9)	Yes (11)
7	Iraq	3.1%	Saudi Arabia	50%	Norway	$56,678	Yes (10)	Yes (29)
8	UAE	3.0%	Gabon	50%	Germany	$55,664	No	No
9	Qatar	2.8%	Angola	50%	Australia	$51,131	Yes (17)	No
10	Norway	2.5%	Azerbaijan	44%	France	$49,199	No	No
11	Kuwait	2.1%	Qatar	40%	United Kingdom	$48,020	Yes (21)	No
12	Brazil	2.0%	Kuwait	40%	UAE	$46,618	Yes (8)	Yes (19)
13	Algeria	2.0%	Trinidad & Tobago	40%	Canada	$46,385	Yes (4)	No
14	Nigeria	1.7%	Oman	36%	Bahrain	$46,234	No	Yes (32)
15	Mexico	1.7%	Timor-Leste	36%	South Korea	$44,127	No	No
16	Kazakhstan	1.6%	Turkmenistan	35%	Italy	$43,775	No	No
17	Australia	1.5%	Algeria	30%	Japan	$43,273	No	No
18	Venezuela	1.4%	Chad	27%	New Zealand	$43,125	No	No
19	Indonesia	1.3%	UAE	27%	Israel	$41,368	No	No
20	Malaysia	1.2%	Venezuela	25%	Estonia	$36,941	No	No
21	United Kingdom	1.1%	Yemen	24%	Poland	$34,278	No	No
22	Egypt	1.1%	Egypt	24%	Hungary	$33,984	No	No
23	Oman	1.0%	Iran	23%	Romania	$30,931	No	No
24	Turkmenistan	1.0%	Ecuador	21%	Croatia	$29,626	No	No
25	Angola	1.0%	Malaysia	20%	Turkey	$29,426	No	No
26	Libya	0.9%	Russia	19%	Kuwait	$27,611	Yes (11)	Yes (12)
27	India	0.9%	Papua New Guinea	18%	Chile	$24,719	No	No
28	Argentina	0.8%	Uzbekistan	16%	Saudi Arabia	$24,608	Yes (3)	Yes (7)
29	Colombia	0.7%	Norway	14%	Brunei	$24,413	No	Yes (3)
30	Azerbaijan	0.7%	Kazakhstan	13%	Kazakhstan	$23,662	Yes (16)	Yes (30)
31	Uzbekistan	0.7%	Indonesia	12%	Malaysia	$23,234	Yes (20)	Yes (25)
32	Thailand	0.5%	Bahrain	11%	Russia	$22,988	Yes (2)	Yes (26)
33	Trinidad and Tobago	0.4%	Brazil	10%	Argentina	$22,123	Yes (28)	No

Table 4: Top thirty-three producer nations ranked according to: (i) share of global oil & gas production; (ii) share of GDP/capita from oil and gas; (iii) non-oil GDP/capita.

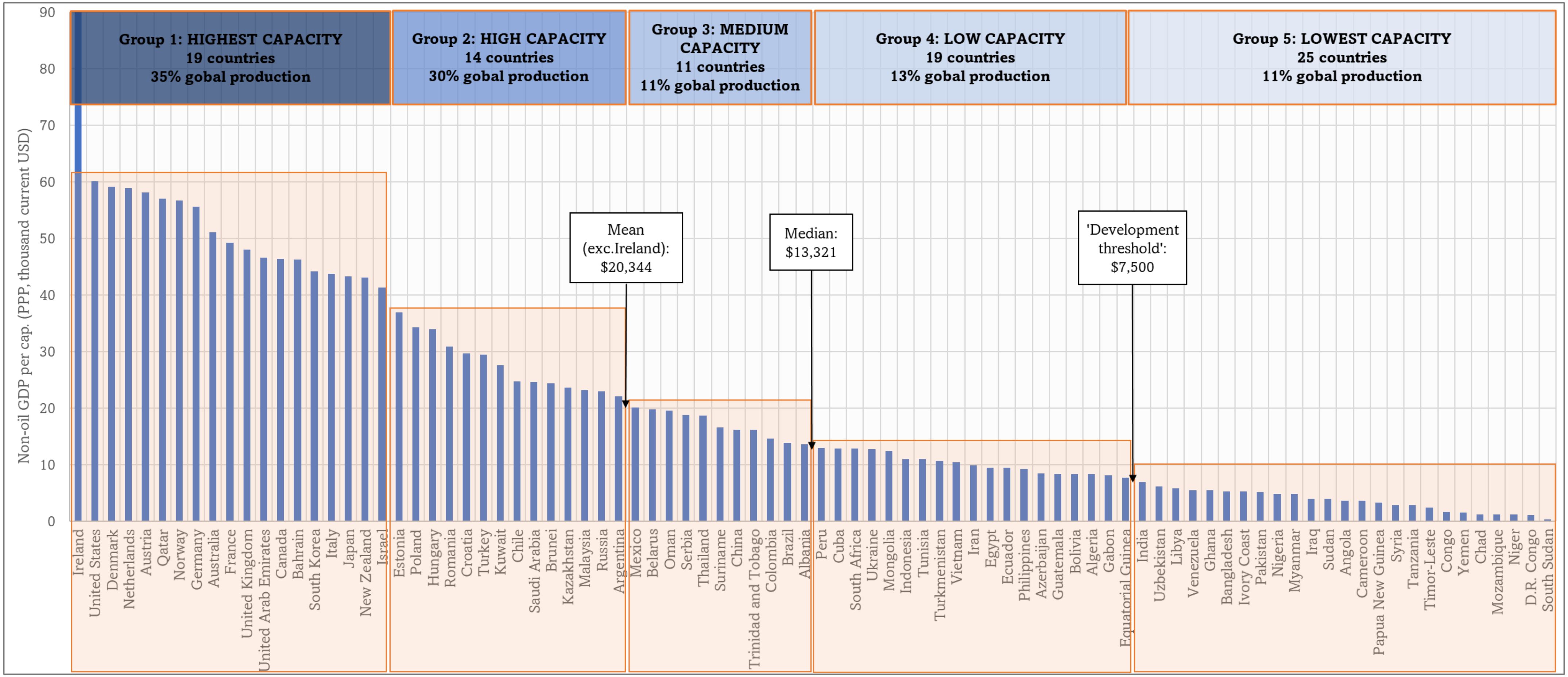

Figure 3: Grouping of producer countries by non-oil GDP/capita

5.4 Ranking and grouping countries by non-oil GDP/capita

Non-oil GDP per capita of the top eighty-eight producer countries is shown in Figure 3, arranged in descending order left to right. Superimposed on the data columns in the Figure are groupings 1 to 5, reflecting subsets of producer countries with broadly comparable values for non-oil GDP per capita. Although in some cases the difference between the bottom of one group and the top of the next is less than the differences within the groups, the boundaries were not imposed arbitrarily.

Two of the four crucial breakpoints for country groupings are based on simple arithmetic averages: the mean and median. Of these the mean is the most salient, since countries whose non-oil GDP/capita is below the mean are taken to have less capacity than average (for all producer nations) to enable a just transition. This key observation informs a pivotal assumption in the next methodological step, whereby production phaseout pathways are developed for each country group reflecting their capacity to transition relative to the mean (see §6.2).

We split the top 88 oil and gas producing countries into five groups according to the size of their economies excluding the contribution from oil and gas.

In short, countries whose non-oil GDP/capita is above the mean are expected to transition away from oil and gas production faster than countries below the mean, with countries below the median value taking longer than countries between the mean and the median.

In addition to the mean and median values, a third breakpoint was introduced at a level of GDP per capita intended to reflect the 'global poverty line', set at $7,500 to coincide with the default 'development threshold' in Holz et al's Climate Equity Reference Calculator [51]. Countries whose non-oil GDP/capita is below this threshold are assumed to have the least capacity to transition away from oil and gas production and will follow slower phaseout pathways than the other four groups.

Finally, the fourth division (between the highest capacity groups, one and two) was placed at the observed inflection point in the side-by-side rankings in Figure 3, where a somewhat larger jump occurs in the values between Estonia and Israel than between their next closest country.

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[30] For example, country A produces 1 $GtCO_2$ equivalent of oil each year but consumes only 0.5 $GtCO_2$ equivalent of oil in the same period. Country B produces 0.5 $GtCO_2$ worth of oil but consumes 2 $GtCO_2$ worth each year. Global trade in oil and oil products balances out these surpluses and deficits.

[31] This analysis does not look in detail at how the energy consumption emissions pathways of countries, whether they be producers or non-producers, fit within temperature-constrained global budgets. Note: throughout this report, where the word *consumption* is used it refers to the use of fossil fuels as distinct from the *production* of fossil fuels. It is not intended in the sense of 'consumption emissions accounting' (as distinguished from 'territorial emissions accounting' or 'production accounting'), which refers to a method of including the emissions embedded in goods produced overseas within national end-use emissions inventories.

[32] Source: Extracted from [40]. See Table 7 in Appendix 2: key data for complete dataset of all eighty-eight producer nations.

[33] See Table 8 in Appendix 2: key data for a full list of sources.

[34] Source: authors' own calculations based on GDP/capita (PPP, 2019, current international dollar), WEO subject code PPPPC [59], and values for share of national GDP from oil and gas (list ii in Table 4). See Appendix 2 for complete dataset of eighty-eight producer nations.

6 Disaggregating production budgets among producer nations

This section explains how production budgets and phaseout schedules were developed for the country groupings above, including the mechanism by which rebalancing and delayed phaseout for the poorest countries was applied.

6.1 Establishing the starting position

For each of the country groupings 1 to 5 in Figure 3, the percentage of global oil and gas production in the baseline year (2018) was obtained. Based on these percentages, each group's 'grandfathered'[35] share of the emissions budget for oil and gas (§4.4) was calculated for each temperature scenario. The grandfathered budgets can be expressed as the number of years remaining at baseline levels of production (hereafter 'years of current production'), which serves as a useful unit of exchange in developing the phaseout pathways for the different groups.

A 'grandfathered budget' is each group's share of the remaining global budget based on its current percentage of total annual emissions.

As the grandfathered budgets are based on each group's current (or rather baseline year) share of annual production, all five country groups have an equal number of years of current production (particular to each temperature scenario) in their de facto 'starting position'.

However, the average capacity to enable a just transition (expressed as non-oil GDP per capita) of the highest capacity countries (Group 1) is estimated at fourteen times that of the lowest capacity countries (Group 5). Thus, phaseout pathways that preserved the status quo would clearly be highly inequitable, strongly favouring the wealthy Groups 1 and 2 and disfavouring poorer Groups 3, 4 and 5.

We made equity-based adjustments to each group's 'grandfathered budget' according to their respective capacities to make a just transition.

Therefore this stage of our analysis seeks to address the unfairness inherent in the status quo by developing pathways that allow longer for poorer nations to phaseout their oil and gas production than the richer nations.

6.2 Capacity weightings

In order to make proportionate adjustments to the de facto starting position, 'share of aggregate absolute deviation' was selected as an adequate mathematical proxy for each group's 'relative capacity to enable a just transition'. In essence this proxy functions as a 'capacity weighting' that can be used to redistribute the oil and gas budget to render new phaseout pathways more equitable than the status quo.

In practical terms, capacity weightings were calculated as follows.

(i) The absolute deviation was obtained for each group[36].

(ii) The absolute deviations of groups above the mean were summed (i.e. Groups 1 and 2).
(iii) Likewise, for groups below the mean (i.e. Groups 3, 4 and 5).
(iv) The capacity weighting for Groups 1 and 2 was their respective share of the sum of absolute deviations above the mean.
(v) The capacity weighting for Groups 3, 4 and 5 was their respective share of the sum of absolute deviations below the mean.

We used each group's average value for capacity to transition to determine a simple ratio to redistribute the remaining global budget for oil and gas production.

Therefore,

CW G1&2 $= (x-\mu) / \Sigma_{1,2}(x-\mu)$

CW G3,4&5 $= (|x-\mu|) / \Sigma_{3,4,5}(|x-\mu|)$

Where: x is the 'group mean non-oil GDP/capita' of each group 1 to 5 and μ is the 'mean of group means'.

	Number of countries	% total O&G production	Mean non-oil GDP/cap	Absolute deviation	Capacity Weighting
Group 1 **Highest capacity**	19	35%	$50,495	$28,661	0.83
Group 2 **High capacity**	14	30%	$27,753	$5,919	0.17
		Above mean ↑		**↓ Below mean**	
Group 3 **Medium capacity**	11	11%	$17,086	-$4,748	0.14
Group 4 **Low capacity**	19	13%	$10,230	-$11,604	0.34
Group 5 **Lowest capacity**	25	11%	$3,605	-$18,229	0.53

Table 5: Capacity weightings of five groups of oil and gas producing countries according to share of aggregate absolute deviation.

6.3 Rebalancing the budgets: equity-based adjustments to the status quo

Redistribution of years of current production was then undertaken, with groups above the mean 'donating' budget space to groups below the mean. Here the capacity weighting serves as a ratio regulating the iterative process of redistribution. Thus, for each year of current production donated from the grandfathered Group 2 budget, 4.8 years of current production is donated by Group 1 (reflecting the ratio of the above-mean groups' capacity weightings, 4.8:1 being equivalent to 83:17).

The donated budget from Groups 1 and 2 is then summed and redistributed among Groups 3, 4 and 5 according to their respective capacity weightings (i.e. at the ratio of 14% to Group 3, 34% to Group 4 and 53% to Group 5).

In our temperature-constrained scenarios, the wealthier (most capable) producers in Groups 1 and 2 'donate' budget to the poorer producers in Groups 3, 4 and 5.

The extent of redistribution applied was the outcome of extensive deliberation and iteration by the research team, client and external stakeholders. Construction of a simple mathematical model permitted calibrated, stepwise increases of redistribution (governed by the capacity weightings), while monitoring the outcomes with respect to the pathway gradient (i.e. rate at which production is being closed down) and functional end dates consistent with the rebalanced budgets for each group.

The rebalanced budgets and pathways presented here are premised on a constant percentage redistribution of the sum of the above-mean groups' grandfathered budgets. That is, in each temperature scenario, a constant 20% of the combined grandfathered budgets of the above-mean Groups 1 and 2 is redistributed amongst the below-mean Groups 3, 4 and 5. Donation and benefit alike are governed by groups' respective capacity weightings.

Groups 1 and 2 donate 20% of their combined budget to the poorer Groups 3, 4 and 5.

Holding the percentage of above-mean budget redistribution constant means that the absolute amount of reallocated budget declines as the overall global budget tightens (for increasing probabilities of lower temperatures). Sensitivity analysis was conducted to explore the effects of increasing and decreasing the percentage of above-mean budget redistribution, and of varying the percentage inversely to the global budget (that is, smaller global budgets saw bigger percentage redistributions). Lower constant percentage reductions produced infeasibly early end dates for below-mean groups, while higher percentages gave infeasibly early end dates for above-mean groups under the tighter global budgets.

The budgetary adjustments in this part of our analysis are therefore an exploration of scenarios that are less inequitable than the starting position, or status quo. However, equitable rebalancing proves to be increasingly difficult under the tighter global budgets; indeed it becomes impossible if a budget with a good chance of 1.5°C is selected.

The differential pathways and their implications are discussed fully in §7.4. In summary: the higher the probability of 1.5°C sought, the more inequitable the budgets and pathways for poorer nations that fall within the bounds of 'feasibility' for all. This unavoidable inequitability strengthens arguments for financial reparations from developed to developing countries.

			(1) Headline AR6 global budget GtCO2 (2) Remaining from Jan 2022	Years of current production: grand-fathered	Donated Group 1&2 budget GtCO2	Donated share of Group 1&2 combined budget	Years current of production: rebalanced budget	Funct-ional zero year	Reduction 2030	Reduction 2035	Reduction 2040	Reduction 2045	Reduction 2050
50% 1.7C	COAL	DD	(1) 850 (2) 671					2031	92%	~	~	~	~
		DG peak						2025	~	~	~	~	~
		DG						2050	1%	7%	34%	79%	~
	OIL & GAS	Group 1		19.4	55	20%	13.2	2045	20%	52%	83%	~	~
		Group 2		19.4			18.1	2050	5%	20%	53%	83%	~
		Group 3		19.4			22.6	2054	1%	6%	23%	57%	85%
		Group 4		19.4			26.2	2058	0%	2%	9%	31%	67%
		Group 5		19.4			30.6	2062	0%	1%	3%	11%	35%
50% 1.5C	COAL	DD	(1) 500 (2) 361					2030	~	~	~	~	~
		DG peak						2022	~	~	~	~	~
		DG						2040	27%	73%	~	~	~
	OIL & GAS	Group 1		9.9	29	21%	6.6	2034	74%	~	~	~	~
		Group 2		9.9			9.3	2039	43%	85%	~	~	~
		Group 3		9.9			11.6	2043	28%	64%	89%	~	~
		Group 4		9.9			13.5	2045	18%	50%	82%	95%	~
		Group 5		9.9			15.9	2050	14%	35%	66%	87%	~
67% 1.5C	COAL	DD	(1) 400 (2) 261					2030	~	~	~	~	~
		DG peak						2022	~	~	~	~	~
		DG						2037	56%	92%	~	~	~
	OIL & GAS	Group 1		7.1	20	20%	4.8	2031	~	~	~	~	~
		Group 2		7.1			6.6	2034	76%	~	~	~	~
		Group 3		7.1			8.2	2037	53%	91%	~	~	~
		Group 4		7.1			9.5	2038	39%	86%	~	~	~
		Group 5		7.1			11.2	2042	28%	69%	93%	~	~

Table 6: Key model parameters and outputs across the three temperature scenarios, including functional zero years for all groups and fuels.

NB: DD = Developed countries / DG = Developing countries (see §4.3.1)

6.4 Fitting pathways to the rebalanced budgets

Like the grandfathered de facto budgets, the rebalanced budgets for each group produced by the redistribution model can be expressed as 'years of current production'. While the climate is agnostic as to how those budgets are 'spent' over time, there are of course many practical constraints on the shape of realistic phaseout pathways.

Oil and gas budgets can be expressed as 'years of current production', but a pathway shape is needed to understand how fast the budget will be used up.

The simplest stylised pathway would follow equal annual reductions – a straight line from current production to zero. Such a stylisation has limited value as a heuristic in practical terms, since it makes no allowance for system inertia or mitigation ramp-up rates. To keep to such a pathway, reductions must begin at maximum pace[37] as soon as the starting gun is fired and continue uniformly until the last barrel of oil is extracted.

In an attempt to offer more useful illustrative pathways, those we offer here incorporate a degree of system inertia and gradual ramp-up of mitigation (as much as this is possible within the constraint of the group budget in question). The simplest version of this is a sigmoidal curve, symmetrical around a straight-line pathway with the same budget (or area).

As in the case of coal production pathways in §4.4, the point at which our oil and gas pathways is considered to have reached zero is the first year in which production is less than or equal to 5% of the baseline 2018 value. This is the pathway's 'functional zero year'.

The end date – or functional zero year – for each pathway is the year in which production falls to 5% of the starting value (baseline).

More technical details of how the sigmoidal pathways were constructed can be found in §10.1.8 in Appendix 1. For present purposes it is enough to note that, for a given budget, the functional zero year is sensitive to an exogenous gradient value. As a simplifying assumption, the pathways presented in this part of the report all take the lowest gradient value possible in order to give the latest functional zero year within budget[38].

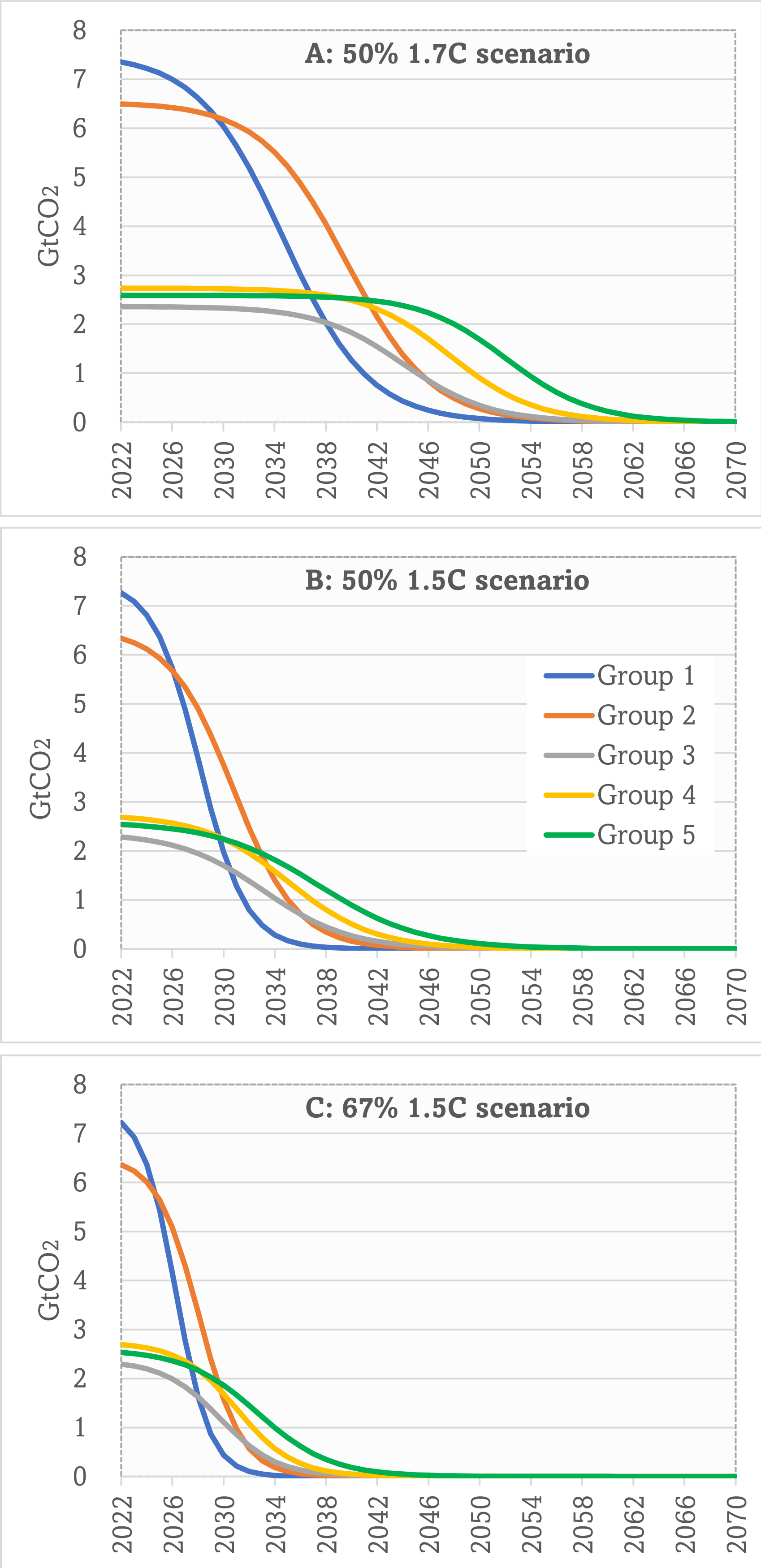

Figure 4: Combined oil & gas phaseout pathways for five groups of countries under three core temperature scenarios.

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[35] Grandfathering is a system of budget allocation whereby a country's or group's historical level of resource use (i.e. emissions space) is used to set its share of future budget entitlement [63]. In this analysis, we use each group's 2018 production emissions to set its de facto grandfathered share of the global oil and gas budgets.

[36] Ireland's non-oil GDP/capita is a conspicuous outlier and was therefore excluded from the mean of Group 1.

[37] That is reduction in 'tonnes of production/year'. The actual percentage reduction, relative to the previous year, actually increases year on year for a straight-line gradient.

[38] The range of possible values for sigmoidal pathway gradients is 0.1 to 1.0. In full, the rubric for setting the gradients was that the lowest value within budget should be selected, down to a lower limit of 0.3. While not in all cases incompatible with certain larger budgets, pathways with a gradient lower than 0.3 have very long tails (hence, in extreme cases, grossly delayed functional zero years), which were deemed to be inconsistent with the ethos of rapid international mitigation effort.

7 Discussion and conclusions

7.1 Overview

This report has focussed specifically on phaseout schedules for oil and gas producing nations. The schedules are aligned with tight and quantified carbon budgets and informed by the equity considerations embedded within the principle of "Common but Differentiated Responsibility and Respective Capabilities" (CBDR-RC).

The three global budgets that have guided the analysis are taken to reflect the commitment enshrined in the 2015 Paris Agreement to hold *"the increase in the global average temperature to well below 2°C … and to pursue efforts to limit the temperature increase to 1.5°C."*. In addition, they also capture the shift in emphasis towards 1.5°C, evident in the IPCC's SR1.5 report [2], the G7 Communique [4] and COP26 [5].

Discussion focusses on our 'central scenario', with a 50:50 chance of not exceeding 1.5°C

The headline budget adopted as the central scenario for this report is for a 50% chance of not exceeding 1.5°C. This central scenario is flanked by a less demanding, 'lower ambition' scenario with a 50% chance of 1.7°C (i.e. "well below 2°C") and a more challenging, 'higher ambition' scenario with a 63% chance of not exceeding 1.5°C.

In 2022, all of these budgets have profound implications for the future of fossil fuel production. However, they embody significant differences in phaseout schedules. Considering the largest of the budgets, 50% of 1.7°C (i.e. equivalent to an 83% chance of not exceeding 2°C), and updated to the start of 2022, this value equates to eighteen years of current fossil fuel production. At the other end of the budget range, the 63% chance of not exceeding 1.5°C, gives just seven years of production, increasing to a decade for a 50:50 chance of 1.5°C.

For a 50% chance of not exceeding 1.5°C, less than 10 years' worth of emissions space remains at current levels of production.

7.2 Findings for coal

Working from these budgets and with a focus on detailing oil and gas phaseouts across the eighty-eight producer nations, it was first necessary to develop a coarse-level schedule for phasing out coal production. This was undertaken in relation to "developed" and "developing country parties" (consistent with the language and designation within the Paris Agreement).

Two key coal-related characteristics evident in compiling the fossil fuel database (production and consumption) that informed this report were:

(i) coal is disproportionately favoured by those nations undergoing rapid industrialisation; and

(ii) there is a close link between national production and consumption of coal.

This second point has direct implications for the proportion of coal that is extracted and subsequently traded on the world market, which is much smaller than for oil and, to a lesser degree, gas.

Collectively, these two characteristics provide a strong steer that there needs to be a clear distinction drawn between the phaseout schedules of coal within "developed" nations and within "developing" nations. However, given the very tight and rapidly dwindling carbon budget associated with this report's emphasis on 1.5°C, even within developing nations the move away from coal needs to be rapid.

Early in the analysis, acknowledging the much higher carbon intensity of coal (i.e. more CO_2 is emitted per unit of energy than from either oil or gas) led to a decision that none of the scenarios should see the coal use, as a proportion of all fossil fuel energy, increase. The implication of this for a 50% or better chance of 1.5°C, led to coal scenarios where production needed to end by 2030 for developed countries and 2040 for developing countries. Any reasonable pathway of coal's use beyond these dates would see it taking up more of the remaining global carbon budget than its current share. Were this to be permitted in a carbon budget-constrained scenario, there would be less emissions space for oil and gas, which would have significant impact on the access to energy for sectors that rely on these fuels – especially transport.

For a 50% chance of not exceeding 1.5°C, coal production needs to be phased out in developed countries by 2030 and in developing countries by 2040.

On the face of it, this conclusion simply reinforces a common understanding that there needs to be an urgent and rapid shift away from coal production. However, quantifying such a shift in relation to a 50% chance of 1.5°C, with a strong emphasis on equity, makes clear just how stark this 'urgency' really is. For developed nations, coal production needs to fall by 50% within five years and be effectively eliminated by 2030. For developing nations, there is some relative leeway. Nevertheless, coal production has to begin an immediate decline, reducing by half within a decade with all extraction ceased by 2040.

7.3 Findings for oil and gas

Having established coal production pathways, with attendant total cumulative emissions, for each of the three global carbon budgets, the remaining non-coal budget was considered in relation to oil and gas production. Here, and as explained in §4.4, oil and gas were brought together as a single energy source, rather than addressed separately.

A central concern in apportioning the oil and gas budget between the eighty-eight producer nations was the issue of equity. Acknowledging that there are several interpretations of such equity within the literature, what quickly became apparent was just how little emissions space remained within which equity could be considered. Constrained by a breadth of factors, ranging from data availability to the physical constraints of the remaining oil and gas budget, we settled on a metric for 'capacity to make a just transition' that achieved a workable balance, but still with fairness at its core.

Oil and gas producing nations differ greatly in their dependence on income from production. Some of the poorest producers have very little income other than from oil and gas.

Probing the production and economic data for oil and gas revealed that nations' reliance on revenue from the sector differs by an order of magnitude. Although striking in itself, this observation painted only a partial picture. Some nations, despite being small producers, have little economic revenue beyond that from oil and gas production (for example, South Sudan, Equatorial Guinea, Congo-Brazzaville and Gabon).

At the other end of the spectrum, some larger producers have such diverse and vibrant economies that the oil and gas revenue is arguably more of a 'nice to have' (for example, United Kingdom, Canada, Australia and, even the USA[39],). Still others are large producers with oil and gas revenue forming a major proportion of their economy, but with very high non-oil-and-gas income too (for example, Qatar, United Arab Emirates[40] and Norway).

Wealthier producers tend to have much more diversified economies, even when they are major producers of oil and gas.

Bringing all of this together, we chose the non-oil-and-gas facet of national GDP (measured in PPP per capita) as a measure of capacity to rapidly phase out oil and gas production and restructure economies without the associated revenue. Using this measure, it was possible to test different redistributions of the production emissions budgets between groups of nations, endeavouring to find a balance between equity and a judgement of what was deliverable. This process of iteration was undertaken for each of the three headline carbon budget constraints.

The specific reference to 'groups of nations' here is key. As detailed in §7.5, the available data were partial, had different or missing dates and was very often poorly specified. Nevertheless, set against other similarly partial datasets, we considered the non-oil-and-gas proportion of GDP the most appropriate proxy for capacity while taking account of equity. To assuage some of our concerns with the quality of the data, we chose to collate nations into five groups. Within each group, the data was averaged to provide generic group characteristics, which subsequently informed the redistribution of the budget allocations between the groups (see §6.2). This approach inevitably loses some national specificity, but in doing so it lends an element of robustness to otherwise ambiguous and partial data.

Wealthier producers are still wealthy even once their revenue from oil and gas is removed.

What quickly became evident from the completed dataset of non-oil-and-gas GDP per capita (PPP), was how those wealthy nations that are major producers, typically remain wealthy even once the oil and gas revenue is removed. In contrast, several of the smaller producers have economies so deeply locked into oil and gas production that they have very little financial capacity to reconfigure their economies once the oil and gas inputs are removed.

This assessment of capacity was a key determinant in testing what level of carbon budgets could be redistributed between the different groups (see §6.3 for details of how this was done). However, and as emphasised earlier, the physical limits of the remaining carbon budgets placed a significant constraint on the levels of redistribution possible; this was particularly evident for the two 1.5°C budgets.

For a 50% chance of 1.5°C, the wealthiest producers (Group 1) need to end production of oil and gas by 2034, while the poorest producers (Group 5) have until 2050.

For our central scenario (50% chance of 1.5°C), the final redistribution that balanced equity with delivery sees oil and gas production in the wealthiest (Group 1) nations reduce by 50% in just six years, and cease by 2034. For the poorest nations most dependent on oil and gas revenue (Group 5), the date for a 50% drop in production extends out to 2037, with complete phaseout by 2050

7.4 Implications of the findings

7.4.1 Phaseout ambition must increase

The fossil fuel phaseout schedules that emerge from our analysis are, for all three temperature scenarios, far removed from proposals forthcoming from the governments of virtually all producer nations.

Our findings suggest that the current proposals by governments of virtually all oil and gas producing nations place the world on course for exceeding 1.5°C.

The very few exceptions include the proposed ending of oil and gas production by France (a minor producer, 0.01% of global oil and gas) in 2040 and by the State of California in 2045. However, these undertakings are only compatible with our lowest ambition temperature scenario, and fall far short of what would be necessary for 1.5°C. Denmark's (0.1% of global production) pledge to phaseout in 2050, would be five years too late to be compatible with the lowest ambition scenario. It bears repeating that it is the pathway to the final end date that is of key importance to respecting the overall temperature-related budget. Achievement of the end date does not alone constitute conformity with the budget, and may actually relate to total emissions far in excess of what is permitted.

7.4.2 No room to expand production in any scenario

Of graver concern than pledges of weak end dates, is that most oil and gas producing countries are planning to increase production in the short term. [52]. This is diametrically opposed to the production pathways identified in this report. Peak production needs to be now, followed, with immediate effect, by the rapid phaseout of existing production.

For a 50% or better chance of 1.5°C, our analysis shows that all producer countries must peak their production immediately and begin an uninterrupted decline. Expanding production in wealthier producers would either shift poorer producers (in fact all producers) onto more steeply declining pathways with earlier end dates, or put the temperature commitments beyond reach.

For context, in our central scenario (50% chance of 1.5°C) – even with the relatively weak version of equity applied here[41] – production in poorer nations needs to come down by between one sixth (for Group 5, the very poorest producers) and almost a third (for Group 3, below average capacity) by 2030. This already represents a significant loss of short-term income opportunity for the countries least able to tolerate such losses.

For a 50% or better chance of staying below 1.5°C, production must start to reduce everywhere. There is no room in a 1.5°C budget for any expansion of oil and gas production.

In this light it is clear that, should wealthy producers (Groups 1 and 2, responsible for two thirds of global oil and gas) expand their production, then either the global carbon budget is breeched (causing greater climate impacts), or the already challenging transition for poorer producers is grievously exacerbated (undermining their development).

It is worth noting that any expansion by poorer producers (Groups 3, 4 and 5, responsible for one third of global oil and gas) would also force their 'group-mate nations' onto steeper phaseout pathways with earlier end dates (thus exacerbating economic hardship), or again jeopardise the overall global budget.

Only in the weaker ambition scenario associated with a 50% chance of 1.7°C is there scope for the poorest producers to effectively flatline their production until the early 2040s. But such leeway is possible if and only if the wealthier producers (Groups 1 and 2) eliminate their production during that same twenty-year period.

In summary, should any group or groups of nations opt for expansion of production, rather than following the pathways illustrated in Figure 4, then the corresponding end dates would be forfeit and steeper reduction curves would be required of all. With even a weak interpretation of equity, the achievement of any of the three temperature-probability scenarios in this analysis would be fatally undermined by an increase in oil and gas production.

7.4.3 Need for financial transfers

While differentiated phaseout timelines, such as those developed in this analysis, are an important means to recognise producer nations' differing capacities to conduct a just transition, they do not fully (or evenly mostly) deliver equity. As noted in §6.3, equity has to be weighed against the need to configure pathways that are 'feasible for all'. In the tighter '50% of 1.5°C' budgets, there was insufficient emission space, and therefore time, for poorer producers (Groups 4 and 5) to phase out their production without severely hampering their socio-economic development needs. This inequitable situation could only be alleviated by releasing additional budget through the almost overnight 'switching off' of production in the wealthier producers (Group 1); a requirement that is infeasible both practically and politically.

There is not enough space left in a 1.5°C global budget to be fully equitable in the treatment of the poorest producers through later phaseout dates alone.

Furthermore, as noted in §7.3, many of poorest producers are the most heavily reliant on income from the oil and gas sector. With low levels of economic diversification such poor nations face a much more difficult transition away from the hydrocarbon 'resource curse' [53]–[55] than do those, typically wealthier, producers with diverse economies.

It will be especially difficult for the poorest, oil-dependent countries to phase out production by the 2040s or 2050, yet this is exactly what is required of them for a 50% or better chance of 1.5°C. Therefore the provision of international financial support will be crucial, in addition to the differentiation of end dates for production developed in this report [56]. Note that the upscaling of climate finance necessary to enable those transitions is separate from and additional to the issue of reparations for loss and damage arising from climate impacts already being suffered and those yet to arise from a warming world.

Financial transfers will be essential to help poorer producers transition from oil and gas production quickly enough to stay below 1.5°C.

SECTION FOOTNOTES

[39] Oil and gas revenue may contribute 8% of the US GDP, but the economy is so diversified, mature and large that relative to the non-oil GDP of virtually all other producer nations the phasing out of oil and gas revenue would still leave a substantial and thriving economy. To put some numbers on this, with the 8% removed, the US has a GDP/capita of over $60k, the second highest globally. Another perspective here, is that with US oil and gas revenue removed, the US still has a GDP/capita that is one third above that of the OECD and the EU (both with oil and gas revenue included) and three-and-a-half times that of the global and Chinese average (again, with including oil and gas revenue).

[40] Whilst the economies of Qatar and UAE remain highly dependent on oil and gas revenue, the past twenty years have also seen some significant diversification of their economies. Both countries now have substantial economic return from manufacturing and heavy industry, as well as thriving financial and tourism sectors. In the case of UAE, there are important differences in the economic make-up of its seven emirates, with, for example, Dubai now much more diversified from oil than Abu Dhabi.

[41] Weak insofar as the attempt to achieve an equitable rebalancing of the budgets was constrained by judgements about feasible rates of real-world energy system transitions.

8 Glossary

AFOLU	agriculture, forestry and other land use
BECCS	bioenergy with carbon capture and storage
capacity	the ability of a producer nation to conduct a just transition away from fossil fuel production
capacity weighting (CW)	a measure of relative capacity developed in this report, based on GDP/capita excluding oil and gas (measured in PPP)
carbon budget	the amount of CO_2 that can be emitted while staying below a given amount of global warming
CBDR-RC	common but differentiated responsibilities and respective capabilities – the principles of equity embedded in the UNFCCC and Paris Agreement
CCS	carbon capture and storage – capturing CO_2 at point of emission and storing it in geological strata
CDR	carbon dioxide removal – extracting carbon dioxide from the atmosphere after it has been emitted by technological or biological means
CH_4	methane, a potent greenhouse gas, significantly from agriculture and fossil fuel production
CO_2	carbon dioxide, the principal greenhouse gas from fossil fuels
DACCS	direct air carbon capture and storage, a form of CDR
Developed countries (DD)	UNFCCC Annex 1 parties plus oil-rich countries with GDP/capita and HDI values above the mean of Annex 1 nations
Developing countries (DG)	UNFCCC non-Annex 1 parties minus oil-rich countries with GDP/capita and HDI values above the mean of Annex 1 nations
GDP	gross domestic product, a broad measure of a country's economic output
$GtCO_2$	gigatonnes of carbon dioxide (billion tonnes)
HDI	Human Development Index, a composite measure of the relative health and prosperity of a country's population
IAM	integrated assessment model
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
just transition	a shift away from fossil fuel production accompanied by social and economic interventions to secure workers' livelihoods
ktoe	kilotonnes of oil equivalent, a unit of energy for fossil fuels
LNG	liquefied natural gas
LUCF	land use change and forestry
$MtCO_2$	million tonnes of CO_2
mtoe	million tonnes of oil equivalent, a unit of energy for fossil fuels
N_2O	nitrous oxide, a potent GHG, largely unavoidable from AFOLU
NbS	nature-based solutions, (such as forestation), a biological form of CDR
NETs	negative emissions technologies (such as DACCS), another form of CDR

NO-GDP	non-oil-and-gas GDP, a measure developed in this report of the size of a country’s economy without income from oil and gas
PPCA	Powering Past Coal Alliance
PPP	purchasing power parity, an adjustment to GDP to allow international comparisons
UNFCCC	United Nations Federation Convention on Climate Change

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10 Appendix 1: Key sensitivities

10.1 Limitations and alternatives

Any assessment of pathways to eliminate fossil fuel emissions is subject to multiple assumptions. Our approach throughout this report has been to adopt a well-reasoned, sequential logic starting from peer-reviewed global carbon budgets and progressing via a sequence of observations and arguments (essentially assumptions) about key factors that influence the rate of depletion of these global budgets. Sections 2 to 6 of this report give detailed information about all of these assumptions. For rigour and transparency, we summarise them again here and offer brief commentary on how the outcomes of the analysis might be affected were alternative assumptions to be applied.

10.1.1 Selection of scenario set

Global emissions budgets form the bedrock on which the rest of the pathway analysis stands. Budgets for a 50% chance of 1.7°C, and 50% and 67% chances of 1.5°C reflect temperature and probability outcomes that the authors and client agreed appropriately represented the imperatives of the Paris Agreement to hold "the increase in the global average temperature to *well below* 2°C … and to pursue efforts to limit the temperature increase to 1.5°C." While, arguably, 67% chance goes further than 'pursuing efforts' to 1.5°C, it was considered a valid representation of both increasing high-level rhetoric on 1.5°C, and of the earlier and more serious impacts of 1.5°C that have emerged in the years since Paris.

Should a lower probability of staying at or below 1.5°C (or indeed 1.7°C) be deemed appropriate, then clearly bigger budgets and less strenuous mitigation pathways would ensue. However, such an assumption would categorically be at odds with calls from climate-vulnerable nations in the Global South to increase ambition on 1.5°C (see for example [57]), and with the scientific consensus on the severity of impacts of exceeding 1.5°C.

10.1.2 Application of precaution (ESFs, CDR, LUCF)

The assumptions made in this analysis about uncertainties regarding the effects on the global carbon budget of earth systems feedbacks (ESFs), carbon dioxide removal (CDR) and land use change and forestry (LUCF) are best characterised as conservative. That is to say, the global budgets are not downsized to reflect the potential for around 145 $GtCO_2$ of additional feedbacks for 1.5°C budgets (±97 $GtCO_2$ of ESFs per degree Celsius of warming, see §2.2.1) in a 'worst case scenario'. At the same time, we do not expand the global carbon budgets by applying planetary-scale quantities of NETs, or by assuming that the land use sector will compensate for emissions of CO_2 over and above the carbon budgets.

Should a stronger framing of precaution be preferred, one might factor in the additional feedbacks identified in AR6. This would mean that, to retain a 50% chance of 1.5°C, it would be necessary to follow a pathway slightly below the one offered here for 67% chance of 1.5°C. In other words, removing 145 $GtCO_2$ of additional feedbacks from the 50% chance of 1.5°C budget would leave rather less than in the 67% chance of 1.5°C budget (361 $GtCO_2$, for a 50% chance, would come down to around 216 $GtCO_2$ – i.e. 45 $GtCO_2$ less than the budget for a 67% chance of 1.5°C).

With regard to CDR, a more bullish (less precautionary) approach might advocate for greater inclusion of CO_2 removal through (amongst others) reforestation, afforestation, BECCS, DACCS and so on. Setting aside the arguments in §3.2 for why, with specific reference to fossil fuel CO_2, this analysis rejects such a move, it is worth remembering that any available CDR should be counted first against unavoidable emissions from agriculture. Only then, and if there are surplus levels of 'removal', should the NETs component of CDR be considered in relation to fossil fuels, for which ready alternatives exist (through a combination of energy supply and demand management).

To recap: in this analysis we assume that any CO_2 released from deforestation and the broader land use sector (including agriculture)[42] will be compensated by sequestration of CO_2 through LUCF over the course of the century. Simultaneously, we optimistically assume that residual emissions of non-CO_2 GHGs from agriculture will be reduced to around 4 to 7 $GtCO_2e$/year by mid-century and hold constant thereafter. In other words, this analysis does not reject CDR, rather it indirectly assumes that any warming from non-CO_2 agricultural emissions will be compensated by some form of CDR.

Should a case be convincingly made for deliverable CDR over and above that assumed here for agriculture, it would have the effect of increasing the probability of a given phaseout pathway being compatible with its respective temperature threshold. For example, if in addition to the CDR necessary to compensate for non-CO_2 warming, there were a further 100 $GtCO_2$ of verifiable and permanent CDR, then this would effectively 'relax' the pathway for a 67% chance of staying below 1.5°C to that of the 50% pathway.

10.1.3 Process emissions

This analysis followed the approach in *Factor of Two* [16], extrapolating the cement industry growth rate in IEA's Cement Technology Roadmap out across the rest of the century. A key assumption was that cement, as an essential material in the construction of zero-carbon energy networks everywhere and other essential infrastructure in developing countries, will continue to be so for several decades to come. However, as noted in §2.2.3, the slowdown in growth rate assumed in the IEA Roadmap is highly optimistic, with no precedent in the post-WW2 era. For this reason we applied a slower rate of decline in cement process emissions in our 1.7°C scenario, (resulting in 100 $GtCO_2$ overhead in the 1.7°C scenario, as opposed to a 60 $GtCO_2$ overhead in the more constrained 1.5°C scenarios). This more precautionary 100 $GtCO_2$ overhead for cement is incompatible with the 50% and 67% 1.5°C budgets. But the more optimistic 60 $GtCO_2$ overhead could, of course, be applied to the 1.7°C scenario. This would mean an additional 40 $GtCO_2$ for our fossil fuel scenarios, equating to one more year of oil and gas production (at current levels). However, this would be at the expense of a major reduction in cement availability to developing countries.

10.1.4 CCS on fossil fuels

In §3.3 we discuss the rationale for not assuming any relaxation of the production emissions budgets on the basis of carbon capture and storage on fossil fuel use. In view of the slow rate of delivery of CCS projects – which, importantly, is *much* slower than touted by the fossil fuel industry – it is our judgement that CCS can contribute virtually nothing towards achieving 1.5°C-compatible pathways. Such pathways require complete decarbonisation of the energy system in developed countries by the early 2030s (see Table 6 and panels B and C of Figure 4).

Without invoking rates of CCS development and roll-out that are beyond anything discussed in the literature, then, only scenarios incompatible with 1.5°C have the flexibility to accept any contribution from CCS. That being so, increased deployment of CCS could allow marginally more fossil fuel use (and by extension production) within 1.7°C-and-warmer scenarios. However, the ongoing track-record of under-delivery in CCS does not support the positing of large-scale deployment even within the 2030s to 2040s phaseout timeframe of 1.7°C scenarios. Thus, the extra budgetary flexibility afforded is likely to be minor (a few gigatonnes of CO_2 at best) over the timeframe of concern for 1.7°C. The difference to phaseout pathways and end dates for oil and gas production from this additional CCS would be similarly trivial, measured in extra months of production (at baseline levels) rather than years.

10.1.5 Coal phaseout parameters

The phaseout pathways for coal production are sensitive to several key assumptions, as follows.

(i) The end year for production for Developed and Developing producer nations;
(ii) The peak year for production in both Developed and Developing nations;
(iii) The phaseout trajectory or pathway shape for Developed and Developing nations (which determines their relative share of the total coal budget);
(iv) The percentage share of the overall global carbon budget that was allowed to be consumed by coal production.

See Table 6 for the key input parameter values, and Table 2 for the outcome of those values with respect to the relative share of the global budget given to coal, oil and gas.

The underpinning analysis for coal was iterative insofar as the interplay of these parameters was configured to represent the fastest feasible phaseout of coal in both Developed and Developing producers. Coal pathway development was subject to deliberative judgement by the authors, client and civil society consultees regarding real-world limitations on rates of transition in both Developed and Developing nations' coal production.

The resulting coal pathways for 1.5°C scenarios are immensely challenging; we assume that Developed countries cease coal production by 2030-1 and Developing countries end by 2037-40. Since our coal assumptions were taken to be maximally demanding, alternative assumptions regarding parameters (i)–(iv) above would likely have the effect of relaxing the rate of phaseout of coal production. Note that our 1.7°C scenario is the only one in which coal occupies less of the total global carbon budget than its current share (in the baseline year). In both 1.5°C scenarios coal is effectively held at its current share of cumulative emissions. This is because faster phaseout was considered implausible without major constraints on access to energy in Developing countries (the major users and producers of coal) on the one hand, or ignoring real world inertia in energy system transformation by pushing Developed countries to end coal in less than eight years on the other. To argue for a faster trajectories or earlier end dates than reflected in the 1.5°C pathways here, one would have to give an account of how these access-to-energy and inertia-based constraints could be overcome. Conversely, to assign slower trajectories or later end dates for coal production (or later peak production in Developing countries) than in the 1.5°C scenarios, one would have to justify giving more budget space to coal than its baseline share (41%), with all the energy efficiency penalties that brings.

In the case of the 1.7°C scenario, there is a little more flexibility. Should the immensely challenging 1.5°C coal phaseout pathways be applied to the 1.7°C budget, it would increase space for oil and gas and postpone their production end dates by a few years for each country group. However, this would be at the cost of substantially limiting access to energy (especially in the short-term) in Developing countries, a constraint out of kilter with the overall pace of reductions in the 1.7°C scenario.

10.1.6 Capacity parameters

The estimation of producer nations' relative capacities to make a just transition away from oil and gas production is based on several key assumptions.

First, the list of producers includes only countries with currently operational oil and/or gas production facilities. As such, potentially soon-to-be producers such as Namibia, Mozambique et al are not considered within the phaseout schedules in this report. This is a limitation of available data and project time, not to mention that the precarious political and security situations of some aspiring producers makes estimation of likely future output too speculative for inclusion at present.

Second, to differentiate the eighty-eight currently operational producers (with at least 0.5 mtoe output of oil and/or gas per year), this report developed a novel metric of 'non-oil-and-gas GDP', adjusted for PPP/capita (see §5.3.1). Compiling this dataset was subject to several limitations, not least the fact that there is no universal standard for reporting the contribution of oil and gas production (or indeed any industry sector) to GDP. Hence, data were gathered from a variety of internet sources (see Table 8). These sources were inevitably heterogeneous with respect to system boundaries (estimates for some countries included both direct and indirect revenue from the sector, others direct only, still others potentially referred only to economic rents); time period (often indeterminate); and aggregation with other extractive industries (such as coal, mineral ores etc).

Other proxies for capacity to transition were explored in the early stages of our analysis, including economic rents and the share of government budget from oil and gas revenues. These were rejected as being too narrow to capture the full extent of economic dependency on hydrocarbon production, not to mention offering scarcely more complete datasets than non-oil GDP. Nevertheless, adopting an alternative proxy for capacity would doubtless have the effect of moving some producers up or down the rankings in Figure 3. However, while a different proxy would change the composition (or membership) of the groups, it would not affect the allocation of emissions budget between groups.

10.1.7 Country grouping parameters

The ordering of producers into groups sharing broadly similar levels of capacity to transition away from oil and gas production is subject to the following key assumptions.

First, 2019 was selected as the reference year for GDP/capita (PPP), being the most recent year for which an almost complete dataset exists. National GDPs can vary not insignificantly from year to year, especially for oil and gas producing countries subject to the forces of global supply and demand. As such, choosing a different reference year for GDP/capita would affect the relative position of producers in the rankings shown in Figure 3. Similarly, choosing a different PPP adjustment to GDP/capita (such as 'constant 2017 international dollars' rather than 'current international dollars') would also affect some countries' ordinal position in the overall ranking.

Second, the break points for country groupings were based on mathematical averages (mean and median) of the non-oil GDP dataset, plus the development threshold at $7,500. Clearly, different groupings would emerge if alternative boundaries were set. The level of the development threshold is the most obvious candidate for further exploration. Indeed some reviewers (of an earlier draft of this report) suggested an additional lower break point might be applied to subdivide the large group of lowest capacity countries (Group 5), and render even more subtly differentiated phaseout schedules for the poorest and 'very poorest' producers.

Further to this, consideration was given to breaking Groups 1 and 5 into two more subgroups each, but was rejected for two reasons. First, project constraints limited the number of iterations possible in the analysis that builds on these groupings. Second, the inherent imprecision in the underlying data for the oil and gas share of GDP (see §10.1.6 above) means that further subdivision would risk placing undue emphasis on the exact values of non-oil GDP rather than on relative values. With access to more precise data on the contribution of oil and gas to the GDP of all eighty-eight producer nations, budgets and pathways could be derived for each country separately. However, researching and compiling such a dataset from scratch would require substantial further research, considerably beyond the scope of the present work.

As with the sensitivities around capacity parameters, fine tuning the grouping parameters is relevant only to the precise outcomes for individual countries (insofar as it assigns them to a particular group); it does not affect the differentiation between pathways for those groups.

10.1.8 Differential phaseout parameters

The final step of our analysis disaggregated the budgets for oil and gas to five groups of producers according to their grandfathered starting positions, before attempting to rebalance these shares in accordance with the equity principles of CBDR-RC. The key parameters in this process are as follows.

(i) Use of each group's share of aggregate absolute deviation as the basis for the capacity weightings. As always, alternative proxies or metrics would yield slightly different country rankings and groupings. For example, the proportion of 'excess' national income above the global poverty threshold could be used to determine weightings. In principle this would accord a higher budgetary reallocation benefit to the poorest countries (which have negative 'excess' in relation to the poverty line). Such a re-weighting would work well with more finely delineated groups, or indeed country-by-country, based on better data on non-oil GDP. However, given the acknowledged imprecision of the non-oil GDP data and the need for a manageable number of discrete groups, it was deemed more appropriate to take group means and shares of aggregate absolute deviation as broadly capturing the relative capacity characteristics of each group.

(ii) The extent of budgetary reallocation between groups was capped at 20% of the combined grandfathered budgets of Groups 1 and 2. This was held constant across all three scenarios. The outcome of this, as noted in §6.3, is that the differentiation between phaseout pathways becomes less equitable as the budgets get tighter for higher probabilities of 1.5°C. It goes almost without saying that altering this reallocated percentage would have noticeable outcomes for the end dates for all five groups, with a greater percentage yielding earlier end dates for Groups 1 and 2 and later end dates for Groups 3, 4 and 5.

It is worth noting that the 20% value emerged from an iterative and deliberative process of calibrated pathway adjustments, with 'feasibility for all' groups being the final arbiter of selection. For a 50% or better chance of 1.5°C, a 20% reallocation renders end dates for Groups 1 and 2 in the 2030s, with 74% and 43% reduction by 2030 respectively. Applying a greater percentage reallocation would bring the Group 1 end date to within a handful of years from now. Applying a smaller percentage reallocation would place the pathways further from a reasonable interpretation of CBDR-RC, and require even more emphasis on financial transfers and reparations from wealthy to poor producers.

(iii) Phaseout end dates on the logit-based, sigmoidal pathways shown in Figure 4 are sensitive to an exogenous gradient value[43]. Put simply, the lower (or shallower) the gradient, the later the end date for a given budget. A simplifying assumption was made across the board for all pathways[44] to set the gradient as low as possible down to a lower limit of 0.3. Higher gradients would render more 'front-loaded' pathways with earlier end dates. Since such pathways consume a greater share of the emissions space in the early years, they rely heavily on steeper rates of reduction soon after. Therefore more evenly-paced phaseout schedules were preferred wherever possible to increase likelihood of compliance. Gradients lower than 0.3 render pathways with very long tails of production (especially for Groups 4 and 5), with small quantities of production extending into the later decades of the century. In such pathways, these small but lingering quantities of production were considered antithetical to the wider interests of global decarbonisation.

(iv) End dates are sensitive to the value taken to mark 'functional zero'; in this report we used 5% of baseline production. Clearly, setting the bar of elimination higher by selecting a lower remaining percentage of baseline production would suggest later end dates for the same pathway. However, given the diminishing returns from dwindling amounts of oil and gas, 5% reflects the likelihood of a final 'coup-de-grâce' closure of the last few facilities in a producer country. Setting the bar of elimination lower with a higher remaining percentage would suggest earlier end dates for the same pathways.

SECTION FOOTNOTES

[42] Sometimes referred to by the acronym AFOLU, for agriculture, forestry and other land use.

[43] Logit-curve based pathways were constrained to cumulative group budgets using:

y =L/(-K*(1+EXP(A1-x0)))

where L = the curve's maximum y-value (production emissions in the baseline year)
x0 = the x-value of the sigmoid midpoint (obtained from number of years of current production in budget)
K = the steepness or gradient of the curve (constant, set as low as possible down to 0.3)

[44] The sole exception being the gradient of Group 5's pathway in the central scenario, (50% chance of 1.5°C), which was set at 0.25 (a single decrement lower than 0.3) to better reflect the strong preference amongst civil society reviewers for a later end date (for the same cumulative budget) for this poorest group of producers.

11 Appendix 2: Key data

Table 7: Key data on eighty-eight producer nations.

COLUMN 1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Producer country	**Deve-loped or Deve-loping**	**Total oil & gas prod'n mtoe (2018)**	**% of global O&G prod'n (2018)**	**Popul-ation, millions (2017)**	**GDP/cap 2019, PPP (current int.$)**	**Oil & gas % of GDP**	**Non-oil GDP/cap. 2019 (PPP, current $)**	**Producer Group in this report**
Ireland	DD	3	0.03%	4.8	91,812	ND	90,894	1
United States	DD	1404	17.87%	325.1	65,254	8%	60,098	1
Denmark	DD	10	0.12%	5.7	60,379	2%	59,139	1
Netherlands	DD	29	0.37%	17.0	59,517	1%	58,922	1
Austria	DD	2	0.02%	8.8	58,685	1%	58,098	1
Qatar	DD	219	2.79%	2.7	95,108	40%	57,065	1
Norway	DD	193	2.46%	5.3	65,905	14%	56,678	1
Germany	DD	8	0.10%	82.7	56,226	ND	55,664	1
Australia	DD	115	1.46%	24.6	52,712	3%	51,131	1
France	DD	1	0.01%	64.8	49,696	ND	49,199	1
United Kingdom	DD	88	1.12%	66.7	48,603	1%	48,020	1
United Arab Emirates	DD	232	2.95%	9.5	63,590	27%	46,618	1
Canada	DD	422	5.37%	36.7	51,481	10%	46,385	1
Bahrain	DD	22	0.29%	1.5	51,948	11%	46,234	1
South Korea	DD	1	0.01%	51.1	44,573	ND	44,127	1
Italy	DD	10	0.12%	60.7	44,218	ND	43,775	1
Japan	DD	3	0.03%	127.5	43,710	ND	43,273	1
New Zealand	DD	5	0.06%	4.7	43,689	1%	43,125	1
Israel	DD	8	0.10%	8.2	41,786	ND	41,368	1
Estonia	DD	5	0.06%	1.3	38,480	4%	36,941	2
Poland	DD	5	0.06%	38.0	34,624	ND	34,278	2
Hungary	DD	3	0.03%	9.7	34,327	ND	33,984	2
Romania	DD	12	0.15%	19.7	31,244	ND	30,931	2
Croatia	DD	2	0.02%	4.2	29,925	ND	29,626	2
Turkey	DD	3	0.04%	81.1	29,724	ND	29,426	2
Kuwait	DD	165	2.09%	4.1	46,018	40%	27,611	2
Chile	DG	1	0.02%	18.5	24,969	ND	24,719	2
Saudi Arabia	DD	665	8.47%	33.1	49,216	50%	24,608	2

Producer country	**Deve-loped or Deve-loping**	**Total oil & gas prod'n mtoe (2018)**	**% of global O&G prod'n (2018)**	**Popul-ation, millions (2017)**	**GDP/cap 2019, PPP (current int.$)**	**Oil & gas % of GDP**	**Non-oil GDP/cap. 2019 (PPP, current $)**	**Producer Group in this report**
Brunei	DD	16	0.21%	0.4	61,032	60%	24,413	2
Kazakhstan	DG	128	1.63%	18.1	27,292	13%	23,662	2
Malaysia	DG	93	1.19%	31.1	29,043	20%	23,234	2
Russia	DD	1165	14.83%	145.5	28,450	19.2%	22,988	2
Argentina	DG	65	0.83%	43.9	22,997	4%	22,123	2
Mexico	DG	131	1.67%	124.8	20,796	4%	20,068	3
Belarus	DD	2	0.02%	9.5	19,984	ND	19,785	3
Oman	DD	82	1.04%	4.7	30,654	36%	19,619	3
Serbia	DG	1	0.02%	8.8	19,027	ND	18,837	3
Thailand	DG	43	0.54%	69.2	19,234	3%	18,657	3
Suriname	DG	1	0.01%	0.6	16,768	ND	16,600	3
China (inc. HK)	DG	325	4.13%	1421.0	16,659	3%	16,160	3
Trinidad & Tobago	DG	34	0.44%	1.4	26,920	40%	16,152	3
Colombia	DG	56	0.71%	48.9	15,345	5%	14,577	3
Brazil	DG	160	2.04%	207.8	15,454	10%	13,847	3
Albania	DG	1	0.01%	2.9	14,534	6%	13,648	3
Peru	DG	18	0.22%	31.4	13,328	3%	12,995	4
Cuba	DG	4	0.05%	11.3	13,028 †	ND	12,898	4
South Africa	DG	1	0.01%	57.0	12,962	ND	12,832	4
Ukraine	DG	19	0.24%	44.5	13,442	5%	12,752	4
Mongolia	DG	1	0.01%	3.1	12,558	ND	12,433	4
Indonesia	DG	102	1.30%	264.7	12,483	12%	10,985	4
Tunisia	DG	4	0.05%	11.4	11,075	ND	10,964	4
Turkmenistan	DG	79	1.01%	5.8	16,438	35%	10,685	4
Vietnam	DG	21	0.27%	94.6	10,535	ND	10,430	4
Iran	DG	401	5.11%	80.7	12,858	23%	9,901	4
Egypt	DG	83	1.06%	96.4	12,445	24%	9,458	4
Ecuador	DG	28	0.35%	16.8	11,924	21%	9,420	4
Philippines	DG	4	0.05%	105.2	9,356	ND	9,263	4
Azerbaijan	DG	55	0.70%	9.8	15,076	44%	8,443	4
Guatemala	DG	1	0.01%	16.9	8,487	ND	8,402	4

Producer country	Deve-loped or Deve-loping	Total oil & gas prod'n mtoe (2018)	% of global O&G prod'n (2018)	Popul-ation, millions (2017)	GDP/cap 2019, PPP (current int.$)	Oil & gas % of GDP	Non-oil GDP/cap. 2019 (PPP, current $)	Producer Group in this report
Bolivia	DG	19	0.24%	11.2	9,064	8%	8,339	4
Algeria	DG	155	1.98%	41.4	11,895	30%	8,326	4
Gabon	DG	10	0.13%	2.1	16,272	50%	8,136	4
Equatorial Guinea	DG	14	0.18%	1.3	19,286	60%	7,715	4
India	DG	67	0.85%	1338.7	6,992	2%	6,887	5
Uzbekistan	DG	53	0.68%	32.0	7,382	16%	6,201	5
Libya	DG	70	0.89%	6.6	14,599	60%	5,840	5
Venezuela	DG	110	1.40%	29.4	7,344	25%	5,508	5
Ghana	DG	10	0.13%	29.1	5,688	4%	5,472	5
Bangladesh	DG	23	0.30%	159.7	5,330	1%	5,298	5
Ivory Coast	DG	3	0.04%	26.4	5,318	ND	5,264	5
Pakistan	DG	23	0.30%	207.9	5,204	ND	5,152	5
Nigeria	DG	136	1.73%	190.9	5,353	10%	4,817	5
Myanmar	DG	16	0.20%	53.4	5,054	5%	4,817	5
Iraq	DG	241	3.07%	37.6	11,379	65%	3,983	5
Sudan	DG	4	0.06%	40.8	4,310	8%	3,965	5
Angola	DG	78	0.99%	29.8	7,346	50%	3,673	5
Cameroon	DG	5	0.06%	24.6	3,801	4%	3,664	5
Papua New Guinea (*)	DG	11	0.14%	8.4	4,022	18%	3,316	5
Syria	DG	4	0.05%	17.1	2,900 ‡	ND	2,871	5
Tanzania	DG	1	0.01%	54.7	2,841	ND	2,812	5
Timor-Leste (*)	DG	6	0.08%	1.2	3,703	36%	2,370	5
Congo	DG	18	0.23%	5.1	4,600	65%	1,610	5
Yemen	DG	2	0.02%	27.8	2,057	24%	1,561	5
Chad (*)	DG	8	0.10%	15.0	1,654	27%	1,208	5
Mozambique	DG	4	0.05%	28.6	1,302	8%	1,198	5
Niger	DG	1	0.01%	21.6	1,276	7%	1,187	5
D.R. Congo	DG	1	0.01%	81.4	1,130	ND	1,118	5
South Sudan	DG	7	0.08%	10.9	862	60%	345	5

DD = Developed; DG = Developing; ND = no data available, 1% default value assumed.

Data sources for Table 7 were as follows:

- Column 2 classification follows that established in *Factor of Two* [16]. In this report, DD is equivalent to *Factor of Two*'s DD2, i.e. Annex-1 nations plus those non-Annex 1 oil-rich states with GDP/capita and HDI values above the mean of developed nations. DG is equivalent to *Factor of Two*'s DG2.
- Column 3 energy data extracted from International Energy Agency, World Summary Energy Balances [45], except those marked (*) from U.S. Environmental Information Agency.
- Column 5 population data from OurWorldinData.org [58].
- Column 6 GDP/capita (PPP) from IMF World Economic Outlook [59]. † Cuba value is for 2016. ‡ Syria value is for 2015.
- Column 7 contribution of oil and gas to national GDP: drawn from multiple online sources, as shown in Table 8 below.

Table 8: sources for contribution of oil and gas to national GDP

Ireland	No data
United States	https://www.naturalgasintel.com/natural-gas-oil-found-to-support-sizeable-chunk-of-u-s-gdp-including-pennsylvania/
Denmark	https://ens.dk/en/our-responsibilities/oil-gas/economy-oil-and-gas
Netherlands	https://www.cbs.nl/en-gb/news/2019/22/natural-gas-revenues-almost-417-billion-euros
Austria	No data
Qatar	https://www.nationsencyclopedia.com/economies/Asia-and-the-Pacific/Qatar-OVERVIEW-OF-ECONOMY.html
Norway	https://oilprice.com/Latest-Energy-News/World-News/Oil-Gas-Share-Of-Russias-GDP-Dropped-To-15-In-2020.html
Germany	No data
Australia	https://www.upstreamonline.com/finance/oil-and-gas-industry-270-billion-boost-to-australias-economy/2-1-1025044
France	No data
United	https://www.ofgem.gov.uk/sites/default/files/docs/2020/02/oguk_evidence_economic_report_2019.pdf
United Arab	https://www.statista.com/statistics/1105966/uae-oil-and-gas-sector-gdp/
Canada	https://oilprice.com/Latest-Energy-News/World-News/Oil-Gas-Share-Of-Russias-GDP-Dropped-To-15-In-2020.html
Bahrain	https://globaledge.msu.edu/countries/bahrain/economy
South Korea	No data
Italy	No data
Japan	No data
New Zealand	https://www.stuff.co.nz/business/110700136/new-report-estimates-oil-and-gas-ban-will-cost-taranaki-30bn
Israel	No data
Estonia	https://icds.ee/wp-content/uploads/2015/Jordan_Kearns_-_Trends_in_Estonian_Oil_Shale_Utilization_Oct_2015.pdf
Poland	No data
Hungary	No data
Romania	No data
Croatia	No data
Turkey	No data

Kuwait	https://www.opec.org/opec_web/en/about_us/165.htm
Chile	No data
Saudi Arabia	https://oilprice.com/Latest-Energy-News/World-News/Oil-Gas-Share-Of-Russias-GDP-Dropped-To-15-In-2020.html
Brunei	https://globaledge.msu.edu/countries/brunei/economy
Kazakhstan	https://oilprice.com/Latest-Energy-News/World-News/Oil-Gas-Share-Of-Russias-GDP-Dropped-To-15-In-2020.html
Malaysia	https://www.internationalinvestor.com/malaysia/sectors/oil-gas/summary/
Russia	https://oilprice.com/Latest-Energy-News/World-News/Oil-Gas-Share-Of-Russias-GDP-Dropped-To-15-In-2020.html
Argentina	https://eiti.org/argentina
Mexico	https://eiti.org/mexico
Belarus	No data
Oman	https://www.brookings.edu/blog/order-from-chaos/2021/01/13/one-year-into-his-reign-omans-sultan-must-renegotiate-the-social-contract-and-prioritize-diversification/
Serbia	No data
Thailand	Various sources pointing to less than 3%
Suriname	No data
China (inc.	https://data.stats.gov.cn/english/easyquery.htm?cn=C01
Trinidad and	https://www.cia.gov/the-world-factbook/countries/trinidad-and-tobago/
Colombia	https://eiti.org/es/implementing_country/17
Brazil	https://www.iioa.org/conferences/16th/files/Papers/Guilhoto Oil Business BR Guilhoto et al.pdf
Albania	https://eiti.org/albania
Peru	https://eiti.org/files/documents/vii_informe_nacional_eiti_peru_2017-2018.pdf
Cuba	No data
South Africa	No data
Ukraine	https://eiti.org/fr/implementing_country/26
Mongolia	No data
Indonesia	https://www.thejakartapost.com/news/2020/03/02/analysis-unlocking-indonesia-s-500b-oil-and-gas-revenue-opportunity.html
Tunisia	No data
Turkmenistan	https://www.trade.gov/country-commercial-guides/turkmenistan-market-overview
Vietnam	No data, other than rapidly declining.
Iran	https://tradingeconomics.com/iran/gdp
Egypt	https://www.trade.gov/country-commercial-guides/egypt-oil-and-gas-equipment
Ecuador	https://www.icontainers.com/us/2020/03/23/ecuador-main-imports-and-exports/
Philippines	Various sources pointing to steep decline with natural gas reserves exhausted by 2027
Azerbaijan	https://www.privacyshield.gov/article?id=Azerbaijan-Market-Overview
Guatemala	No data
Bolivia	https://www.eia.gov/international/analysis/country/BOL
Algeria	https://theodora.com/wfbcurrent/algeria/algeria_economy.html
Gabon	https://www.mordorintelligence.com/industry-reports/gabon-oil-and-gas-market
Equatorial	https://www.eia.gov/international/analysis/country/GNQ
India	https://statisticstimes.com/economy/country/india-gdp-sectorwise.php
Uzbekistan	https://www.export.gov/apex/article2?id=Uzbekistan-Oil-and-Gas-Industry
Libya	https://www.opec.org/opec_web/en/about_us/166.htm
Venezuela	https://www.investopedia.com/ask/answers/032515/how-does-price-oil-affect-venezuelas-economy.asp
Ghana	https://eiti.org/ghana
Bangladesh	http://203.112.218.65:8008/WebTestApplication/userfiles/Image/GDP/GDP_2015-16_p.pdf
Ivory Coast	Various sources pointing to small but growing fraction.

Pakistan	No data
Nigeria	https://www.statista.com/statistics/1165865/contribution-of-oil-sector-to-gdp-in-nigeria/
Myanmar	https://www.statista.com/statistics/1062945/myanmar-gdp-contribution-energy-sector/
Iraq	http://documents.worldbank.org/curated/en/771451524124058858/pdf/125406-WP-PUBLIC-P163016-Iraq-Economic-Monitor-text-Spring-2018-4-18-18web.pdf
Sudan	https://www.researchgate.net/publication/259484744_Oil_and_Agriculture_in_the_Post-Separation_Sudan
Angola	https://theodora.com/wfbcurrent/angola/angola_economy.html
Cameroon	https://eiti.org/es/implementing_country/20
Papua New	https://eiti.org/ru/implementing_country/46
Syria	No data
Tanzania	No data
Timor-Leste	https://eiti.org/timorleste
Congo	https://globaledge.msu.edu/countries/republic-of-congo/economy
Yemen	https://reliefweb.int/sites/reliefweb.int/files/resources/yseu14_english_final_1.pdf
Chad (*)	https://globaledge.msu.edu/countries/chad/memo
Mozambique	https://eiti.org/files/documents/itie_mocambique_9o_relatorio_i2a_consultoria_versao_inglesa_002.pdf
Niger	https://www.savannah-energy.com/operations/niger/country-overview/
D.R. Congo	https://eiti.org/democratic-republic-of-congo
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Published in final edited form as:
Nature. 2019 August ; 572(7769): 373–377. doi:10.1038/s41586-019-1364-3.

Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target

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Abstract

Net anthropogenic CO_2 emissions must approach zero by mid-century to stabilize global mean temperature at the levels targeted by international efforts[1–5]. Yet continued expansion of fossil fuel energy infrastructure implies already 'committed' future CO_2 emissions[6–13]. Here we use detailed datasets of current fossil fuel-burning energy infrastructure in 2018 to estimate regional and sectoral patterns of "committed" CO_2 emissions, the sensitivity of such emissions to assumed operating lifetimes and schedules, and the economic value of associated infrastructure. We estimate that, if operated as historically, existing infrastructure will emit ~658 Gt CO_2 (ranging from 226 to 1479 Gt CO_2 depending on assumed lifetimes and utilization rates). More than half of these emissions are projected to come from the electricity sector, and infrastructure in China, the U.S.A., and the EU28 represent ~41%, ~9% and ~7% of the total, respectively. If built, proposed power plants (planned, permitted, or under construction) would emit an additional ~188 (37–427) Gt CO_2. Committed emissions from existing and proposed energy infrastructure (~846 Gt CO_2) thus represent more than the entire carbon budget to limit mean warming to 1.5 °C with 50–66% probability (420–580 Gt CO_2)[5], and perhaps two-thirds of the budget required to similarly limit warming to below 2 °C (1170–1500 Gt CO_2)[5]. The remaining carbon budget estimates are varied and nuanced[14,15], depending on the climate target and the availability of large-scale negative emissions[16], Nevertheless, our emission estimates suggest that little or no additional CO_2-emitting infrastructure can be commissioned, and that earlier than historical infrastructure retirements (or retrofits with carbon capture and storage technology) may be necessary, in order meet Paris climate agreement goals[17]. Based on asset value per ton of committed emissions, we estimate that

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Author Contributions
S.J.D. and D.T. designed the study. D.T. performed the analyses, with the additional support from Q.Z., Y.Z. and C.S. on datasets and K.C., C.H. and Y.Q. on analytical approaches. D.T. and S.J.D. led the writing with input from all coauthors.

Competing interests
The authors declare no competing interests.

the most cost-effective premature infrastructure retirements will be in the electricity and industry sectors, if non-emitting alternative technologies are available and affordable[4,18].

International efforts to limit the increase in global mean temperature to well below 2 °C and to "pursue efforts" to avoid 1.5 °C entail a transition to net-zero emissions energy systems by mid-century[1–5]. Yet recent decades have witnessed an unprecedented expansion of historically long-lived fossil fuel energy infrastructure, particularly associated with rapid economic development and industrialization of emerging markets such as China and India[9,10] and a shift towards natural gas-fired power plants in the U.S. Although such expansion may be slowing[19,20], substantial new electricity generating capacity is proposed —and in many cases already under construction[12]. Consequently, there is a tension between dwindling carbon emissions budgets and future CO_2 emissions locked-in or "committed" by existing and proposed energy infrastructure[6,21,22].

A 2010 study estimated that operating fossil energy infrastructure would emit ~500 Gt CO_2 over its lifetime[8]. Subsequent studies estimated that existing power plants alone committed ~300 Gt CO_2 as of 2012 and 2016[9,12], and existing and proposed coal-fired power plants represented 340 Gt CO_2 as of 2016[11] (Extended Data Table 1). Other studies have used integrated assessment models (IAMs) to assess the economic costs of "unlocking" emissions under stringent climate goals[23,24], and to identify "points of no return" where no new infrastructure can be built without exceeding the 2°C target[25]. Most recently, Smith et al.[13] explored the potential climate responses to committed emissions, using a reduced-complexity climate model and an idealized phase-out of fossil infrastructure to argue that aggressive mitigation of non-CO_2 forcing could yet limit global warming to 1.5°C. However, it has been nearly a decade since a comprehensive bottom-up assessment of fossil infrastructure and committed emissions was made, during which years China's economy has grown tremendously, there has been a global financial crisis and a natural gas boom in the U.S., and the Paris Agreement was ratified and entered into force. Substantial new fossil energy infrastructure has been commissioned over this time period, proposals of new power plants have waxed and waned, and climate mitigation efforts have grown more ambitious in many countries.

Here, we present region- and sector-specific estimates of future CO_2 emissions related to fossil fuel-burning infrastructure existing and power plants proposed as of the end of 2018, as well as the sensitivity of such estimates to assumed lifetime and utilization rates, and the economic value of associated energy assets. Our analyses are based upon a compilation of the most detailed and up-to-date datasets of energy infrastructure available, as described in the Methods section. Our central estimates assume historical lifetimes (e.g., 40 years for power plants and industrial boilers, 15 years for a light-duty vehicle, etc.) and utilization rates (e.g., region- and fuel-specific power plant capacity factors, region-specific averages of vehicle fuel economy and annual kilometers traveled).

Figure 1 shows future CO_2 emissions from existing and proposed energy and transportation infrastructure by sector (Fig. 1a) and country/region (Fig. 1b). We estimate that cumulative emissions by existing infrastructure, if operated as historically, will be 658 Gt CO_2. Of this total commitment, 54% or 358 Gt CO_2 is anticipated to come from existing electricity

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infrastructure (mainly power plants), reflecting the large share of annual emissions from electricity infrastructure (46% in 2018) and the long historical lifetimes of generating infrastructure. Another 25% of the total, or 162 Gt CO_2, is related to industrial infrastructure, and 10% or 64 Gt CO_2 is related to the transportation sector (mainly on-road vehicles; Fig. 1a). This difference reveals the effect of infrastructure lifetimes: although industry and road transportation sectors have similar annual CO_2 emissions (6.2 and 5.9 Gt CO_2 in 2018, respectively), vehicle lifetimes are roughly a third as long as industrial capital. Finally, existing residential and commercial infrastructure represent 42 Gt CO_2 and 18 Gt CO_2 of all committed emissions, respectively.

Global committed emissions are now at the apex of a 20-year trend. Between 2002 to 2014, as China emerged as a global economic power, total committed emissions grew at an average annual rate of 9% per year (Extended Data Fig. 1a). Meanwhile, committed emissions related to infrastructure in the U.S. and EU28 have been shrinking since 2006 (Extended Data Fig. 1c). Since 2014, the rate of infrastructural expansion in China and India has also fallen, and committed emissions in China declined by 7% between 2014 and 2018, even as committed emissions in the Rest of World have continued to climb (Extended Data Figs. 1a and 1c). These most recent trends may reflect nascent shifts in China's economic structure[19] and global trade[20], and may be important harbingers of future changes in regions' annual CO_2 emissions[9].

Figure 2 shows the age distribution of electricity generating units worldwide. Overall, the youth of fossil generating units worldwide is striking: 49% of the capacity now in operation worldwide was commissioned after 2004, and this share is 79% and 69% in China and India, respectively. The average age of coal-fired power plants operating in China and India (11.1 and 12.2 years, respectively) is thus much lower than those in the U.S. and the EU28 (39.6 and 32.8 years, respectively; Fig. 2b), with correspondingly longer remaining lifetimes. The predominance of young Chinese infrastructure (which extends to the industrial and transportation sectors; Extended Data Figs. 2 and 3) reflects the scale and speed of the country's industrialization and urbanization since the turn of the century. As a result, infrastructural inertia is greatest in China, accounting for 41% of all committed emissions (270 Gt CO_2; Fig. 1b). In comparison, infrastructure in India, the U.S., and the EU28 represents much smaller commitments: 57 Gt, 57 Gt, and 49 Gt CO_2, respectively (Fig. 1b; Table S1 in Supporting Information).

In addition to existing infrastructure, new power plants are being planned, permitted, or constructed, and the committed emissions related to such proposed plants may be estimated[11,12]. As of the end of 2018, the best-available data showed 579 GW, 583 GW, and 40 GW of coal-, gas-, and oil-fired generating capacity were proposed to be built over the next several years, respectively (~20% of it in China; Fig. 2). If built and operated as historically, this proposed capacity would represent an additional 188 Gt CO_2 committed: 97 Gt CO_2 from coal-, 91 Gt CO_2 from gas-, oil-, and other-fuel-fired generating units (Table S2).

Together, committed emissions from existing infrastructure and proposed power plants total 846 Gt CO_2 if all proposed plants are built and all infrastructure operated as historically (Fig. 1).

Existing electricity and industry infrastructure accounts for 79% of total committed emissions if operated as historically (i.e. with a 40-year lifetime and 53% utilization rate; Fig. 1a). However, the lifetime and operation of such infrastructure will ultimately depend on the relative costs of competing technologies, in turn influenced by factors such as technological progress and the climate and energy policies in each region[22,26]. Figure 3 highlights the sensitivity of committed emissions (Figs. 3a and 3b) and the rate of annual emissions reductions (Figs. 3c and 3d; see Methods) to the assumed lifetime and utilization rates (i.e. capacity factors) of industry and electricity infrastructure (n.b. lifetimes and operation of infrastructure in other sectors are not varied from historical averages), with the star in each panel indicating historical average values. For example, total committed emissions related to existing infrastructure decrease to ~200 Gt CO_2 if lifetimes are and capacity factors decrease to 20 years and 20%, respectively, but increase to almost 1500 Gt CO_2 if lifetimes and capacity factors increase to 60 years and 80%, respectively (Fig. 3a). These ranges of lifetimes and utilization are quite wide, at the low end probably exceeding economic feasibility for recouping capital investments and covering fixed operating and maintenance costs. When proposed power plants are included, total committed emissions over the same range of lifetimes and capacity factors increase to 263–1906 Gt CO_2 (Fig. 3b). Maintaining historical capacity factors, a 5-year difference in the lifetime of existing infrastructure represents roughly 70–100 Gt of future CO_2 emissions (Fig. 3a), or about 90–130 Gt if proposed power plants are included (Fig. 3b). Maintaining historical lifetime and changing the assumed capacity factor by a comparable 9% (e.g., from 46% to 55%) results in roughly the same changes in committed emissions, suggesting these factors have a similar influence.

For comparison, the hatched red and orange zones in Figures 3a and 3b show the Intergovernmental Panel on Climate Change’s (IPCC) most recent estimated ranges of remaining cumulative carbon budgets spanning 50% to 66% probabilities of limiting global warming to 1.5°C and 2°C relative to the preindustrial era[5]. Excluding proposed power plants, our central estimate of committed emissions (658 Gt CO_2; star in Fig. 3a) exceeds the range of the remaining 1.5°C budget (420–580 Gt CO_2)[5]. When proposed plants are included, our estimate of committed emissions (846 Gt CO_2; star in Fig. 3b) is two-thirds of the lower estimates of the 2°C budgets (1170–1500 Gt CO_2)[5]. This suggests that, unless compensated by negative emissions technologies or retrofitted with carbon capture and storage, 1.5°C carbon budgets allow for no new emitting infrastructure and require substantial changes to the lifetime or operation of already existing energy infrastructure (e.g., decreasing lifetimes to <25 years or capacity factors to <30%; Fig. 3a). Moreover, CO_2 emissions related to the extraction and transport of fossil fuels[27] and non-energy CO_2 emissions (e.g., due to land use change)[28] are not included in our estimates and will further reduce the remaining carbon budgets.

Climate targets have also sometimes been contextualized by the annual rate of emissions reduction they imply. For example, Raupach et al.[29] showed, as of 2013, the cumulative carbon budgets likely to avoid 2°C of mean warming implied necessary average annual reductions in global CO_2 emissions (i.e. mitigation rates) of ~6% per year. The hatched areas in Figures 3c and 3d show that such mitigation rates, recalculated from the latest carbon budgets, are about 5% per year for the 2°C budgets (4.5–5.7%) and about 13% per year for 1.5°C budgets (11.4–15.7%). In comparison, the contours in the figure show mitigation rates if no new emitting infrastructure is commissioned (10.1%; star in Fig. 3c) or only proposed power plants but no other emitting infrastructure is commissioned (7.9%; star in Fig. 3d). Again the international targets leave little or no room for new infrastructure if existing plants operate as they have historically (stars) unless fully compensated by negative emissions or retrofitted with carbon capture and storage technologies.

Given the constraints of 1.5°C and 2°C carbon budgets, we also explore the economic value of existing infrastructure relative to its associated committed emissions. Figure 4a highlights the disproportionality of committed emissions per unit asset value. Together power and industry infrastructure (purple and dark blue in Fig. 4a, respectively) represent >75% of total committed emissions (519 of 658 Gt CO_2) but <25% of the estimated economic value of CO_2-emitting energy infrastructure (~$5 trillion of $22 trillion; Extended Data Fig. 4; Table S3; see Methods for details of how asset values were amortized). In contrast, transportation infrastructure, with shorter average lifetimes but high capacity costs and a vast number of discrete units, represents roughly two-thirds of the value of emitting assets and less than 10% of committed emissions (Fig. 4a). This analysis suggests that efforts to reduce committed emissions might cost-effectively target early retirement of electricity and industry infrastructure—despite their often powerful influence on policy and institutions[6,21,22]—if non-emitting alternative technologies are affordable: the magnitude of commitments in these sectors is large and a single dollar of asset value is related to >10 kg of future CO_2 emissions (Fig. 4b; red rectangle). Industry and electricity sectors in China represent especially prime targets for unlocking future emissions: nearly half (46%) of these sectors' committed emissions are associated with Chinese infrastructure (Fig. 4a).

Detailed and up-to-date analysis of existing and proposed CO_2-emitting energy infrastructure worldwide reveals incredibly tight constraints of current international climate targets even if no new emitting-infrastructure is ever built. Although climate and energy analysts have emphasized that avoiding 1.5°C of warming, for example, remains "technically possible"[5], our results lend vivid context to that possibility: we would have a reasonable chance of achieving the 1.5°C target with (1) a global prohibition of all new CO_2-emitting devices—including many or most of the already proposed fossil fuel-burning power plants, and (2) substantial reductions in the historical lifetimes and/or utilization rates of already existing industry and electricity infrastructure.

Barring such radical changes, the global climate goals adopted in the Paris Agreement are already in jeopardy and may be contingent upon widespread retrofitting of existing emitting infrastructure with carbon capture and storage technologies (which retrofits would be tremendously expensive[30]), large-scale deployment of negative emissions technologies[16], and/or solar radiation management[4]. On the other hand, our results suggest that the level of future warming in excess of the Paris targets is largely dependent on infrastructure that has not been built yet (Extended Data Fig. 5).

Some important caveats and limitations apply to our findings. The trajectory of future emissions depicted in Figure 1 represents a scenario in which existing (and proposed) emitting infrastructure "ages out," and no new emitting infrastructure is ever commissioned. These constraints are not intended as realistic; rather, they allow us to isolate and quantify infrastructural—and related economic—lock-in of energy-related emissions[22]. Indeed, technological trends and climate-energy policies that encourage growth in renewable electricity (e.g., solar and wind) may lead to earlier than historical retirements of existing fossil fuel power plants in some regions, although recent growth of renewable generation has not always displaced fossil generation[18]. It is also instructive to compare our estimates of committed emissions to plausible energy-emissions scenarios generated by much more sophisticated (but less transparent) IAMs that calculate infrastructure lifetimes and capacity factors endogenously. For example, a recent IAM study of 1.5°C scenarios found that large-scale carbon dioxide removal may be necessary to compensate for "residual" emissions from long-lived and difficult-to-decarbonize sectors of the energy system (e.g., freight, aviation, and shipping[4])[31].

The size of carbon budgets associated with a given temperature target is also a complicated matter that is sensitive to a host of factors such as climate sensitivity and non-CO_2 emissions[14,15]. The budgets from the recent IPCC Special Report are estimates of cumulative net global anthropogenic CO_2 emissions from the start of 2018 until net-zero global CO_2 emissions are achieved (i.e. climate is stabilized) with a 50–66% probability of limiting an increase of mean near-surface air temperatures to 1.5°C or 2°C with limited (<0.1°C) or no overshoot[5] (see Methods for further discussion).

Although ambitious climate targets such as 1.5°C may help to motivate and accelerate the transition toward net-zero energy systems, their feasibility is often evaluated by the existence of consistent scenarios from IAMs. However, these models have been used to analyze a very large possibility space, and some scenarios may thus reflect aspirational trajectories of energy demand or technological progress and scale whose likelihood may be difficult to evaluate[32,33]. Our data-driven assessment of existing, operating, and valuable energy infrastructure may therefore help to elucidate the infrastructural and economic implications of such targets, and also help to identify targeted regional and sectoral opportunities for unlocking future CO_2 emissions.

Methods

Committed emissions from existing and proposed infrastructure

We extend the approach of Davis et al[9] to quantify the committed emissions from existing energy infrastructure by integrating more detailed and up-to-date data of energy infrastructure available, including country- and duty-specific vehicle sales data, and unit-level details of global power plants and Chinese cement kilns and blast furnaces[10,34–39]. We also estimate committed emission from proposed power plants by collecting all proposed power generators from the latest available databases[34,37], in recognition of substantial changes in the pipeline of planned power plants (especially coal) in recent years[34]. Energy infrastructure as quantified in this study is categorized into eight sectors: (1) electricity, (2) industry, (3) road transport, (4) other transport, (5) international transport, (6) residential, (7) commercial and (8) other energy infrastructure (see Tables S4 and S5).

Electricity infrastructure

Emissions from electricity infrastructure in this study include all emissions under category 1A1 of the IPCC's Revised Guidelines[40]. Electricity infrastructure here mainly includes main activity electricity and heat production (1A1a), and petroleum refining (1A1b), as well as manufacturing of solid fuels and other energy industries (1A1c) (Table S5).

Emissions intensities.—Previously, we built and published a comprehensive global thermal power plants database in 2010 (named GPED) by integrating high-quality national databases (China, India, and the U.S.)[10]. Here we update the GPED database to the year 2018 (named GPED-2018) using the latest power plant database from China (CPED)[36] and the Platts World Electric Power Plant (WEPP) database for other regions[37], including all retired and operating units through the end of 2018. We obtain data and estimates of unit-based CO_2 emission intensity (i.e. gCO_2/kwh) for all units that were operating in 2010 from GPED-2010. For units retired prior to 2010 or commissioned since 2010, we estimate unit-level CO_2 emission intensity by the methods of Davis et al[9] based on the Carbon Monitoring for Action (CARMA) database[35] (for older units) or else use national or regional average CO_2 emission intensity for units with the same fuel type and similar nameplate capacity. As prior studies have done, we assume these emissions intensities are constant over a unit's lifetime[8,9].

Assumed lifetime.—In the resulting GPED-2018, global average lifetimes of retired coal-, nature gas-, and oil-fired power units is 35.9, 37.1, and 33.9 years, respectively. Consistent with prior study[9] have done, we simplify these ranges to a single reference lifetime of 40 years for all electricity-generating units for our "as historically" case, and show the sensitivity of committed emissions to this assumption in Figure 3. When units already operating beyond their assumed lifetime, these units are randomly retired over the next 5 years in order to avoid unrealistically abrupt changes in emissions between 2018 and 2019.

In addition, we assume that the age structure and lifetime of autoproducers (industrial and commercial facilities which generate their own electricity on-site)[40] and other energy industries are similar to the main activity power plants in each region. Therefore, committed emissions from existing electricity infrastructure are quantified by employing the survival curves derived from main activity power plants, scaled to include these other types of electricity infrastructure using country-level electricity emissions totals in 2018 from the International Energy Agency (IEA). It is noted that the country-level CO_2 emissions from fossil fuel combustions for 2018 were derived from multiplying country-level CO_2 emissions in 2016 by projected change rates during 2016–2018 due to data availability[41].

Finally, we quantify the cumulative future CO_2 emissions from proposed power plants by the same procedure (assuming historical average unitization rates and lifetimes) using a database of proposed coal-fired units that has been developed by CoalSwarm[34] and the planned units fired with other fossil fuels from the Q4 2018 WEPP database[37].

Industry infrastructure

Industrial emissions in this study include all emissions under category 1A2 of the IPCC's Revised Guidelines[40]. For all countries but China, we estimate cumulative future emissions from industry infrastructure using country-level emissions data for the year 2018 obtained from the IEA and assuming that the age distribution and survival curves of each region's industry infrastructure is consistent with its electricity infrastructure. To derive China's industrial survival curves, we use unit-level details of cement kilns and blast furnaces (iron & steel) currently operating in China (Extended Data Fig. 2), obtained from China's Ministry of Ecology and Environment (MEE) (unpublished data, hereinafter refer to as the MEE database).

The detailed data of Chinese infrastructure represent an important improvement in the current study over prior estimates of committed emissions, as we China alone accounts for ~47% of total industrial emissions[41]. In particular, the iron/steel and non-metallic minerals (e.g., cement and glass) industries account for ~50% of all industrial CO_2 emissions in recent years[41], and China produced 49.6% of the world's raw steel and 57.3% of the world's cement in 2016[42]. The unit-level data of China's industrial infrastructure thus substantially decreases uncertainty of committed industry emissions by alleviating the need for assumptions related to almost half of global industry infrastructure (i.e. 9.0% of global CO_2 emissions from all sources[41]). Moreover, we observed that the age distributions of electricity and industry infrastructure in China are quite similar (Extended Data Fig. 6), which lends support to our assumption that this is the case in other regions where we lack detailed data of industrial infrastructure.

Transportation infrastructure

Transport emissions in this study include all emissions under category 1A3 of the IPCC's Revised Guidelines[40], which includes emissions from road transport, other transport and international transport (Tables S4 and S5).

Cumulative future emissions from road transport were calculated following the approach in Davis et al.[8] and further updating the activity rates with updated country-, region-, and duty-specific vehicle sales data[38,39] (i.e. 18% of global CO_2 emissions from all sources[41]). Specifically, we use the number, class, and vintage of motor vehicles sold during 1977–2017 from 40 major countries and regions[38,39] (information for 2018 was derived by projecting 2016–2017 rates of change one additional year; Extended Data Fig. 3). We then estimate the number of vehicles remaining on the road over time using class- and model year-specific survival rates of U.S. and Chinese vehicles to represent developed and developing countries or regions due to data availability, respectively[43,44]. We then calculate annual vehicle emissions based on the average miles driven per year (MPY) per vehicles by class and carbon emission factors of 10.23 and 11.80 kg CO_2 per gallon of gas and diesel, respectively, and scale our estimated emissions to match country-level road transport emissions in 2018 as reported by the IEA[41].

"Other transportation" infrastructure includes existing aviation, rail, pipeline, navigation and other non-specified transport. International transport infrastructure includes international

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marine bunkers and international aviation bunkers in this work (Table S4). Again, we follow Davis et al.[8], estimating cumulative future CO_2 emissions from existing other and international transport using country-level emissions data of 2018 from IEA, and assuming lifetimes and age distributions similar to motor vehicle fleets in each country/region.

Residential, commercial and other energy infrastructure

Residential and commercial emissions are included under category 1A4 of the IPCC's Revised Guidelines[40], and "Other energy" emissions include, e.g., emissions from agriculture, forestry, fishing, and aquaculture under category 1A4 as well as and stationary, mobile, and multilateral operations under category 1A5 of the IPCC's Revised Guidelines. Cumulative future emissions from this infrastructure were calculated using country-level emissions data of 2018 derived from the IEA[41], and assuming age distributions and lifetimes of residential, commercial and other energy infrastructure in each region were similar to electricity infrastructure in the same region in the absence of better information.

The least-supported methodological assumptions we make thus concern this residential, commercial and other energy infrastructure (~10% of total fossil fuel CO_2 emissions in 2016[41]), where we lack any unit-level data. In order to test the sensitivity of total committed emissions from this infrastructure, we performed additional analyses of different assumed lifetimes. We found the committed emissions from residential, commercial, and other energy infrastructure are 29, 74, and 135 Gt CO_2 when lifetimes of 20, 40, and 60 years are assumed, respectively (Extended Data Fig. 7). That is, our estimates of total committed emissions from all existing energy infrastructure decrease by 7% (to 613 Gt CO_2) if lifetimes of residential, commercial, and other energy infrastructure are assumed to be 20 years, and increase by 9% (to 719 Gt CO_2) if the lifetimes are assumed to be 60 years. In comparison to the carbon budgets associated with targets of 1.5 °C and 2 °C, these are relatively small effects, and not substantial enough to affect the main conclusions of our study.

Comparison of cumulative future emissions estimates

Other studies have analyzed committed emissions of various infrastructure in different ways, as mentioned in the text and summarized in Extended Data Table 1[8,9,11–13].

For example, both Edenhofer et al.[11] and Pfeiffer et al.[12] reported committed emissions related to existing and planned power plants using 2016 data. Although the latter analyzed committed emissions of all fossil electricity infrastructure[12], the former focused particularly on coal-fired units[11]. Importantly, the 2018 data used in the current study reveals that substantial cancellations of proposed plants have occurred over the intervening two years: whereas the previous studies estimated ~150 Gt CO_2 and 210 Gt CO_2 were committed by proposed coal plants, we estimate only ~100 Gt CO_2, 50–100 Gt CO_2 less, respectively (or 10–20% of the remaining carbon budget consistent with 1.5°C, respectively). Moreover, our study contains more detailed estimates of regional commitments and the sensitivity of these commitments to assumed lifetime and capacity factor.

Most recently, Smith et al.[13] estimated the global warming related to committed emissions using a reduced-complexity climate model (FaIR). Their study also included estimates of committed emissions from all sectors, but these relied on past estimates of the age distribution of fossil fuel infrastructure and an idealized, linear phase-out of such infrastructure[13]. Because turnover of infrastructure has decreased the median age of electricity generating capacity in many regions (Fig. 2), our estimates of electric power sector commitments (358 Gt CO_2) are ~13 Gt CO_2 greater than those used by Smith et al[13] (345 Gt CO_2). Our data-driven approach also permits region-specific results, analysis of the trend in commitments over time, inclusion of proposed power plants, and an assessment of the economic value of underlying infrastructures. Yet, because Smith et al.'s estimates of CO_2 emissions committed by other infrastructure are larger than our bottom-up estimates (Extended Data Table 1), the overall estimate reached by their idealized approach (715 Gt CO_2) is nonetheless similar to that of the current study (658 Gt CO_2).

In turn, Smith et al.[13] assess the global climate responses to the committed CO_2 and conclude that the world is not yet committed to 1.5°C[13]. However, it is difficult to directly compare the magnitude of the CO_2 emissions in Smith et al.'s phase-out scenarios with the SR1.5 carbon budgets for two reasons: First, although SR1.5 also used the FaIR model in its procedure of evaluating non-CO_2 forcing, it did not use the FaIR model's transient climate response to cumulative emissions (TCRE), which is smaller and would have led to considerably larger carbon budgets. Second, the mitigation scenarios evaluated by Smith et al. also assumed that non-CO_2 emissions are completely phased out in parallel to CO_2, while the integrated assessment model scenarios on which the SR1.5 report's non-CO_2 forcing (and carbon budgets) are based do not completely eliminate non-CO_2 emissions this century[45].

Variation of utilization rates and assumed lifetimes

As described above, cumulative future committed emissions from electricity and industry infrastructure depend on utilization rates and assumed lifetimes. The longer the assumed lifetime and higher the utilization, the greater the estimate of committed emissions will be. In this study, we therefore test the sensitivity of committed emissions to assumed lifetimes and utilization rates of energy and industry infrastructure across lifetimes from 20 to 60 years and utilization rates of 20% to 80%.

Remaining carbon budgets to limit mean warming to 1.5 and 2 °C

As described in the text and discussed in recent literature, the size of carbon budgets associated with a given temperature target is a complicated matter that is sensitive to a host of factors[14,15], including (1) whether the budget reflects cumulative net emissions until the temperature target is exceeded or cumulative net emissions that limits global temperature increase to below the target (i.e. climate is stabilized), (2) whether there can be a temporary overshoot of the temperature target (and by how much)[46], (3) the climate responses to CO_2 and non-CO_2 forcings[47], (4) the magnitude and Earth system response to negative emissions[48], (5) how global temperature is calculated, (6) the pre-industrial baseline used[49], (7) whether Earth system feedbacks such as permafrost thawing are included[50–53], and (8) future emissions of non-CO_2 greenhouse gases and aerosols[54,55].

The magnitude of non-CO_2 forcing is particularly relevant to assessments of committed emissions because non-CO_2 forcing is inversely related to the remaining carbon budget[54,55], and because some non-CO_2 greenhouse gases and aerosols are directly related to the current energy system (e.g., fugitive methane[56]) or are co-emitted with CO_2 by fossil fuel-burning infrastructure. Other large sources of non-CO_2 gases and aerosols exist outside of the energy system, such as agriculture[57]. For the SR1.5 budgets, non-CO_2 forcing was estimated using integrated assessment model scenarios and a pair of reduced-complexity climate models (MAGICC and FaIR), with substantial uncertainties associated with both scenario variations (±250 Gt CO_2) and climate responses (-400 to 200 Gt CO_2) for the 1.5°C budget[5]. Non-CO_2 greenhouse gases and aerosols decline but do not reach zero in any of the scenarios assessed by the SR1.5 report. In contrast, the recent study by Smith et al. modeled the complete phase-out of non-CO_2 emissions in parallel with energy-related CO_2 emissions, a formidable scenario that was found to have a high probability (64%) of limiting warming to 1.5°C[13].

In this study, we compare our estimates of committed emissions to the SR1.5 budgets[5]. As defined by the recent SR1.5 report, remaining carbon budgets are the cumulative net global anthropogenic CO_2 emissions from a given start date (January 1, 2018) to the year in which such emissions reach net zero that would result, at some probability, in limiting global warming to a given level[5]. By this definition, budgets are not simply cumulative emissions until the time when mean temperature exceeds a given threshold[14], but rather what have been called “threshold avoidance” or called “stabilization” budgets. The SR1.5 budgets were derived from the transient climate response to cumulative CO_2 emissions in climate model simulations that have been further adjusted to include additional climate forcing related to non-CO_2 greenhouse gases and aerosols[45]. They do not include Earth system feedbacks (which the report suggests could reduce the remaining budgets by 100 Gt CO_2 over the century).

However, as remaining budgets associated with mean surface warming of 1.5°C dwindle, uncertainties in transient climate response to CO_2 emissions[15,47] and the current and future non-CO_2 forcing loom large[53–55]. In order to make our results as useful, transparent, and comparable as possible, we report positive, CO_2-only commitments from existing and proposed fossil fuel-burning infrastructure and compare to these to the remaining (stabilization) carbon budgets reported by the SR1.5 report to give a 50–66% probability of limiting warming to 1.5°C and 2°C with little (0.1°C) or no overshoot: 420–580 Gt CO_2 and 1170–1500 Gt CO_2, respectively (See Table 2.2 in ref.[5]). Thus, if not offset by negative emissions, the total committed emissions we estimate if existing infrastructure operates as it has historically (i.e. 658 Gt CO_2) would make it likely that global temperatures will exceed 1.5°C unless the remaining carbon budgets in the SR1.5 are substantially wrong. For example, the climate response to CO_2 could be less than expected based on the climate model simulations the SR1.5 assessed and/or non-CO_2 forcing in the future could be much less than it is on average in the integrated assessment model scenarios that were assessed by the SR1.5. Indeed, Smith et al.[13] analyzed a future where both are true.

Estimates of the annual rate of emission reductions

We estimate annual rate of emissions reduction ("mitigation rates") following Raupach et al (2014)[29]:

$$\mathrm{f(t)} = f_0(1 + (r + m)t)$$

where f(t) is the emissions at time t, f_0 is the emissions at the start of mitigation ($t = 0$), r is an initially linear growth rate, and r and m both have units of per year. When the necessary annual rate of emission reductions to meet quota q from t=0 onward (with emission time T = q/f0), we estimate the annual rate of emission reductions, m, as:

$$\mathrm{m(q)} = \frac{1 + \sqrt{1 + rq/f_0}}{q/f_0} = \frac{1 + \sqrt{1 + r/T}}{T}$$

We use initial emissions f_0 at 2018 and growth rates r averaged over 2013–2018. Therefore, f_0= 32.7 Gt and r = 0.028% used obtained from IEA[41] when estimating mitigation rates under different cumulative CO_2 emissions, which we assumed to be equivalent to the carbon quota, q.

Estimates of asset value from existing infrastructure

We estimate the asset value by sector and by country/region using the following equation:

$$\mathrm{AV}_{i,s} = \sum_{n = PY - LT}^{PY} \sum_{y} \left(\mathrm{TC}_{i,\ s,n,y} \times \mathrm{CC}_{i,\ s,n,y} \times \left((1 - \mathrm{RV}) \times \mathrm{DR}_{i,s,n,y} + RV\right)\right)$$

where i, s, n, y represents country/region, sector, years, and combustion/production technology, AV represents asset value, TC represents equivalent total capacity, CC represents capital costs, RV represents the ratio of residual value, and 5% is applied for all the infrastructure; DR represents depreciation rate, PY represents present year, referring 2018 in this study.LT represents lifetimes.

We adopt sector-dependent method, and apply straight-line and geometric models for different infrastructure, as shown in Table S6. Data on capital costs used to estimate the asset value was collected from previous literature[12,21,23–25,58,59] and various reports[60–64]. Wherever possible, we use interannual and national average capital costs for different combustion/production technology and equipment. Where an interannual and national averages were not available, we instead use an average of all the countries in the same region where capital cost data were available.

Electricity infrastructure

We estimate the total value of fossil fuel electricity-generating assets according to each unit's power generating capacity (kW) and age, as well as fuel- and technology-specific capital costs ($/kW).

The assumed lifetime of coal power plants is 40 years. Although plants can operate for considerably longer periods, shutting down a plant after its assumed lifetime will not result in any stranded capital investment since the initial capital cost will have been fully paid[24]. Thus, our estimates only include the asset value of operating electricity-generating units that are now less than 40 years old. Unit-level details of electricity-generating technologies were obtained from GPED-2018 database.

In addition, part of committed CO_2 emissions in electricity infrastructure are from heating plants. The asset value of combined heat and power (CHP) plants have been evaluated along with other power plants, but we estimate the asset value of individual heating plants separately, using IEA data on heating output (TJ)[65,66] to estimate the capacity of such heating plants and converting this to an equivalent power capacity (GW) assuming they operate with the average utilization rates of power generating units in the same region. Table S6 summarizes the assumptions of estimating asset value of individual heating plants.

Industrial infrastructure

Industrial infrastructure includes various facilities and systems from different sub-industrial sectors (Tables S4 and S5). Considering the difficulty of collecting the operating capacity for all the sub-industrial sectors, we estimate the value of industry infrastructure as the combined asset values of cement, iron and steel plants, and industrial boilers. As described above, only the asset value for cement, iron and steel capacity operating less than 40 years was estimated in this work. Asset value from cement, iron and steel industry are quantified through total capacity and capital investment per unit (Table S6).

We estimate total capacities (t/h) of industrial boilers at country- or region-level by fuel type by through total energy consumptions obtained from IEA[65,66]. The utilization rates of industrial boilers are assumed to be the same as the average utilization rate of electricity infrastructure. The related assumptions are shown in Table S6.

Transport infrastructure

We quantify the value from road transport, other transport and international transport assets separately. For road transport infrastructure, we estimate asset value by number of annual vehicle sales, annual average new car prices, and a depreciation rate function. The data sources of number of annual vehicle sales is described above, and we further collect annual average new car prices by vehicle type and country/region[39]. Because depreciation rates tend to be considerably lower in developing countries than industrialized countries[67], we adopt different depreciation rate functions for developing and developed countries[67].

For international transport infrastructure, we estimate the value of international ships and international airplanes. Due to limited data availability, we use the same approach as with heating infrastructure, basing our estimates on the total energy consumption (fuels) for international aviation and international navigation from the IEA, and converting to the number of reference narrow-body aircraft and standardized international freight ships by such fuel consumption. Specifically, we assume 2 million-km/year per aircraft and 149 MJ/airplane-km for reference narrow-body aircrafts[21] (Table S6); 940 million annual ton-km and an average ship energy intensity of 0.125 MJ/ton-km for international freight ships[21].

We use the same total average depreciation rates for international transport as we do for road transport infrastructure.

We use a similar approach for other transport (i.e. domestic ships, domestic airplanes, and non-specific transport), adopting the same assumptions applied in the international transport for domestic ships and domestic airplanes. For non-specific transport, we quantify asset values by converting to the number of conventional diesel heavy-duty freight truck. The corresponding assumptions are shown in Table S6.

Residential, commercial and other energy infrastructure

We quantify the asset values of residential, commercial and other energy infrastructure separately using sector- and fuel-specific energy consumption data from the IEA[65,66].

Residential and commercial infrastructure use energy for space heating, heating water, and cooking. Other energy infrastructure includes uses of energy for agriculture, fishing and other activities. Given very limited data, we quantify the value of residential and commercial infrastructure by according to an equivalent capacity of normalized space heating units, water heating units, and cooking equipment. In the other energy infrastructure, we quantified the asset value by converting to normalized agriculture machines, fishing boats and boilers. We then apply the total average depreciation rates of electricity infrastructure to these residential, commercial and other energy infrastructures.

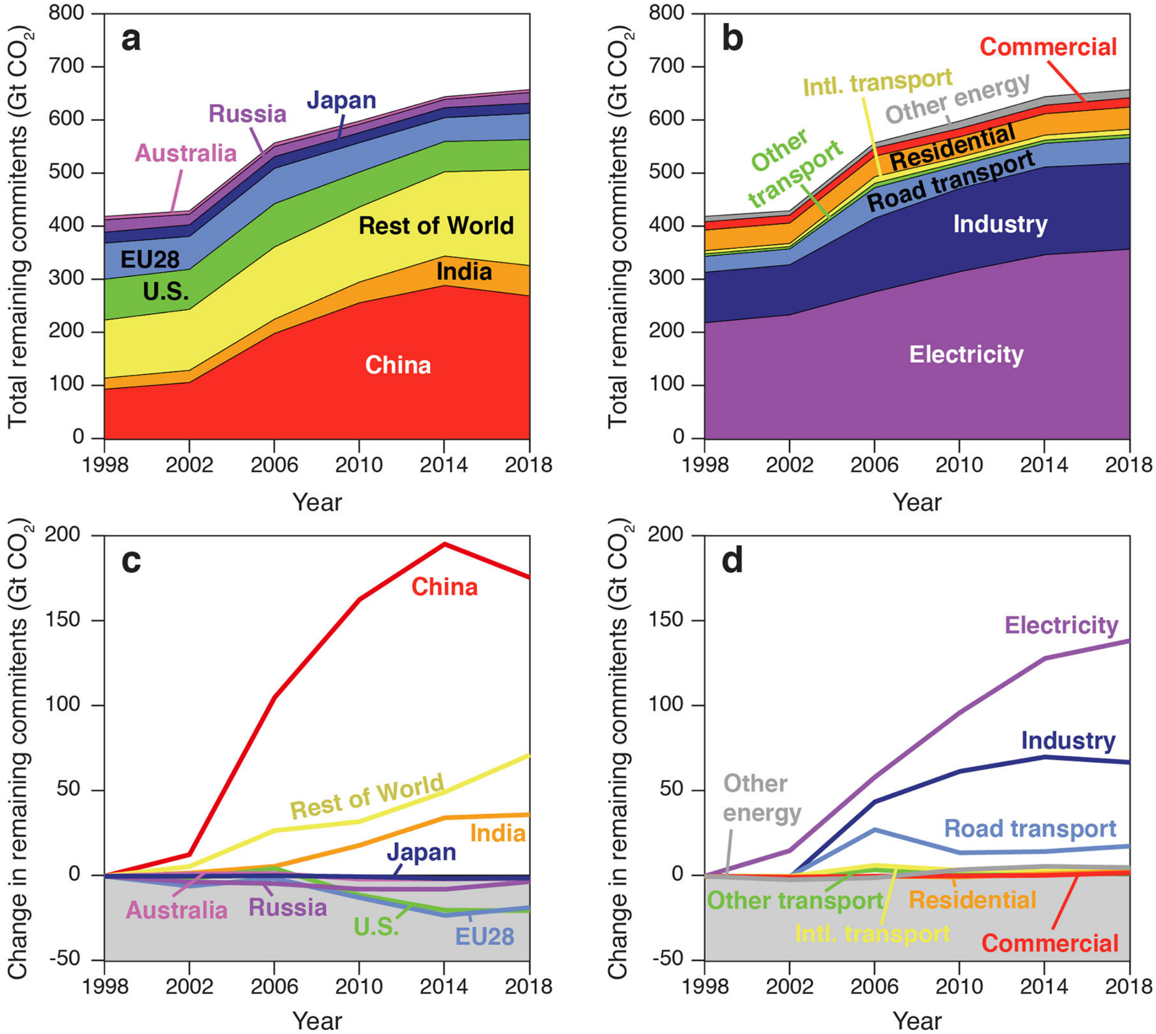
Uncertainty estimated

Our estimates of asset values are subject to uncertainty due to incomplete knowledge of operating capacities, their age structure, and the capital costs per unit. In order to more completely assess uncertainties in our results, we perform a Monte Carlo analysis of asset values by sector and by country/region in which we vary key parameters according to ranges in the literature[58,68,69] and collected capital costs data above. The error bars shown in Figure 4 depict the results of this analysis, showing the lower and upper bounds of a 95% confidence interval (CI) around our central estimate. The Monte Carlo simulation uses specified probability distributions for each input parameter (e.g., capital cost per unit, and the ratio of residual value) to generate random variables[68]. The probability distribution of asset value is estimated according to a set of runs (n=10,000) in a Monte Carlo framework with probability distributions of the input parameters. The ranges of sector- and -region-parameter values vary in part due to the quality of their statistical infrastructure[69]. Table S7 summarizes the probability distributions of the asset value estimation-related parameters.

Data availability

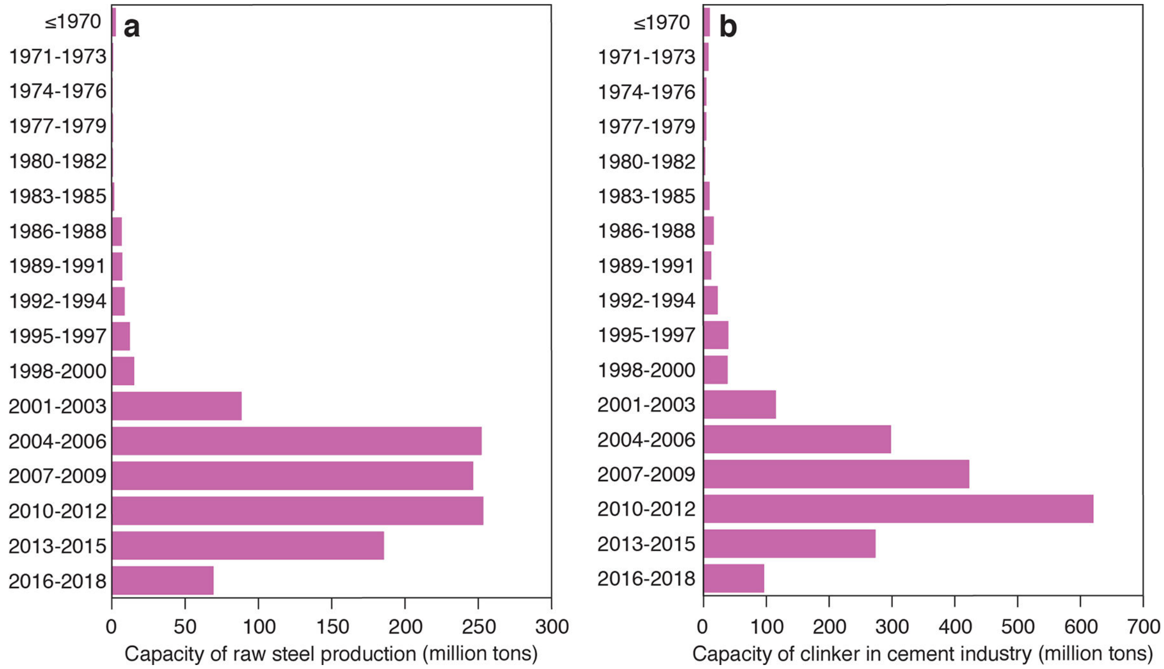
The numerical results plotted in Figures 1–4 are provided with the manuscript. Our analysis relies on six different datasets, each used with permission and/or by license. Five are available from their original creators: (1) the GPED database: http://www.meicmodel.org/dataset-gped.html, (2) Platt's WEPP database: https://www.spglobal.com/platts/en/products-services/electric-power/world-electric-power-plants-database, (3) the CARMA database: http://carma.org/, (4) the CoalSwarm database: https://endcoal.org/tracker/, and (5) vehicle sales data: https://www.statista.com/markets/419/topic/487/vehicles-road-traffic/. The sixth dataset includes unit-level data of Chinese iron, steel and cement infrastructure which we obtained directly from the Chinese Ministry of Ecology and Environment. We do not have permission to share the raw data, but we provide it in an aggregated form (Extended Data Figure 2).

Extended Data



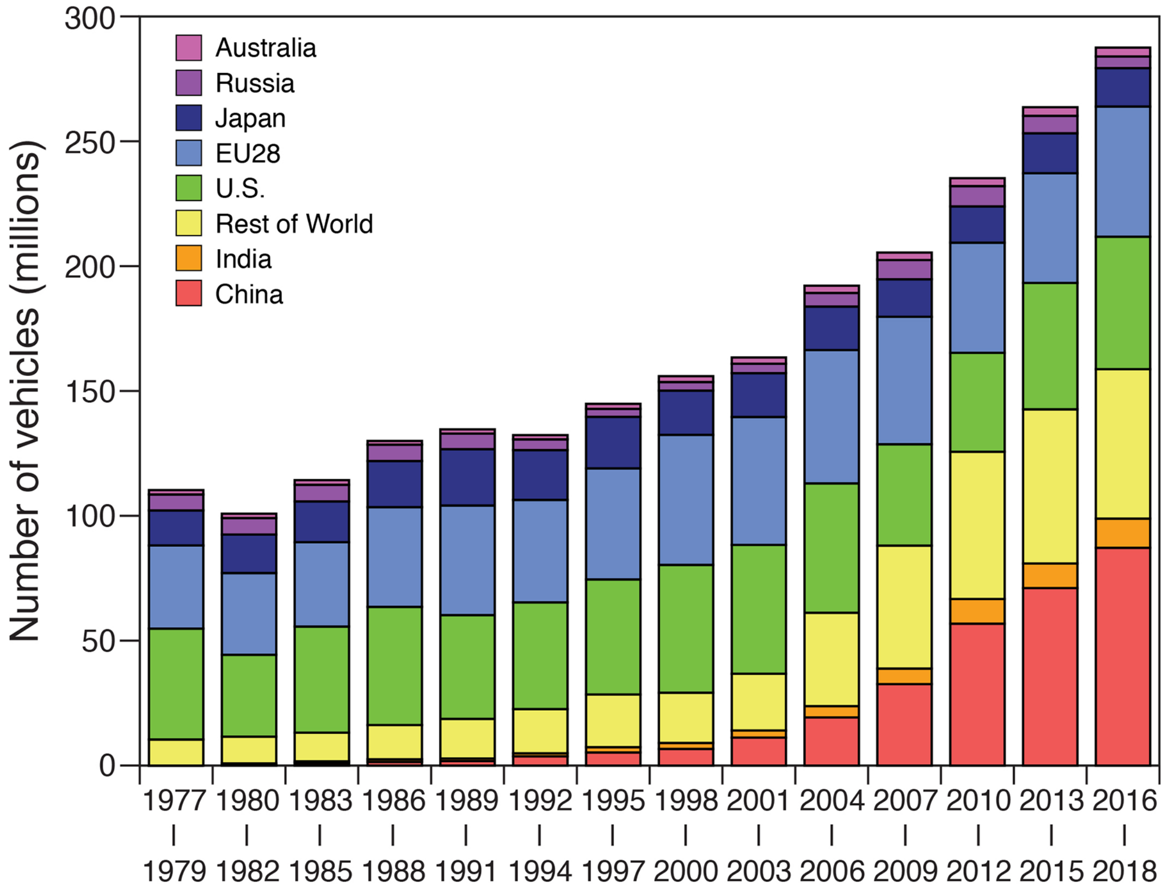
Extended Data Figure 1 |. Changes in remaining commitments from existing energy infrastructure.

Estimates of future CO_2 emissions every four years by industry sector (**a**) and country/region (**b**) from 1998 to 2018 (1998, 2002, 2006, 2010, 2014, and 2018), assuming historical lifetimes and utilization rates. Panels (**c**) and (**d**) show corresponding changes in remaining commitments by industry sector (**c**) and country/region (**d**).



Extended Data Figure 2 |. Age structure of Chinese major industrial capacity.

The operating capacity of raw steel in iron and steel industry (**a**) and clinker in cement industry (**b**) where the youngest units are at the bottom.



Extended Data Figure 3 |. Age structure of currently road transport infrastructure.
This figure shows the population of vehicle sales by country/region.

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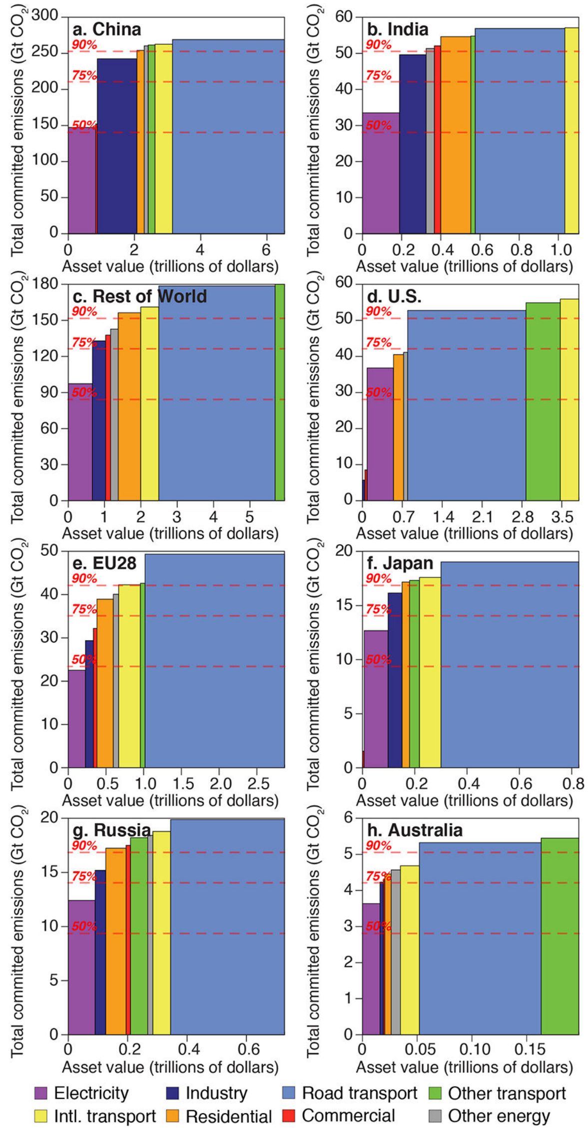
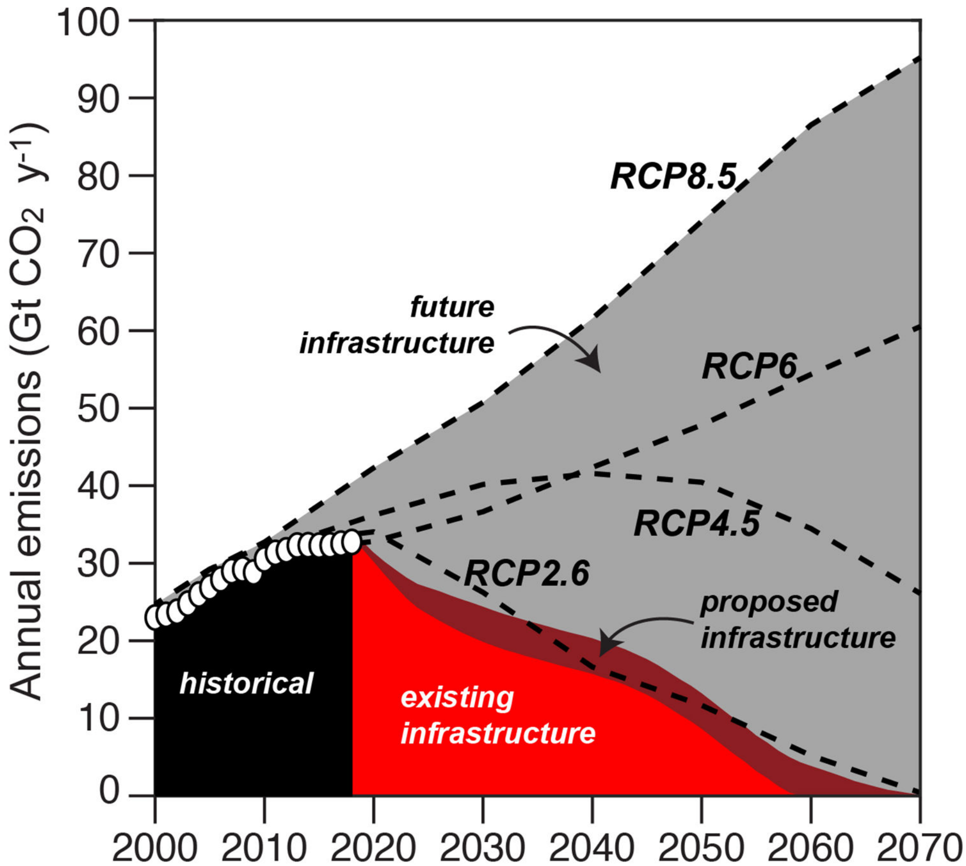


Extended Data Figure 4 |. Asset value and committed emissions of existing infrastructure.

Cumulative committed CO_2 emissions in the order of committed emission per value (kg CO_2 per $) (from high to low) by country/region and sector. Dash horizontal lines indicate 50%, 75% and 90% of total committed emissions if operated as historically, respectively.



Extended Data Figure 5 |. Annual emissions from existing, proposed and future infrastructure.
This figure shows historical CO_2 emissions from fossil fuel energy infrastructure (black area), and future CO_2 emissions from existing (red area) and proposed energy infrastructure (dark red area), as well as future infrastructure (dark grey area) under representative concentration pathways (RCPs: RCP8.5, RCP6, RCP4.5, and RCP2.6).

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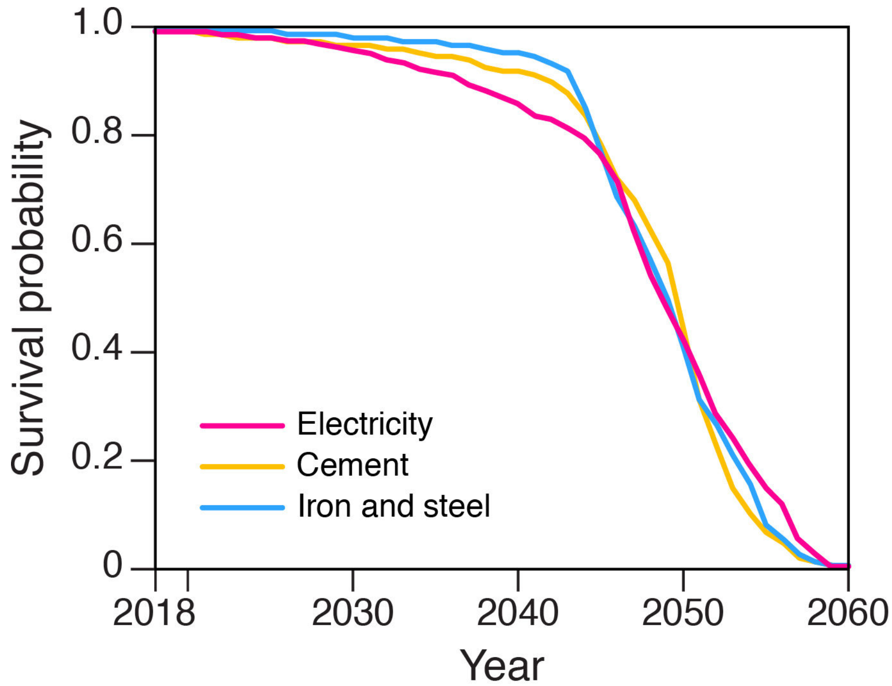

Extended Data Figure 6 |. Survival curves of power and major industries in China.

This figure shows survival curves of power sector (peachblow line), cement industry (orange line), and iron and steel industry (blue line) in China under the assumption of 40-year lifetimes.

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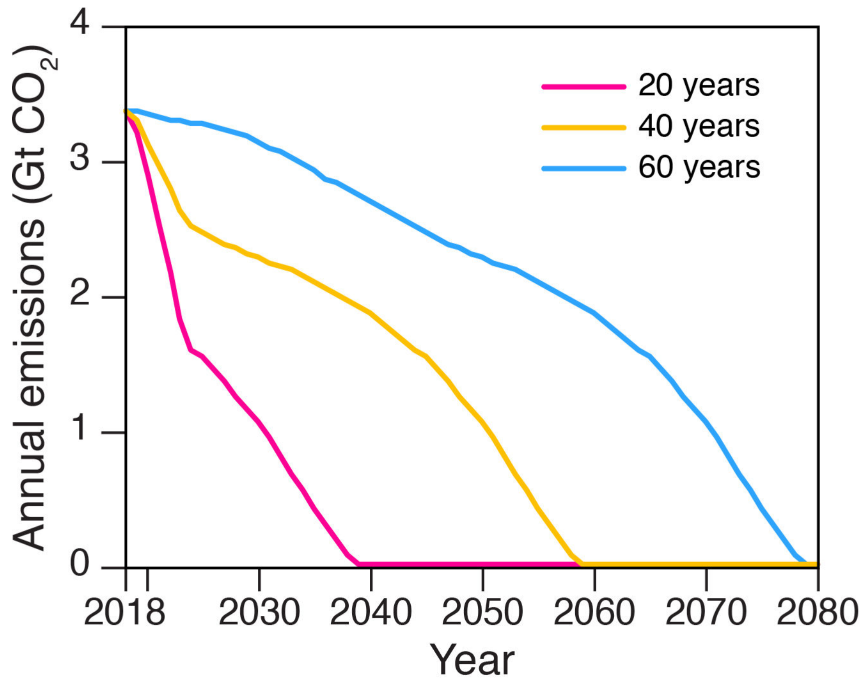

Extended Data Figure 7 |. Annual emissions from residential, commercial, and other energy infrastructure.

This figure shows future annual CO_2 emissions from residential, commercial, and other energy infrastructure under the assumptions of 20- (peachblow line), 40- (orange line), and 60-year (blue line) lifetimes.

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Extended Data Table 1 |

Comparing commitments.

Comparison of committed emissions by sector estimated in the current study and prior studies. Note that in some cases, the totals may not correspond to the sum of underlying sectors due to rounding.

		Davis et al. (2010)[8]		Davis and Socolow (2014)[9]		Edenhofer et al. (2018)[11]		Pfeiffer et al. (2018)[12]		Smith et al. (2019)[13]		This study	
		Gt CO_2	Year of dataset	Gt CO_2	Year of dataset	Gt CO_2	Year of dataset	Gt CO_2	Year of dataset	Gt CO_2	Year of dataset	Gt CO_2	Year of dataset
Existing	Electricity	224	2009	307	2012	-	-	308	2016	345 (261–451)	2009**	358 (240–493)	2018
	Coal		2009	206	2012	190	2016	220	2016	-	-	260 (175–358)	2018
	Gas, oil, and other fuels		2009	100	2012	-	-	88	2016	-	-	98 (65–135)	2018
	Industry	104	2009			-	-	-	-	154 (117–191)	2009	162 (110–219)	2017
	Transport	116	2009			-	-	-	-	92 (73–110)	2017	64 (53–75)	2017
	Residential, commercial, and other energy	53	2009			-	-	-	-	121 (91–158)	2009*	74 (52–105)	2018
	All Sectors	**496 (282–701)**				-	-	-	-	**715 (546–909)**	-	**658 (455–892)**	-
Proposed	Electricity					-	-	271	2016	-	-	188 (142–234)	2018
	Coal					150	2016	210	2016	-	-	97 (74–121)	2018
	Gas, oil, and other fuels					-	-	61	2016	-	-	91 (68–113)	2018
All Sectors + Proposed Electricity												**846 (597–1,126)**	

* The range represents the committed emissions estimated under the assumptions of 30–50 years' lifetimes for all the sectors except transportation sector (12–18 years' lifetimes).

** The age distribution of infrastructure was assumed to be the same as 2009, but annual emissions from the infrastructure was adjusted up to 2018 levels.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

D.T. was supported by NASA's IDS program (80NSSC17K0416). Q.Z. was supported by the National Natural Science Foundation of China (41625020). C.H., Y.Q., and S.J.D. were supported by the U.S. National Science Foundation (INFEWS grant EAR 1639318).

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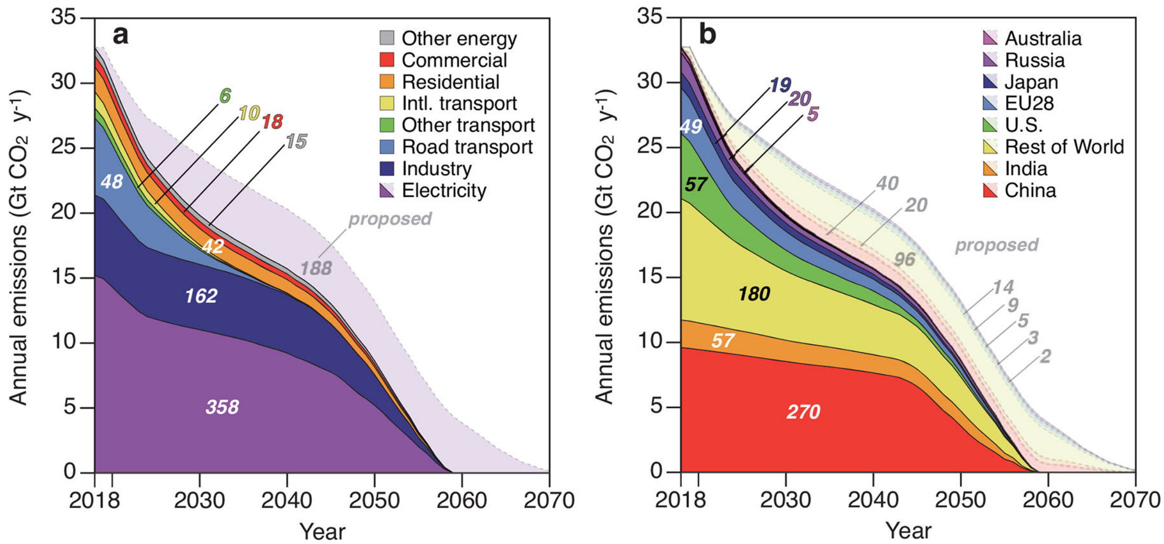

Figure 1 |. Committed CO_2 emissions from existing and proposed energy infrastructure.

Estimates of future CO_2 emissions by industry sector (**a**; see also Tables S1 and S2) and country/region (**b**), assuming historical lifetimes and utilization rates. Emissions from existing infrastructure are shown by darker shading, and emissions from proposed power plants (i.e. electricity) are more lightly shaded.

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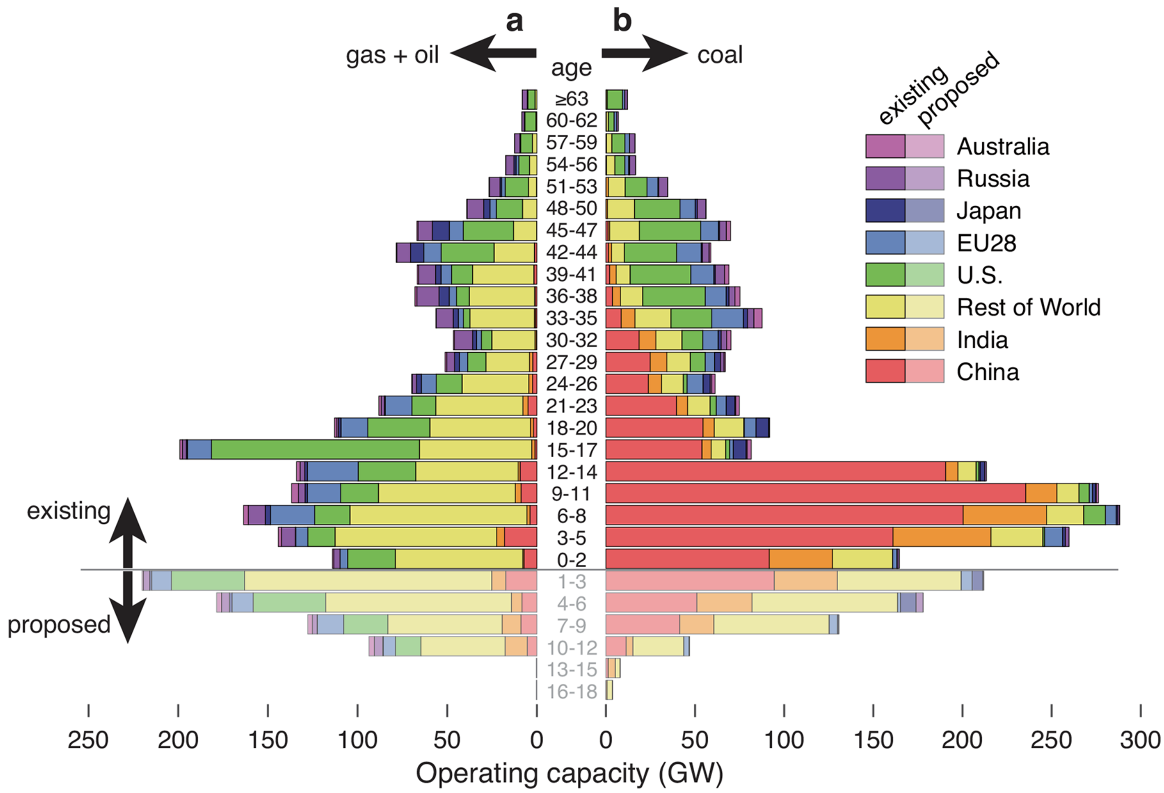

Figure 2 |. Age structure of global electricity-generating capacity.

The operating capacity of gas- and oil-fired electricity-generating units (**a**) and coal-fired units (**b**) where the youngest units are at the bottom. Lighter shaded bars at the bottom show proposed electricity-generating units according to the year they are expected to be commissioned. Recent trends in Chinese and Indian coal-fired units (red and orange at lower right, respectively) and U.S. gas-fired units (green at left) is apparent. Note that 0 years old means the power units began operating in 2018.

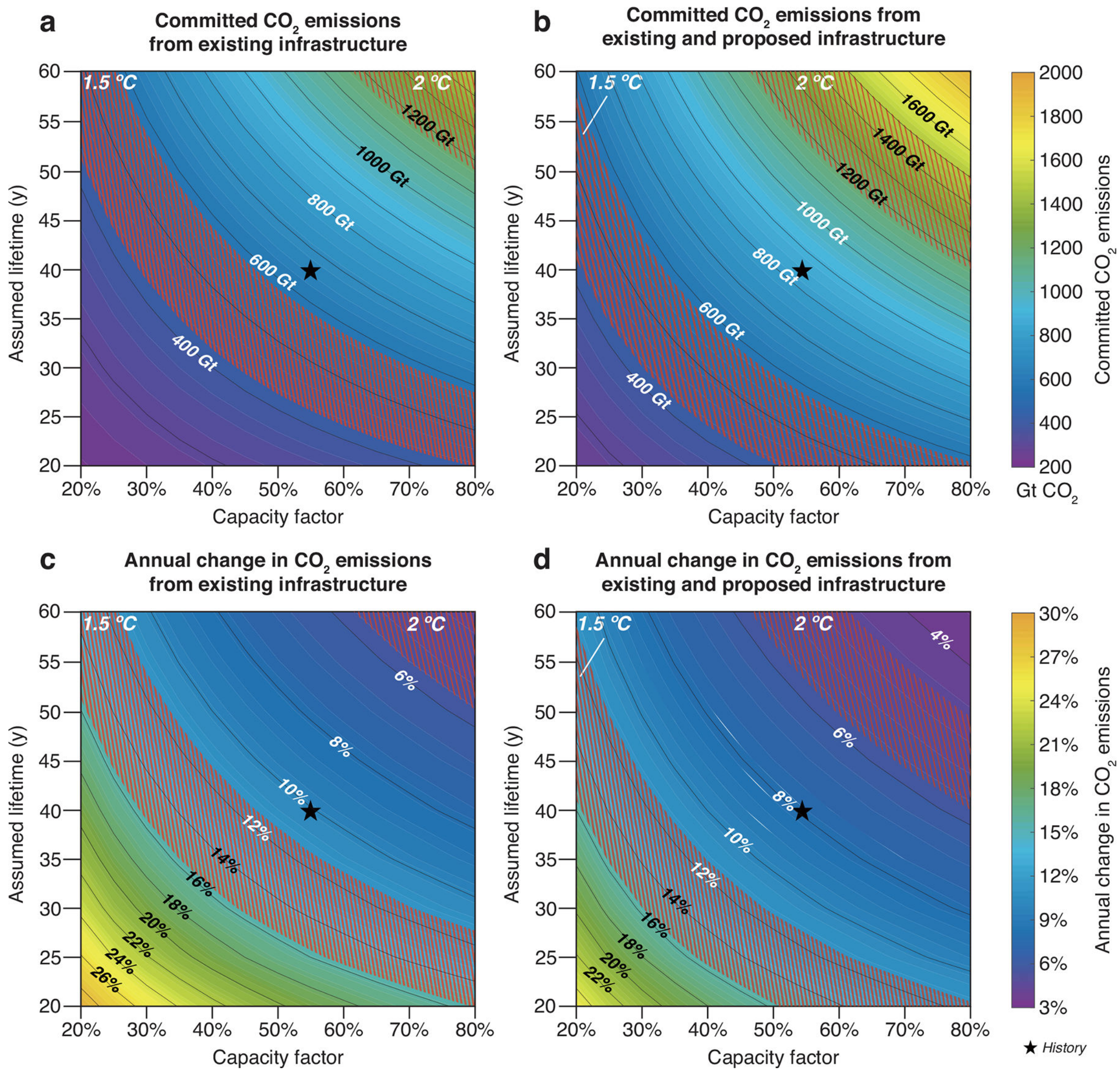

Figure 3 |. Sensitivity of committed emissions (a, b) and mitigation rates (c, d) to utilization rates and assumed lifetimes.

Contours show estimates of committed emissions related to existing infrastructure (**a**) and existing infrastructure and proposed power plants (**b**) when the assumed lifetimes and utilization rates of electricity and industry infrastructure are varied from 20–60 years 20–80%, respectively. Across the same ranges of lifetime and utilization, corresponding annual rates of emission reduction span from 3% to 30% (**c** and **d**). Hatched orange and red zones indicate carbon budgets and mitigation rates likely to limit mean warming to 1.5°C and 2°C, respectively (see Methods), and stars denote committed emissions and mitigation rates if existing/and proposed infrastructure is operated as historically.

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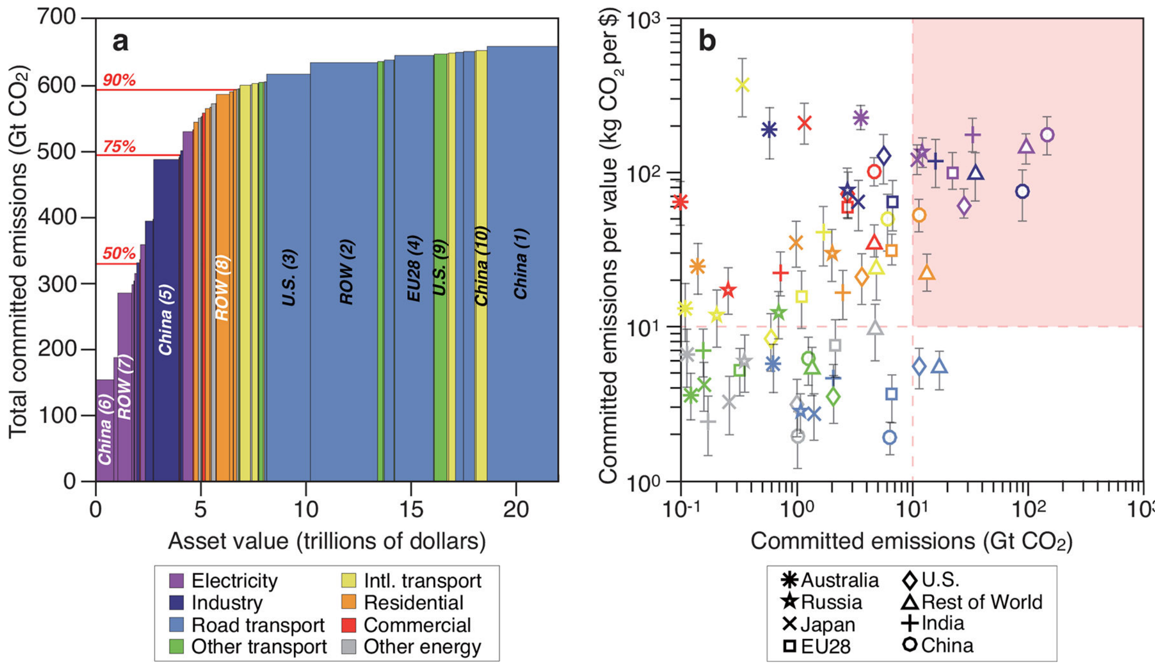

Figure 4 |. Asset value and committed emissions of existing infrastructure.

Rank ordering of CO_2-emitting assets by committed emissions per dollar value reveals large disparities (**a**; colored by sector). Horizontal red lines in **a** indicate 50%, 75% and 90% of total committed emissions (658 Gt CO_2) if operated as historically, and the top ten most valuable region-sectors are labeled (see Extended Data Fig. 4 for region-specific versions). Plotting emissions per value (kg CO_2/\$) against committed emissions suggests targeted opportunities to “unlock” future CO_2 emissions if alternative technologies are affordable (region-sectors in the pink-shaded quadrant in **b**; showing 95% confidence intervals with regions denoted by symbols).

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Extended Data Table 1 |

Comparing commitments.

Comparison of committed emissions by sector estimated in the current study and prior studies. Note that in some cases, the totals may not correspond to the sum of underlying sectors due to rounding.

		Davis et al. (2010)[8]		Davis and Socolow (2014)[9]		Edenhofer et al. (2018)[11]		Pfeiffer et al. (2018)[12]		Smith et al. (2019)[13]		This study	
		Gt CO_2	Year of dataset	Gt CO_2	Year of dataset	Gt CO_2	Year of dataset	Gt CO_2	Year of dataset	Gt CO_2	Year of dataset	Gt CO_2	Year of dataset
Existing	Electricity	224	2009	307	2012	-	-	308	2016	345 (261–451)	2009**	358 (240–493)	2018
	Coal		2009	206	2012	190	2016	220	2016	-	-	260 (175–358)	2018
	Gas, oil, and other fuels		2009	100	2012	-	-	88	2016	-	-	98 (65–135)	2018
	Industry	104	2009			-	-	-	-	154 (117–191)	2009	162 (110–219)	2017
	Transport	116	2009			-	-	-	-	92 (73–110)	2017	64 (53–75)	2017
	Residential, commercial, and other energy	53	2009			-	-	-	-	121 (91–158)	2009*	74 (52–105)	2018
	All Sectors	**496 (282–701)**				-	-	-	-	**715 (546–909)**	-	**658 (455–892)**	-
Proposed	Electricity					-	-	271	2016	-	-	188 (142–234)	2018
	Coal					150	2016	210	2016	-	-	97 (74–121)	2018
	Gas, oil, and other fuels					-	-	61	2016	-	-	91 (68–113)	2018
All Sectors + Proposed Electricity												**846 (597–1,126)**	

* The range represents the committed emissions estimated under the assumptions of 30–50 years' lifetimes for all the sectors except transportation sector (12–18 years' lifetimes).

** The age distribution of infrastructure was assumed to be the same as 2009, but annual emissions from the infrastructure was adjusted up to 2018 levels.

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To cite this article: Alexander Pfeiffer *et al* 2018 *Environ. Res. Lett.* **13** 054019

Environmental Research Letters

OPEN ACCESS

RECEIVED
31 October 2017

REVISED
23 March 2018

ACCEPTED FOR PUBLICATION
9 April 2018

PUBLISHED
4 May 2018

LETTER

Committed emissions from existing and planned power plants and asset stranding required to meet the Paris Agreement

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Keywords: life cycle assessment, stranded assets, carbon budget, committed emissions, electricity generation, climate policy

Supplementary material for this article is available online

Abstract

Over the coming decade, the power sector is expected to invest ~7.2 trillion USD in power plants and grids globally, much of it into CO_2-emitting coal and gas plants. These assets typically have long lifetimes and commit large amounts of (future) CO_2 emissions. Here, we analyze the historic development of emission commitments from power plants and compare the emissions committed by current and planned plants with remaining carbon budgets. Based on this comparison we derive the likely amount of stranded assets that would be required to meet the 1.5 °C–2 °C global warming goal. We find that even though the growth of emission commitments has slowed down in recent years, currently operating generators still commit us to emissions (~300 $GtCO_2$) above the levels compatible with the average 1.5 °C–2 °C scenario (~240 $GtCO_2$). Furthermore, the current pipeline of power plants would add almost the same amount of additional commitments (~270 $GtCO_2$). Even if the entire pipeline was cancelled, therefore, ~20% of global capacity would need to be stranded to meet the climate goals set out in the Paris Agreement. Our results can help companies and investors re-assess their investments in fossil-fuel power plants, and policymakers strengthen their policies to avoid further carbon lock-in.

1. Committed CO_2 emissions and carbon budgets in the power sector

The power sector is expected to invest about 7.2 trillion USD in power plants and transmission and distribution grids over the next decade (IEA 2016). The average expected lifetime of generators can range from 20–25 years for solar PV up to 70 years and longer for hydroelectric generators (EIA 2011, IEA 2016). Coal-, gas- and oil-powered generators have a typical lifetime of between 35–40 years (Davis and Socolow 2014). These lifetimes probably represent only economic rather than technical lifetimes, however, since many power generators operate long beyond their expected end of life. The relatively long payback periods for such assets expose investments to the risk of future changes in economic and regulatory conditions. Changes in input prices, the competitive landscape, or regulation can have large impacts on the profitability and economic viability of such assets, before they have a chance to pay their investment back (Caldecott *et al* 2017).

These long lifetimes mean that any investment made today in carbon dioxide (CO_2) emitting infrastructure will have a considerable effect on the ability to achieve required CO_2 emission reductions in the future—even if these desired reductions are many years away (Davis *et al* 2010, Rozenberg *et al* 2015). In recent years, therefore, the concept of (expected) *committed cumulative carbon emissions* (hereafter referred to as *committed emissions*) has been developed, and gained popularity within the scientific community (Guivarch and Hallegatte 2011, Davis and Socolow 2014, Pfeiffer *et al* 2016, Shearer *et al* 2017). Committed emissions are the cumulative emissions an asset would emit over its remaining lifetime under normal economic conditions, i.e. if it were to be operated at normal utilization (Davis and Socolow 2014).

To stabilize global warming at any level, not just 1.5 °C or 2 °C but virtually any level, anthropogenic emissions of long-lived climate pollutants (LLCPs) must eventually reach net-zero (Matthews and Caldeira 2008). Therefore, global warming can be seen as a function of the cumulative emissions of such LLCPs, chiefly CO_2, rather than of annual emission rates (Matthews and Caldeira 2008, Allen *et al* 2009, Matthews *et al* 2009, Meinshausen *et al* 2009). The cumulative future emissions of currently operating and planned infrastructure, are therefore likely to be much more relevant to climate outcomes than the individual annual emissions of such assets (Millar *et al* 2016). In this regard, it should be noted that power and heat generation was responsible for ~38% of total global emissions in 2014 (IEA 2016, Le Quéré *et al* 2016), more than any other sector. Committed emissions from power plants are, therefore, particularly important for climate policies.

Davis and Socolow (2014) suggest a methodology for *Commitment Accounting of CO_2 Emissions* in the power sector, and find that, under standard lifetime assumptions, in 2012, assets in the power sector were committed to ~307 $GtCO_2$ future emissions and that these commitments had been growing at ~4% per year over the previous decade. Based on their results Pfeiffer *et al* (2016) calculated that 2017 would be the year when the global *2 °C Capital Stock for Electricity Generation* was reached, i.e. when existing power generators would commit to enough CO_2 emissions, to consume the remaining generation-only carbon budget for a 50% chance for global warming below 2 °C. Other studies have since used the same or similar methodologies to calculate the CO_2 emission commitments of different assets or sectors and assess their impact on climate policies, investments and the consequent costs of achieving climate goals (Bertram *et al* 2015, Johnson *et al* 2015, Rozenberg *et al* 2015, Sanchez *et al* 2015, Shearer *et al* 2017).

This paper updates previous efforts, especially those of Davis and Socolow (2014) and Pfeiffer *et al* (2016), by using an improved generator database and updating this data to late 2016. Moreover, for the first time, we include generators currently under construction, or in different stages of the planning process, to estimate the development of future committed emissions from the global pipeline of currently planned power generators. Finally, we use a significantly improved estimate of the currently remaining generation-only carbon budgets for different climate scenarios (compared to Pfeiffer *et al* 2016), and compare this new estimate with the emission commitments. This effort allows us to derive the likely cumulative amount of power sector stranding each climate scenario would imply.

The updated capital stock and budget numbers suggest that 2017, the previous estimate for the commitment year for the 2 °C capital stock (Pfeiffer *et al* 2016), might have been too optimistic—however, not by far. The cross-comparison with recently updated carbon budget figures (Millar *et al* 2017) suggests that the commitment year for a realistic chance to limit warming to only 2 °C was probably sometime between 2011 and 2016. Consequently, we find that the committed cumulative future emissions from currently operating power plants (~300 $GtCO_2$) would now already surpass the currently available generation-only carbon budget for the average 430–480 ppm scenario (~240 $GtCO_2$). In addition, plants in various stages of the planning process would add almost the same amount of commitments (~270 $GtCO_2$) as those plants currently operational. Even if all currently planned projects are immediately suspended, up to 20% of global fossil-fuel generation capacity would still have be stranded (that is, prematurely decommissioned, underutilized, or subject to costly retrofitting) if humanity is to meet the climate goals set out in the Paris Agreement.

2. Data and methods

We calculate historic and current committed emissions from currently operating, planned and already retired power generators[5]. Since these are not typically reported in any publicly available source, we use existing databases on generator capacity vintages (in GW), combined with (historic) average annual utilization rates (in percent), heat rates (in mbtu per GWh), fuel emission factors (in tCO_2/mbtu), and expected operational lifetimes. In the rest of this section we describe the databases and sources used (2.1), and how we calculate the committed emissions and how this differs from previously used methodologies (2.2).

2.1. Databases and sources

We determine generation capacities by merging all generators from the most recent versions of five databases: (1) CoalSwarm (Feb 2017); (2) Platt's UDI World Electric Power Plants (WEPP) database (Q4 2016); (3) Greenpeace's database of planned coal generators in China; (4) Sekitan's Japan coal-fired power plant database (Q1 2016); and (5) Kiko Network's Japan coal-fired power plant database (Q1 2016). We merge these sources by manually confirming unique power plant names, locations, current statuses, online years and capacity, using internet research as required[6]. The most recent data is used where matched generators

[5] We differentiate between generator and plant. The generator is the device that generates the electrical power for use in an external circuit. A plant can consist of several generators. We calculate committed emissions on a generator level since generators within plants are often replaced, such that the remaining lifetime of a plant is less helpful than the remaining lifetime of a generator.

[6] Most generators could be matched using an algorithm. Only generators that did not match were manually confirmed.

have conflicting fields (for example different operating statuses). The resulting database effectively defines the locations of all the world's power generators, their ownership, age, fuel type, technology, expected lifetime and capacity. It is particularly current and comprehensive for coal-fired power generators, the most carbon-intensive assets[7].

We use three additional sources to calculate committed emissions: (1) current and historic heat rates from the US Energy Information Agency (EIA) and the US Environmental Protection Agency (EPA) (EPA 2009, EIA 2017)[8]; (2) emission factors for individual fuels from the EIA (EIA 2016)[9]; and (3) global technology specific utilization rates for power generators from the International Energy Agency, IEA's World Energy Outlooks (WEO) 2005–15.

2.2. Approach and methods

Davis and Socolow's (2014) *Commitment Accounting of CO_2 Emissions* marks the first time a comprehensive methodology has been described to calculate future emissions from existing power generators. One criticism of their approach, however, applies to CARMA[10], one of the databases they use. They make the '*arbitrary assumption that CARMA's emissions and energy data for 2009 (or, occasionally, 2004) are an accurate estimate throughout a plant's lifetime*' (Davis and Socolow 2014). 2009 was in many respects not a representative year for global energy consumption and emissions—in fact, with the financial and economic crisis at its height, 2009 was one of the few years in recent decades in which global emissions decreased year-on-year (Le Quéré *et al* 2016). In this paper, we therefore refine the approach described by Davis and Socolow.

First, a broader and updated (late 2016) base of power generators is used that completes known gaps in the Platt's UDI WEPP database, e.g. in microgeneration and in China (see section 2.1). Second, for missing online years[11] a similar, but more granular, methodology was used as the one described by Davis and Socolow. Most importantly, the estimation of online years and lifetimes is conducted based not only on technology, capacity and country, but also by taking account of generator and turbine type, online year (for lifetimes), and steam-type (e.g. subcritical vs. supercritical).

Third, actual lifetimes were simulated by using a Poisson distribution around the expected lifetimes of the power generators. This simulates managerial discretion as to when power generators are retired, and accommodates the fact that generators are rarely retired in the exact year of their estimated end of life. As expected lifetimes we use the median end-of-life age of already retired generators with the same fuel and technology, and similar nameplate capacity. Expected lifetime represents the economic rather than the technical lifetime (taking the maximum lifetime of similar already retired generators would come closer to the technical lifetime).

Fourth, instead of applying the CARMA database for the annual emissions of these generators, a different approach was applied. Generator-specific technical data was combined with (year-specific) heat rates and fuel emission factors from the EIA and EPA to calculate annual maximum emissions per generator. When multiplied by the simulated lifetime of each generator, and the historic (average) utilization rates, from the IEA, this results in an estimate of actual historic, current and expected electricity generation and emissions. By using historic average utilization rates over many years (ten years between 2004–2014) instead of a point estimate (CARMA uses 2009 utilization rates), a more realistic estimate of future utilization can be achieved. A detailed description and discussion of this methodology and in particular the use of historic average utilization rates can be found in appendix A.1 available at stacks.iop.org/ERL/13/054019/mmedia.

The described approach results in an emission commitment estimate of ~300 $GtCO_2$ in 2016. This estimate is ~14% lower than an extrapolation of Davis and Socolow's results suggests, and implies that currently operating capital stock commits to significantly less future emissions than expected only four years ago. While the methodological differences explain some of the variance, the real-world explanation for this is that, in recent years, since Davis and Socolow's paper, the growth rate of committed emissions was much lower than expected. Between 2012 and 2016 emission commitments grew only by 2.1% p.a. globally instead of the 4% p.a. as expected based on Davis and Socolow's results. In some regions, emission commitments even decreased significantly in this period (see section 3.1). These results are particularly sensitive towards generator lifetimes and utilization rates. We discuss these sensitivities in section 3.4.

3. Findings

We find that currently operating generators would already commit to more future CO_2 emissions (~300 $GtCO_2$) than would be consistent with the remaining generation-only carbon budget in the median 430–580 ppm scenarios. For a good chance for warming below 2 °C (430–480 ppm scenarios) ~20%

[7] See appendix A.2 for additional limitations of the final database used.

[8] The EIA and EPA provide data on current and historic heat rates for different generators, turbine types, and fuels. Historic EIA data on technology level goes back to 2001 and aggregated data for all fossil fuels back to 1949.

[9] Datasets obtained from the EIA contain emission factors for different fuels, i.e. the amount of CO_2 in relation to the energy content of e.g. coal, lignite, oil, etc.

[10] CARMA: Carbon Monitoring for Action (CARMA 2010).

[11] The online year refers to the year in which the generator started operations.

Table 1. Installed capacity and remaining committed emissions of electricity generators operating in 2016.

	Capacity [GW]	Remaining cum. generation [TWh]	Remaining cum. emissions[12] [$GtCO_2$]
COAL	2136	263 959	220.1
GAS	1385	92 534	65.9
OIL	428	11 245	7.6
WASTE	296	12 697	11.2
BIOENERGY	57	5475	2.9
RENEWABLES[a]	1522	134 256	—
OTHER[b]	384	17 106	0.1
Total	**6207**	**537 272**	**307.7**

[a] Renewables include hydro, solar and wind, and do not result in committed emissions.

[b] Other includes nuclear and geothermal; the non-zero committed emissions associated with these generators stems from a small amount of fugitive emissions from geothermal power generation.

of currently operating capital stock would have to be stranded. Instead, the pipeline of currently planned generators would add another ~270 $GtCO_2$ to the capital stock.

3.1. Committed emissions of generators operating in late 2016

In late 2016, a global total of ~161 000 generators in our database were labelled as *operating*, *idle*, *stand-by*, or with a similar status indicating that a power generator was still in operation (table 1). This comprises ~6200 GW of installed capacity, which has, on average, operated since 1997, and which had a remaining lifetime of 18 years in 2016 (see appendix C.1 for a full table with descriptive statistics).

Overall, this capacity, if operated over its full remaining lifetime at current utilization rates, could generate ~537 k TWh (~23 years of generation at current levels)[13] and would emit ~300 $GtCO_2$ over the coming decades (i.e. ~7 years-worth of current total global CO_2 emissions)[14]. These committed emissions are largely locked-in by coal generators (~71%) and located in Asian countries (~64%)[15].

Figure 1 shows the development of committed emissions over time by technologies (panel *a*) and regions (panel *b*). After the present day, we show decreasing commitments as they 'realize' into actual emissions. Committed emissions from coal decreased by 1.4% between 2000 and 2003, presumably because coal capacity was replaced by gas, which grew by ~26.8% in the same period. Most of the growth in committed emissions after 2005, however, comes from coal-fired generators which accounted for 59% of total committed emissions in 2005 and account for 71% today. In recent years, Asia[16] has seen an especially strong increase in commitments. In 2000, committed emissions in Asia accounted for approximately one quarter of the global total but this share had increased to almost two thirds in 2016. Especially after 2004, most of the overall growth in emission commitments has come from the addition of fossil-fuel-powered generators in Asia.

Figure 2 provides more details on annual growth rates of committed emissions. Countries of the former Soviet Union and OECD countries (since 2004) have seen a decrease in overall commitments from power generators, indicated by negative annual growth rates (panel *c*). This development indicates that annual retirements or realizations of committed emissions are larger than additions to the capital stock. Panel *a* confirms the previous finding that the growth rates of gas capital stock between 2000 and 2003 crowded out coal infrastructure (negative growth rates) but were subsequently replaced by coal again. The overall annual growth of coal capital stock remains strong in 2016 (~2.1% p.a.) while all other CO_2 emitting capital stock has decreased over the last couple of years.

We find that, on average, emission commitments from electricity generators grew by 3.2% per year between 2000 and 2016, and that most of that overall growth came from coal generators (3.9% p.a.) and happened in Asia (9.1% p.a.). The only technologies with stronger or similar committed emissions growth rates to coal were bioenergy (4.3% p.a.) and waste (3.6% p.a.). Growth in these technologies took place from a much lower base, however, and was hence negligible for overall committed emissions growth. Besides Asia, countries in Latin America (3.1% p.a.) the Middle East and Africa (2.9% p.a.) experienced committed emissions growth in the analyzed period, while OECD countries (−2.1% p.a.), and countries of the former Soviet Union (REF) (−3.5% p.a.), decreased their remaining committed emissions from electricity capital stock.

3.2. The pipeline of planned electricity generators in early 2017

In addition to the previously described operating generators, in early-2017 ~24 000 further generators

[12] Cumulative CO_2 emissions that can be expected from the future operation of these generators over an expected economic lifetime under standard economic conditions.

[13] According to the IEA the 2014 global electricity generation was 23 808 TWh.

[14] According to the Global Carbon Budget Project, total CO_2 emissions (Fossil Fuel and Industries and Land-use) in 2015 were 41 $GtCO_2$ (Le Quéré *et al* 2016).

[15] See appendix C.2 for the full regional split.

[16] Our definition of Asia includes all non-OECD Asian countries (i.e. most Asian countries except the Middle East, Japan and countries of the former Soviet Union.

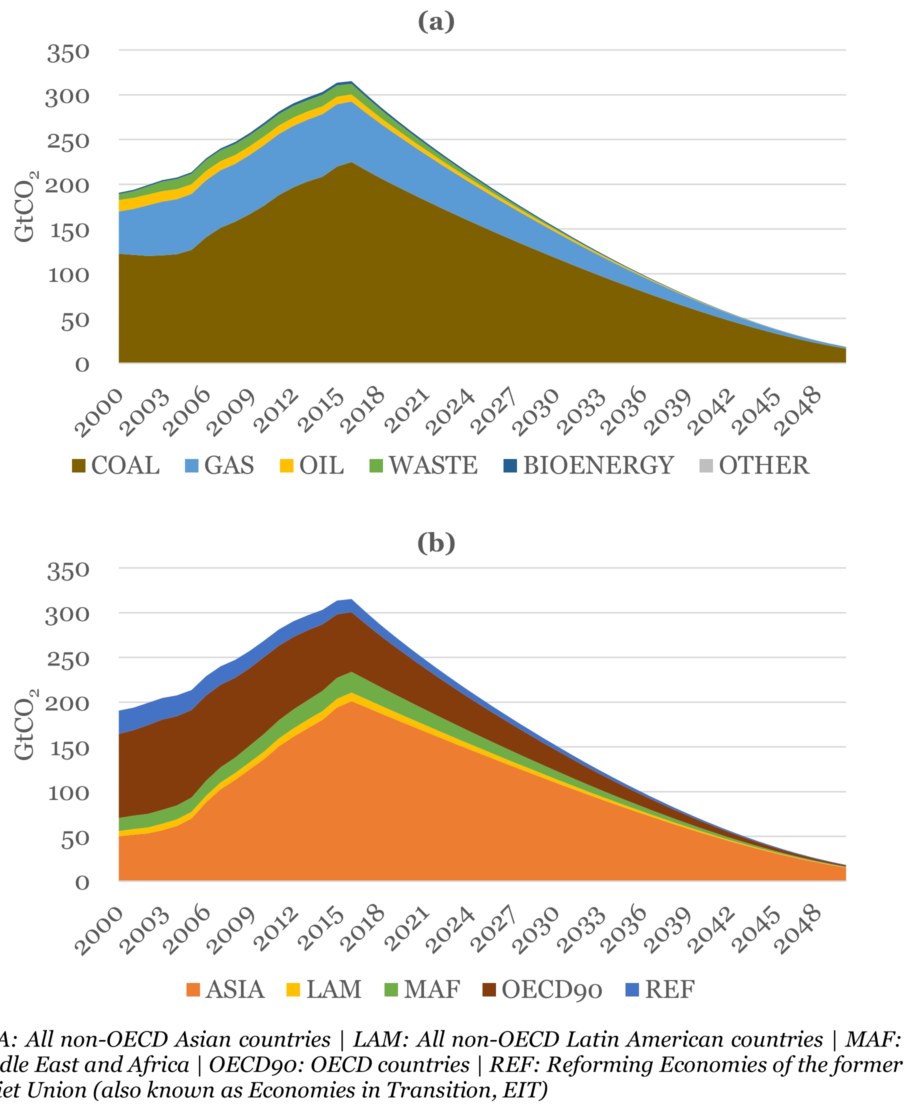


Figure 1. Historic development of committed emissions from electricity generators in operation in 2016, by technologies (panel *a*) and regions (panel *b*). The strongest growth between 2005 and 2016 took place in Asia and comes from coal emission commitments. After 2016, emission commitments would decrease as indicated if no further investments in polluting capital stock take place.

were either under construction (845 GW in ~5200 generators) or in some stage of the planning process (2597 GW in ~18 900 generators). Overall, this pipeline of generators would add ~3440 GW to the global capital stock and add ~270 $GtCO_2$ to the committed future carbon emissions.

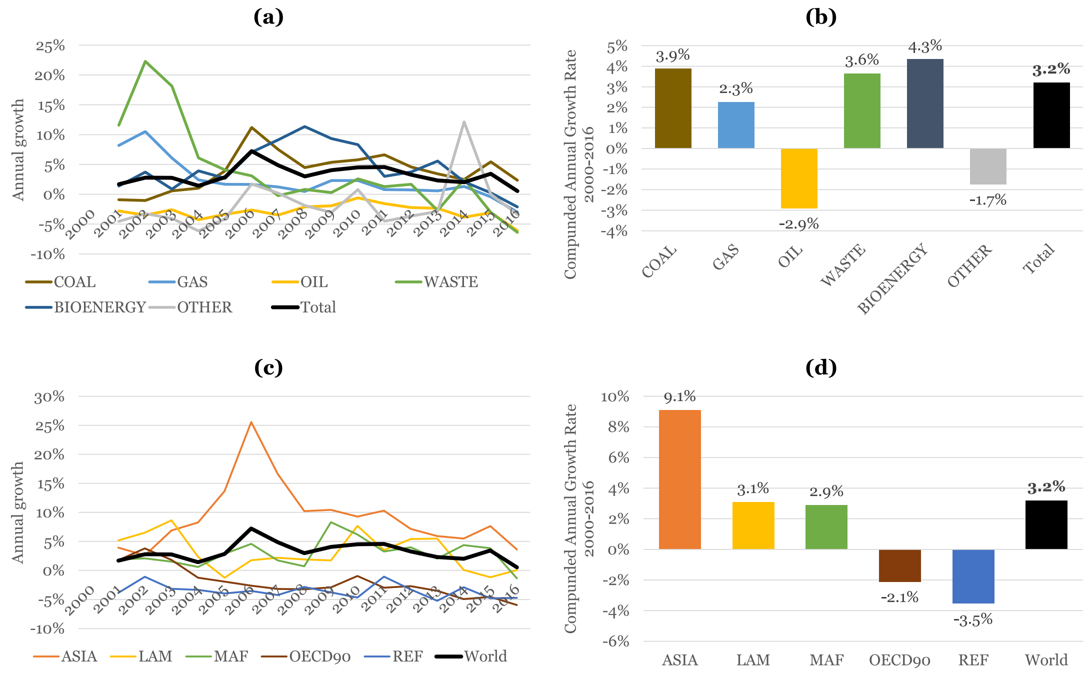
In table 2 we split this pipeline of committed emissions by technologies and regions. Consistent with the development in recent years already illustrated above, by far the largest share of planned committed emissions is occupied by coal (~78%) and is planned in Asia (~65%). Just by finalizing all planned coal-fired generators, the world would add an additional five years of total global CO_2 emissions at current levels. Gas-fired generators follow with 18% and are expected to add ~50 $GtCO_2$ to the global capital stock (~1.2 years of current total emissions).

If all current plans and construction projects for carbon emitting power generators were to be stopped, however, the remaining committed emissions in 2050 would amount to ~20 $GtCO_2$. If, however, all planned generators were to be built and come online, then remaining commitments in 2050 would be 4–5 times higher (~90 $GtCO_2$). Figure 3 (panel *a*) illustrates this. Panel *d* shows the regional split of the current pipeline. In Asia, almost as much polluting capital stock is planned (119 $GtCO_2$) or already under construction (57 $GtCO_2$) as is currently operating (198 $GtCO_2$)[17].

These findings consider all generators that were either planned or under construction in early 2017. This should include most changes, especially cancellations in the global coal pipeline, that were made before February 2017[18]. In 2016 and early 2017, many previously planned coal-fired generators were cancelled

[17] See appendix B.1 for split by technologies.

[18] See appendix A.2 for limitations with respect of the global generator pipeline.



ASIA: All non-OECD Asian countries | LAM: All non-OECD Latin American countries | MAF: Middle East and Africa | OECD90: OECD countries | REF: Reforming Economies of the former Soviet Union (also known as Economies in Transition, EIT)

Figure 2. Historic annual growth rates and compounded annual growth rates (CAGR) between 2000 and 2016 of emission commitments from electricity generators in operation in 2016, by technologies (panels *a* and *b*) and regions (panels *c* and *d*). Countries in the OECD and REF have seen a reduction of their commitments over the past 16 years. On the technology side, oil, in particular, has seen less additions than realizations (or retirements) of commitments (negative growth rates).

Table 2. Cumulative emissions of electricity generators under construction or planned in early 2017, by technologies and regions.

[$GtCO_2$]	Asia	Latin America	Middle East and Africa	OECD 90 countries	Reforming economies (former USSR)	Global
Coal	162.4	2.6	13.1	23.1	8.8	210.0
Gas	11.3	3.1	12.3	18.0	3.8	48.7
Oil	0.4	0.3	1.6	0.2	0.0	2.5
Waste	1.1	0.7	2.4	3.2	0.5	7.8
Bioenergy	0.4	0.2	0.1	0.9	0.1	1.6
Renewables[a]	—	—	—	—	—	—
Other[b]	0.1	0.0	0.0	0.1	0.0	0.2
Total	**175.6**	**6.9**	**29.5**	**45.5**	**13.2**	**270.8**

[a] Renewables include hydro, solar and wind, and do not result in committed emissions.

[b] Other includes nuclear and geothermal; the non-zero committed emissions associated with these generators stems from a small amount of fugitive emissions from geothermal power generation.

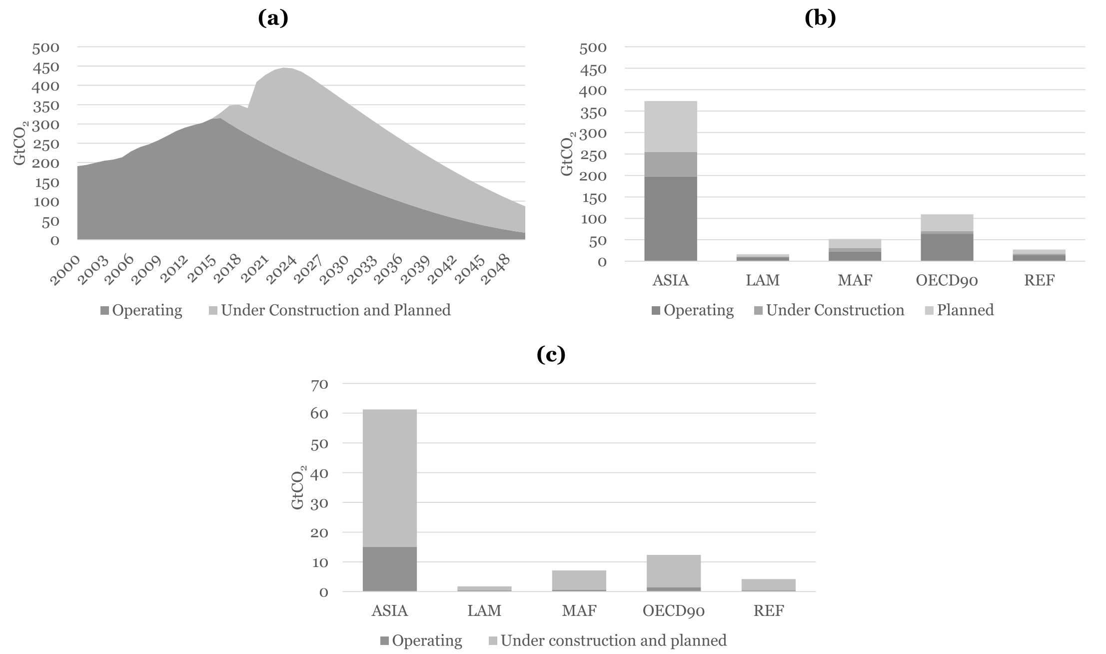
(Shearer *et al* 2017). Most prominently, in January 2017, China announced the cancellation of 103 planned coal power plants with a combined capacity of 130 GW (Forsythe 2017). Based on our analysis, this capacity alone would have added an additional ~23 $GtCO_2$ to the capital stock (~9% of planned committed emissions). Despite these recent cancellations, however, our analysis suggests that currently planned power generators would add a very significant amount of emission commitments to the already existing global capital stock. Much of this would still be left in 2050 when most economies around the world will already have to be widely decarbonized if the world were to reach its 1.5 °C–2 °C target (panel *c*).

3.3. Compatibility of the capital stock with remaining carbon budgets

To improve on the previous estimates of the currently remaining generation-only carbon budget we use all scenarios, assessed by the *Intergovernmental Panel on Climate Change* (IPCC) for its *Fifth Assessment Report* (AR5) (IPCC 2013, IIASA 2014b) combined with the results from a further climate modelling effort from a recent cross-comparison IAM[19] study: AMPERE[20] (IIASA 2014a, Kriegler *et al* 2015). The analysis of the scenario outputs from these two

[19] IAM: Integrated Assessment Model.

[20] AMPERE: Assessment of Climate Change Mitigation Pathways and Evaluation of the Robustness of Mitigation Cost Estimates.



ASIA: All non-OECD Asian countries | LAM: All non-OECD Latin American countries | MAF: Middle East and Africa | OECD90: OECD countries | REF: Reforming Economies of the former Soviet Union (also known as Economies in Transition, EIT)

Figure 3. Historic (until 2016) and expected (thereafter) development of committed emissions from electricity generators in operation, under construction, or planned in 2016, by status (panel *a*), 2016 committed emissions by regions (panel *b*), and remaining emission commitments in 2050 if all generators that are either planned or already under construction in 2016 will actually be completed and go online (panel *c*). The dent between 2018 and 2020 in panel (*a*) stems from the methodology that has been used to assign online year to generators that are delayed (after construction start) or deferred (before construction start) in 2016.

databases suggests that the median remaining carbon budget available in 2005 for a good chance for 1.5 °C–2 °C warming (430–480 ppm scenarios), was 1333 $GtCO_2$. According to the same scenarios ~14% of that budget in 2005 was earmarked for electricity generation, leaving a net generation-only carbon budget in 2005 of ~187 $GtCO_2$. In addition to this net budget, the median 2005–2100 cumulative electricity generation from bioenergy with carbon capture and storage (BECCS) in these scenarios was ~1330 EJ (~370 000 TWh). This amount of BECCS generation would remove ~110 $GtCO_2$ from the atmosphere by the end of the 21st century[21], thereby increasing the carbon budget for electricity production.

Using the same calculation method for 480–530 ppm and 530–580 ppm scenarios, respectively, and updating these numbers over time with realized annual emissions (Le Quéré *et al* 2016), results in the annual remaining generation-only carbon budgets illustrated in figure 4. For better comparison, we also include carbon budget estimates from a recently published study which finds that the remaining post-2015 carbon budgets for a 50% chance for 1.5 °C or 2 °C warming were 817 $GtCO_2$ and 1524 $GtCO_2$, respectively (Millar *et al* 2017)[22].

We compare these remaining generation-only carbon budgets over time with the development of commitments from operating generators and find that the year in which built infrastructure committed us to enough emissions to reach the 1.5 °C–2 °C budget was in 2011, and hence six years earlier than previously estimated (Pfeiffer *et al* 2016). In 2014, emission commitments exceeded the remaining carbon budget for 480–530 and 530–580 ppm scenarios.

The above suggests that, if the climate goals set out in the Paris Agreement (UNFCCC 2015) are to be reached, some of the existing and planned power plants will need to be underutilized, retired early, or retrofitted with expensive CCS or efficiency upgrades, or—in short—stranded. Figure 5 illustrates, for different climate goals, all combinations of stranding (in percent of normal utilization) between *old* (currently operating) and *new* (planned or under construction) power generators.

We find that, in different combinations, only 42% (430–480 ppm) to 49% (530–580 ppm) of the total capital stock of both operating and planned generators can be utilized. Even if every single currently planned project was cancelled, the generators that are already operating now would still have to see reduced utilization resulting in~20% of capacity becoming

[21] 83 $MtCO_2$/EJ (Kriegler *et al* 2013).

[22] To calculate generation-only carbon budgets we also multiply these total carbon budgets with 14% and add 110 $GtCO_2$ BECCS carbon removal.

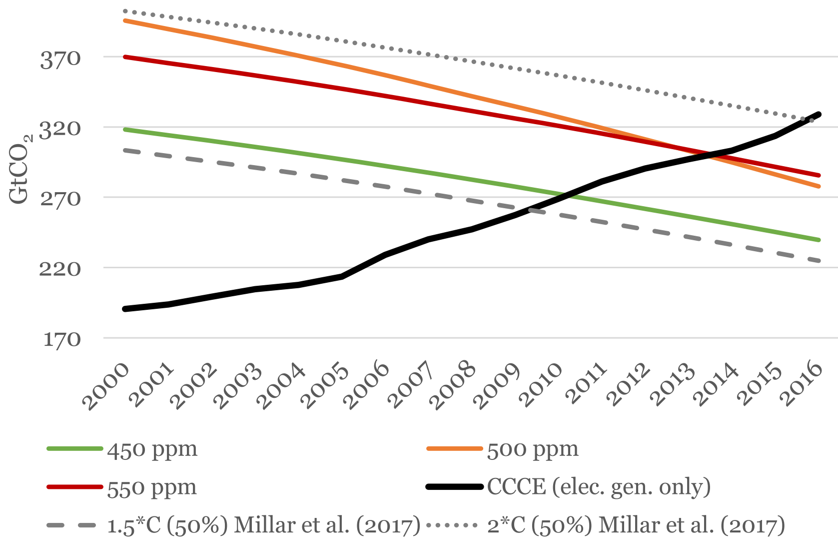


Figure 4. Development of remaining generation-only carbon budget in different climate scenarios (median) and committed emissions from generation capacity. In 2011, committed emissions from electricity generators reached the remaining total generation-only budget for the median 430–480 ppm scenario (good chance for only 1.5 °C–2 °C warming). In 2014, the remaining budget for the 480–530 and 530–580 ppm scenarios was reached. Following Millar *et al* (2017), the generation-only budget for a 50% chance for warming of less than 2 °C was reached in 2016.

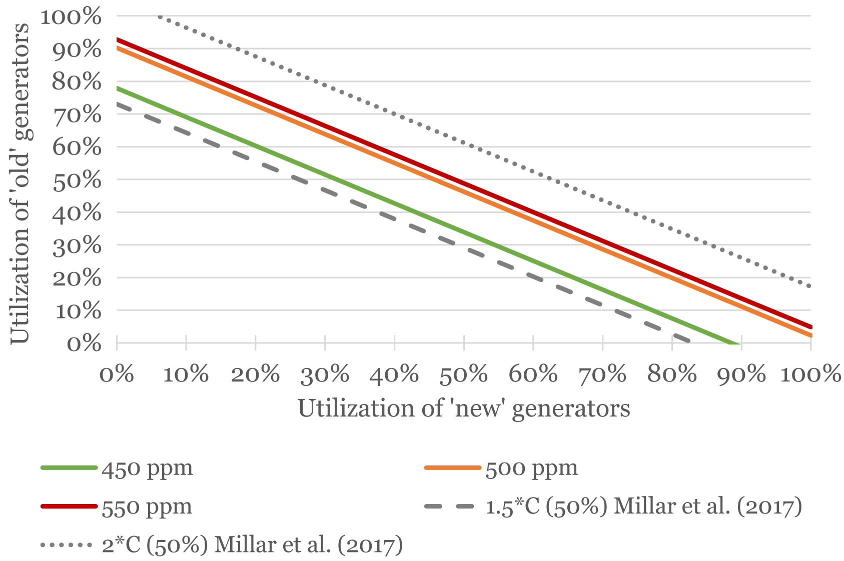


Figure 5. Different combinations of maximum possible utilizations of currently operating and pipeline electricity generators under different carbon budgets. Even if plans for all new generators were to be cancelled, and current constructions halted (i.e. 0% utilization of new generators), already operating power generators could still only be utilized with ~80% (430–480 ppm) to ~90% (530–580 ppm) of their normal utilization to meet the respective climate goals.

stranded (~80% of normal utilization) to meet the 430–480 ppm climate target.

Taking the remaining total global carbon budget as exogenous, the two most important factors in this analysis are the share of this budget that can be allocated to power generation (~14%) and the additional generation-only budget that is added by BECCS generation. Changing these numbers would change the results of this analysis considerably. Should the share of generation-only budget be one percentage point smaller (~13%) or bigger (~15%) the stranding estimates for the 430–480 ppm scenario would change by 1.6 percentage points. In a scenario in which power generation would have only 13% of remaining total carbon budget left (under unchanged future BECCS generation) the 1.5 °C–2 °C compatible average utilization for currently operating and under construction or planned generators would drop from ~42% to ~39%. Should generation-only budget be 15% of total instead of 14% possible utilization would increase to ~44%. The total amount of GHG captured by BECCS is also important. If BECCs turns out to be entirely unable to remove carbon from the atmosphere, the utilization rate of power generators compatible with 1.5 °C–2 °C would drop from 42%–22%.

3.4. Sensitivity of findings

Our findings regarding the committed emissions of currently operating and under construction or planned power generators are particularly sensitive towards simulated lifetimes and target utilization rates.

Realised lifetimes of power generators depend on a variety of factors that affect the economic viability of the generator, such as electricity, fuel, and carbon prices, regulation, and technological change (see appendix A.1). At the same time, the future lifetime for a currently operating (or planned) generator has a considerable effect on its remaining emission commitments. Based on a 42 year lifetime for coal generators, every additional year of lifetime would increase the original emission commitments of currently planned coal generators (210 $GtCO_2$ commitments) by 5 $GtCO_2$ (+2.4%). For currently operating coal generators (220 $GtCO_2$ commitments remaining in 2016), each additional year of lifetime increases committed emissions by 10 $GtCO_2$ (+4.6%)[23]. For gas-fired generators currently operating (emission commitments of 66 $GtCO_2$ in 2016) every additional year increases emission commitments by 3.3 $GtCO_2$ (+5%)[24]. For new gas generators each year would increase the emission commitments from 49 $GtCO_2$ to 50 $GtCO_2$ (+2%).

Utilization rates, as well, have a significant impact on our results. For instance for coal we apply a global average utilization rate of 61%. Reducing (or increasing) this utilization rate by one percentage point would result in a reduction (or increase) of committed emissions by 4 $GtCO_2$ (1.6%). For gas the applied utilization rate is 39% and every percentage point change hence a 2.6% increase or decrease in committed emissions. For a further discussion of utilization rates please see appendix A.1.

4. Discussion of findings

We analyze the expected (business as usual) cumulative carbon emissions from currently operating and planned power generators around the world and find that this capital stock would likely emit more CO_2 than compatible with the median scenarios that would meet current climate goals. Moreover, we estimate that commitments reached the remaining carbon budget for 1.5 °C–2 °C warming in 2011; with the carbon budget for 2 °C–3 °C warming being breached in 2014. Despite making similarly conservative assumptions with regards to decarbonization in other sectors, this finding updates an earlier estimate in which we identified 2017 as the year in which operating capital stock would commit us to 2 °C (Pfeiffer *et al* 2016). The changes compared to the previous finding come from updated, and more accurate, carbon budget figures as well as an update of the previously used power generator database. Supplemental databases add power generators (especially in China) and close known gaps, thereby improving the representation of the global generation capital stock.

The updated findings suggest that much of the global electricity generation capital stock would need to become stranded if the world were to meet its climate goals. This result postulates that power generation is assigned the same share of the overall carbon budget as in the median pathway and that future BECCS generation can add the expected atmospheric space. Under these conditions, some stranding would occur (~10 to 20% of operating capacity) even if all current plans and construction projects for additional power generators would be suspended. This stranding would likely have the strongest impact on the coal sector in Asia, where 64% of current and 65% of planned committed emissions are located, most of it in coal-fired generators.

Committed emissions depend on future lifetimes and utilization rates of existing and newly build power plants. Shorter realised lifetimes or lower utilization rates would reduce remaining emission commitments of operating and planned generators considerably. Indeed, developments in recent years point towards decreasing utilization rates, at least for coal-fired power generators. In the context of this analysis, lower utilization rates would constitute stranding.

The stranding of power generation assets can have several causes and materializes in different ways (Caldecott *et al* 2016b). Among the most important causes for stranding in power generation are changing regulations (e.g. emission standards), higher input costs (e.g. rising prices for coal, gas and CO_2 permits), and changing market conditions (e.g. falling wholesale prices). Regulatory and technological efforts to keep within carbon budgets compatible with the Paris Agreement will result in significant stranding of both operational and planned fossil fuel power generation. The extent to which this affects existing assets, or those currently in planning, is largely a market and policy question. Regardless of where the stranding occurs, however, it will generate significant social and political economy impacts. Power plant owners, operators, connected communities and investors will be affected, but so too will producers of coal and gas upstream. These different groups, whether directly or indirectly, might have the political power to block policy reforms (Caldecott *et al* 2016a, Vogt-Schilb and Hallegatte 2017).

[23] Current global average age of coal generators is 20 years with remaining lifetime of 22 years.

[24] Current global average age of gas generators is 18 years with remaining lifetime of 20 years.

Options to avoid stranding if carbon budgets are inflexible are limited: the carbon budget 'allocated' to the power sector could in principle be expanded, but the power sector appears to be the one that is technically easiest to decarbonize (Clarke and Jiang 2014, Audoly *et al* 2017). Another radical solution around the issue of stranding coal power plants could be to relax climate goals (Guivarch and Hallegatte 2013), but that would be at odds with the Paris Agreement and result in elevated climate risk for the most vulnerable countries (Stern 2007, IPCC 2014).

Our findings may help investors and companies to consider stranding risks and materialization scenarios in their capital allocation decisions. In recent years, the interest within the financial community for such evaluation frameworks and scenario assessments has increased (CTI 2013, Caldecott *et al* 2015, Carney 2015). Some recent developments in the global power generation sector, such as the cancellation of ~130 GW of planned coal-fired generators in China, might have been motivated in part by the realization that said capacity could be at risk of becoming stranded if renewables continue to grow at high rates. The substantial pipeline of fossil-fuel powered generators, however, suggests that these risks are still not sufficiently considered (or considered sufficient). Furthermore, the trade-off between the stranding of currently operating and yet to be built generators imposes challenges for investors with broader generation portfolios. Under the constraint of a carbon budget, the optimization of such portfolios might include the stranding of *old* in favour of *new*, more efficient, generators, extended lifetimes for *old* instead of building *new* generators, the retrofit of some generators with efficiency enhancing or CCS technology, and the shifting of future capacity additions towards low-carbon technologies (such as renewables and, maybe, gas).

Our findings may also help policymakers improve the set of economic incentives for different types of generation infrastructure. Any further additions to the polluting generation capital stock increase the cost that will need to be paid to achieve the agreed climate goals in the. Efficient and effective policies would incentivize investors to optimize their portfolios to meet carbon budgets, and shift current and future investments towards low-carbon technologies. In the meantime, regulation, such as emission standards, coal moratoriums, and emission levies could help to avoid any further carbon lock-in in the electricity sector and to un-commit some of the budget by decommissioning old and, particularly, dirty generators. Longer lifetimes, and maybe even subsidies for existing and relatively clean generators, on the other hand, could also help reduce the need for additional dirty infrastructure.

5. Conclusion

Current carbon emission commitments exceed the remaining carbon budget for the electricity generation sector if the world is to meet its climate goals. Nonetheless, the sector will see large amounts of carbon emitting infrastructure being added to its capital stock over the next few years. Investors should re-assess their investment decisions in dirty infrastructure, and policy makers should design their policies to avoid any further carbon lock-in that will prove costly in the future when emissions must decrease to meet climate targets. While long-term policies are not yet in place, some short-term measures, such as emission standards, coal levies and moratoriums, and even lifetime extensions for relatively clean fossil-fuel powered generators could help to avoid further dirty investments.

Acknowledgments

We thank our colleagues and collaborators at the Institute for New Economic Thinking (INET) at the Oxford Martin School (OMS), the Sustainable Finance Programme (SFP) at the Smith School for Enterprise and the Environment (SSEE), and especially participants of the INET's weekly researcher seminar series for their useful comments and feedback. The views expressed in this paper are the sole responsibility of the authors. They do not necessarily reflect the views of the Inter-American Development Bank or the countries it represents.

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APRIL 22, 2021

FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies

Building on Past U.S. Leadership, including Efforts by States, Cities, Tribes, and Territories, the New Target Aims at 50-52 Percent Reduction in U.S. Greenhouse Gas Pollution from 2005 Levels in 2030

Today, President Biden will announce a new target for the United States to achieve a 50-52 percent reduction from 2005 levels in economy-wide net greenhouse gas pollution in 2030 – building on progress to-date and by positioning American workers and industry to tackle the climate crisis.

The announcement – made during the Leaders Summit on Climate that President Biden is holding to challenge the world on increased ambition in combatting climate change – is part of the President's focus on building back better in a way that will create millions of good-paying, union jobs, ensure economic competitiveness, advance environmental justice, and improve the health and security of communities across America.

On Day One, President Biden fulfilled his promise to rejoin the Paris Agreement and set a course for the United States to tackle the climate crisis at home and abroad, reaching net zero emissions economy-wide by no later than 2050. As part of re-entering the Paris Agreement, he also launched a whole-of-government process, organized through his National Climate Task Force, to establish this new 2030 emissions target – known as the "nationally determined contribution" or "NDC," a formal submission to the United Nations Framework Convention on Climate Change (UNFCCC). Today's announcement is the product of this government-wide assessment of how to make the most of the opportunity combatting climate change presents.

PUSHING PROGRESS, CREATING JOBS, AND ACHIEVING JUSTICE

The United States is not waiting, the costs of delay are too great, and our nation is resolved to act now. Climate change poses an existential threat, but responding to this threat offers an opportunity to support good-paying, union jobs, strengthen America's working communities, protect public health, and advance environmental justice. Creating jobs and tackling climate change go hand in hand – empowering the U.S. to build more resilient infrastructure, expand access to clean air and drinking water, spur American technological innovations, and create good-paying, union jobs along the way.

To develop the goal, the Administration analyzed how every sector of the economy can spur innovation, unleash new opportunities, drive competitiveness, and cut pollution. The target builds on leadership from mayors, county executives, governors, tribal leaders, businesses, faith groups, cultural institutions, health care organizations, investors, and communities who have worked together tirelessly to ensure sustained progress in reducing pollution in the United States.

Building on and benefiting from that foundation, America's 2030 target picks up the pace of emissions reductions in the United States, compared to historical levels, while supporting President Biden's existing goals to create a carbon pollution-free power sector by 2035 and net zero emissions economy by no later than 2050. There are multiple paths to reach these goals, and the U.S. federal, state, local, and tribal governments have many tools available to work with civil society and the private sector to mobilize investment to meet these goals while supporting a strong economy.

SUPPORTING AMERICAN WORKERS

This target prioritizes American workers. Meeting the 2030 emissions target will create millions of good-paying, middle class, union jobs – line workers who will lay thousands of miles of transmission lines for a clean, modern, resilient grid; workers capping abandoned wells and reclaiming mines and stopping methane leaks; autoworkers building modern, efficient, electric vehicles and the charging infrastructure to support them; engineers and construction workers expanding carbon capture and green hydrogen to forge cleaner steel and cement; and farmers using cutting-edge tools to make American soil the next frontier of carbon innovation.

The health of our communities, well-being of our workers, and competitiveness of our economy requires this quick and bold action to reduce greenhouse gas emissions. We must:

- **Invest in infrastructure and innovation.** America must lead the critical industries that produce and deploy the clean technologies that we can harness today – and the ones that we will improve and invent tomorrow.
- **Fuel an economic recovery that creates jobs.** We have the opportunity to fuel an equitable recovery, expand supply chains and bolster manufacturing, create millions of good-paying, union jobs, and build a more sustainable, resilient future.
- **Breathe clean air and drink clean water and advance environmental justice.** We can improve the health and well-being of our families and communities – especially those places too often left out and left behind.
- **Make it in America.** We can bolster our domestic supply chains and position the U.S. to ship American-made, clean energy products — like EV batteries – around the world.

MEETING THE MOMENT

The target is consistent with the President's goal of achieving net-zero greenhouse gas emissions by no later than 2050 and of limiting global warming to 1.5 degrees Celsius, as the science demands. To develop the target, the Administration:

- **Used a whole-of-government approach:** The NDC was developed by the National Climate Task Force using a whole-of-government approach, relying on a detailed bottom-up analysis that reviewed technology availability, current costs, and future cost reductions, as well as the role of enabling infrastructure. Standards, incentives, programs, and support for innovation were all weighed in the analysis. The National Climate Task Force is developing this into a national climate strategy to be issued later this year.

- **Consulted important and diverse stakeholders:** From unions that collectively bargain for millions of Americans who have built our country and work to keep it running to groups representing tens of millions of advocates and young Americans, the Administration listened to Americans across the country. This also included groups representing thousands of scientists; hundreds of governmental leaders like governors, mayors, and tribal leaders; hundreds of businesses; hundreds of schools and institutions of higher education; as well as with many specialized researchers focused on questions of pollution reduction.

- **Explored multiple pathways across the economy**: The target is grounded in analysis that explored multiple pathways for each economic sector of the economy that produces CO_2 and non-CO_2 greenhouse gases: electricity, transportation, buildings, industry, and lands.

Each policy considered for reducing emissions is also an opportunity to support good jobs and improve equity:

- The United States has set a goal to reach **100 percent carbon pollution-free electricity by 2035**, which can be achieved through multiple cost-effective pathways each resulting in meaningful emissions reductions in this decade. That means good-paying jobs deploying carbon pollution-free electricity generating resources, transmission, and energy storage and leveraging the carbon pollution-free energy potential of power plants retrofitted with carbon capture and existing nuclear, while ensuring those facilities meet robust and rigorous standards for worker, public, environmental safety and environmental justice.

- The United States can create good-paying jobs and **cut emissions and energy costs for families by supporting efficiency upgrades and electrification in buildings** through support for job-creating retrofit programs and sustainable affordable housing, wider use of heat pumps and induction stoves, and adoption of modern energy codes for new buildings. The United States will also invest in new technologies to reduce emissions associated with construction, including for high-performance electrified buildings.

- The United States can **reduce carbon pollution from the transportation sector** by reducing tailpipe emissions and boosting the efficiency of cars and trucks; providing funding for charging infrastructure; and spurring research, development, demonstration, and deployment efforts that drive forward very low carbon new-generation renewable fuels for applications like aviation, and other cutting-edge transportation technologies across modes. Investment in a wider array of transportation infrastructure, including transit, rail, and biking improvements, will make more choices available to travelers.

- The United States can **reduce emissions from forests and agriculture and enhance carbon sinks** through a range of programs and measures including nature-based solutions for ecosystems ranging from our forests and agricultural soils to our rivers and coasts. Ocean-based solutions can also contribute towards reducing U.S. emissions.
- The United States can **address carbon pollution from industrial processes** by supporting carbon capture as well as new sources of hydrogen—produced from renewable energy, nuclear energy, or waste—to power industrial facilities. The government can use its procurement power to support early markets for these very low- and zero-carbon industrial goods.
- The United States will also reduce non-CO2 greenhouse gases, including methane, hydrofluorocarbons and other potent short-lived climate pollutants. Reducing these pollutants delivers fast climate benefits.
- In addition, the United States will **invest in innovation** to improve and broaden the set of solutions as a critical complement to deploying the affordable, reliable, and resilient clean technologies and infrastructure available today.

America must act— and not just the federal government, but cities and states, small and big business, working communities. Together, we can seize the opportunity to drive prosperity, create jobs, and build the clean energy economy of tomorrow.

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INTERGOVERNMENTAL PANEL ON climate change

CLIMATE CHANGE 2023

Synthesis Report

Summary for Policymakers

A Report of the Intergovernmental Panel on Climate Change

WMO UNEP

CLIMATE CHANGE 2023

Synthesis Report

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Referencing this report:

IPCC, 2023: Summary for Policymakers. In: *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

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Photo Reference

"Fog opening the dawn" by Chung Jin Sil

The Weather and Climate Photography & Video Contest 2021, Korea Meteorological Administration
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THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

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In the Summary for Policymakers, the references refer to the numbers of the sections, figures, tables and boxes in the underlying Introduction and Topics of this Synthesis Report.

In the Introduction and Sections of the longer report, the references refer to the contributions of the Working Groups I, II and III (WGI, WGII, WGIII) to the Sixth Assessment Report and other IPCC Reports (in italicized curly brackets), or to other sections of the Synthesis Report itself (in round brackets).

The following abbreviations have been used:
SPM: Summary for Policymakers
TS: Technical Summary
ES: Executive Summary of a chapter
Numbers denote specific chapters and sections of a report.

Other IPCC reports cited in this Synthesis Report:
SR1.5: Global Warming of 1.5°C
SRCCL: Climate Change and Land
SROCC: The Ocean and Cryosphere in a Changing Climate

Summary for Policymakers

This Summary for Policymakers should be cited as:
IPCC, 2023: Summary for Policymakers. In: *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

Introduction

This Synthesis Report (SYR) of the IPCC Sixth Assessment Report (AR6) summarises the state of knowledge of climate change, its widespread impacts and risks, and climate change mitigation and adaptation. It integrates the main findings of the Sixth Assessment Report (AR6) based on contributions from the three Working Groups[1], and the three Special Reports[2]. The summary for Policymakers (SPM) is structured in three parts: SPM.A Current Status and Trends, SPM.B Future Climate Change, Risks, and Long-Term Responses, and SPM.C Responses in the Near Term[3].

This report recognizes the interdependence of climate, ecosystems and biodiversity, and human societies; the value of diverse forms of knowledge; and the close linkages between climate change adaptation, mitigation, ecosystem health, human well-being and sustainable development, and reflects the increasing diversity of actors involved in climate action.

Based on scientific understanding, key findings can be formulated as statements of fact or associated with an assessed level of confidence using the IPCC calibrated language[4].

1 The three Working Group contributions to AR6 are: AR6 Climate Change 2021: The Physical Science Basis; AR6 Climate Change 2022: Impacts, Adaptation and Vulnerability; and AR6 Climate Change 2022: Mitigation of Climate Change. Their assessments cover scientific literature accepted for publication respectively by 31 January 2021, 1 September 2021 and 11 October 2021.

2 The three Special Reports are: Global Warming of 1.5°C (2018): an IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (SR1.5); Climate Change and Land (2019): an IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL); and The Ocean and Cryosphere in a Changing Climate (2019) (SROCC). The Special Reports cover scientific literature accepted for publication respectively by 15 May 2018, 7 April 2019 and 15 May 2019.

3 In this report, the near term is defined as the period until 2040. The long term is defined as the period beyond 2040.

4 Each finding is grounded in an evaluation of underlying evidence and agreement. The IPCC calibrated language uses five qualifiers to express a level of confidence: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms are used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, more likely than not >50–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%; and extremely unlikely 0–5%) are also used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*. This is consistent with AR5 and the other AR6 Reports.

A. Current Status and Trends

Observed Warming and its Causes

A.1 Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020. Global greenhouse gas emissions have continued to increase, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals (*high confidence*). {*2.1, Figure 2.1, Figure 2.2*}

A.1.1 Global surface temperature was 1.09 [0.95 to 1.20]°C[5] higher in 2011–2020 than 1850–1900[6], with larger increases over land (1.59 [1.34 to 1.83]°C) than over the ocean (0.88 [0.68 to 1.01]°C). Global surface temperature in the first two decades of the 21st century (2001–2020) was 0.99 [0.84 to 1.10]°C higher than 1850–1900. Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years (*high confidence*). {*2.1.1*, *Figure 2.1*}

A.1.2 The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019[7] is 0.8°C to 1.3°C, with a best estimate of 1.07°C. Over this period, it is *likely* that well-mixed greenhouse gases (GHGs) contributed a warming of 1.0°C to 2.0°C[8], and other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural (solar and volcanic) drivers changed global surface temperature by –0.1°C to +0.1°C, and internal variability changed it by –0.2°C to +0.2°C. {*2.1.1*, *Figure 2.1*}

A.1.3 Observed increases in well-mixed GHG concentrations since around 1750 are unequivocally caused by GHG emissions from human activities over this period. Historical cumulative net CO_2 emissions from 1850 to 2019 were 2400 ± 240 $GtCO_2$ of which more than half (58%) occurred between 1850 and 1989, and about 42% occurred between 1990 and 2019 (*high confidence*). In 2019, atmospheric CO_2 concentrations (410 parts per million) were higher than at any time in at least 2 million years (*high confidence*), and concentrations of methane (1866 parts per billion) and nitrous oxide (332 parts per billion) were higher than at any time in at least 800,000 years (*very high confidence*). {*2.1.1*, *Figure 2.1*}

A.1.4 Global net anthropogenic GHG emissions have been estimated to be 59 ± 6.6 $GtCO_2$-eq[9] in 2019, about 12% (6.5 $GtCO_2$-eq) higher than in 2010 and 54% (21 $GtCO_2$-eq) higher than in 1990, with the largest share and growth in gross GHG emissions occurring in CO_2 from fossil fuels combustion and industrial processes (CO_2-FFI) followed by methane, whereas the highest relative growth occurred in fluorinated gases (F-gases), starting from low levels in 1990. Average annual GHG emissions during 2010–2019 were higher than in any previous decade on record, while the rate of growth between 2010 and 2019 (1.3% yr^{-1}) was lower than that between 2000 and 2009 (2.1% yr^{-1}). In 2019, approximately 79% of global GHG

5 Ranges given throughout the SPM represent *very likely* ranges (5–95% range) unless otherwise stated.

6 The estimated increase in global surface temperature since AR5 is principally due to further warming since 2003–2012 (0.19 [0.16 to 0.22] °C). Additionally, methodological advances and new datasets have provided a more complete spatial representation of changes in surface temperature, including in the Arctic. These and other improvements have also increased the estimate of global surface temperature change by approximately 0.1°C, but this increase does not represent additional physical warming since AR5.

7 The period distinction with A.1.1 arises because the attribution studies consider this slightly earlier period. The observed warming to 2010–2019 is 1.06 [0.88 to 1.21]°C.

8 Contributions from emissions to the 2010–2019 warming relative to 1850–1900 assessed from radiative forcing studies are: CO_2 0.8 [0.5 to 1.2]°C; methane 0.5 [0.3 to 0.8]°C; nitrous oxide 0.1 [0.0 to 0.2]°C and fluorinated gases 0.1 [0.0 to 0.2]°C. {*2.1.1*}

9 GHG emission metrics are used to express emissions of different greenhouse gases in a common unit. Aggregated GHG emissions in this report are stated in CO_2-equivalents (CO_2-eq) using the Global Warming Potential with a time horizon of 100 years (GWP100) with values based on the contribution of Working Group I to the AR6. The AR6 WGI and WGIII reports contain updated emission metric values, evaluations of different metrics with regard to mitigation objectives, and assess new approaches to aggregating gases. The choice of metric depends on the purpose of the analysis and all GHG emission metrics have limitations and uncertainties, given that they simplify the complexity of the physical climate system and its response to past and future GHG emissions. {*2.1.1*}

emissions came from the sectors of energy, industry, transport, and buildings together and 22%[10] from agriculture, forestry and other land use (AFOLU). Emissions reductions in CO_2-FFI due to improvements in energy intensity of GDP and carbon intensity of energy, have been less than emissions increases from rising global activity levels in industry, energy supply, transport, agriculture and buildings. (*high confidence*) {*2.1.1*}

A.1.5 Historical contributions of CO_2 emissions vary substantially across regions in terms of total magnitude, but also in terms of contributions to CO_2-FFI and net CO_2 emissions from land use, land-use change and forestry (CO_2-LULUCF). In 2019, around 35% of the global population live in countries emitting more than 9 tCO_2-eq per capita[11] (excluding CO_2-LULUCF) while 41% live in countries emitting less than 3 tCO_2-eq per capita; of the latter a substantial share lacks access to modern energy services. Least Developed Countries (LDCs) and Small Island Developing States (SIDS) have much lower per capita emissions (1.7 tCO_2-eq and 4.6 tCO_2-eq, respectively) than the global average (6.9 tCO_2-eq), excluding CO_2-LULUCF. The 10% of households with the highest per capita emissions contribute 34–45% of global consumption-based household GHG emissions, while the bottom 50% contribute 13–15%. (*high confidence*) {*2.1.1, Figure 2.2*}

Observed Changes and Impacts

A.2 Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred. Human-caused climate change is already affecting many weather and climate extremes in every region across the globe. This has led to widespread adverse impacts and related losses and damages to nature and people (*high confidence*). Vulnerable communities who have historically contributed the least to current climate change are disproportionately affected (*high confidence*). {*2.1, Table 2.1, Figure 2.2, Figure 2.3*} (*Figure SPM.1*)

A.2.1 It is unequivocal that human influence has warmed the atmosphere, ocean and land. Global mean sea level increased by 0.20 [0.15 to 0.25] m between 1901 and 2018. The average rate of sea level rise was 1.3 [0.6 to 2.1] mm yr^{-1} between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm yr^{-1} between 1971 and 2006, and further increasing to 3.7 [3.2 to 4.2] mm yr^{-1} between 2006 and 2018 (*high confidence*). Human influence was *very likely* the main driver of these increases since at least 1971. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has further strengthened since AR5. Human influence has *likely* increased the chance of compound extreme events since the 1950s, including increases in the frequency of concurrent heatwaves and droughts (*high confidence*). {*2.1.2, Table 2.1, Figure 2.3, Figure 3.4*} (*Figure SPM.1*)

A.2.2 Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change. Human and ecosystem vulnerability are interdependent. Regions and people with considerable development constraints have high vulnerability to climatic hazards. Increasing weather and climate extreme events have exposed millions of people to acute food insecurity[12] and reduced water security, with the largest adverse impacts observed in many locations and/or communities in Africa, Asia, Central and South America, LDCs, Small Islands and the Arctic, and globally for Indigenous Peoples, small-scale food producers and low-income households. Between 2010 and 2020, human mortality from floods, droughts and storms was 15 times higher in highly vulnerable regions, compared to regions with very low vulnerability. (*high confidence*) {*2.1.2, 4.4*} (*Figure SPM.1*)

A.2.3 Climate change has caused substantial damages, and increasingly irreversible losses, in terrestrial, freshwater, cryospheric, and coastal and open ocean ecosystems (*high confidence*). Hundreds of local losses of species have been driven by increases in the magnitude of heat extremes (*high confidence*) with mass mortality events recorded on land and in the ocean (*very high confidence*). Impacts on some ecosystems are approaching irreversibility such as the impacts of hydrological changes resulting from the retreat of glaciers, or the changes in some mountain (*medium confidence*) and Arctic ecosystems driven by permafrost thaw (*high confidence*). {*2.1.2, Figure 2.3*} (*Figure SPM.1*)

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10 GHG emission levels are rounded to two significant digits; as a consequence, small differences in sums due to rounding may occur. {*2.1.1*}

11 Territorial emissions.

12 Acute food insecurity can occur at any time with a severity that threatens lives, livelihoods or both, regardless of the causes, context or duration, as a result of shocks risking determinants of food security and nutrition, and is used to assess the need for humanitarian action. {*2.1*}

A.2.4 Climate change has reduced food security and affected water security, hindering efforts to meet Sustainable Development Goals (*high confidence*). Although overall agricultural productivity has increased, climate change has slowed this growth over the past 50 years globally (*medium confidence*), with related negative impacts mainly in mid- and low latitude regions but positive impacts in some high latitude regions (*high confidence*). Ocean warming and ocean acidification have adversely affected food production from fisheries and shellfish aquaculture in some oceanic regions *(high confidence)*. Roughly half of the world's population currently experience severe water scarcity for at least part of the year due to a combination of climatic and non-climatic drivers (*medium confidence*). {*2.1.2, Figure 2.3*} (*Figure SPM.1*)

A.2.5 In all regions increases in extreme heat events have resulted in human mortality and morbidity (*very high confidence*). The occurrence of climate-related food-borne and water-borne diseases (*very high confidence*) and the incidence of vector-borne diseases (*high confidence*) have increased. In assessed regions, some mental health challenges are associated with increasing temperatures (*high confidence*), trauma from extreme events (*very high confidence*), and loss of livelihoods and culture (*high confidence*). Climate and weather extremes are increasingly driving displacement in Africa, Asia, North America (*high confidence*), and Central and South America (*medium confidence*), with small island states in the Caribbean and South Pacific being disproportionately affected relative to their small population size (*high confidence*). {*2.1.2, Figure 2.3*} (*Figure SPM.1*)

A.2.6 Climate change has caused widespread adverse impacts and related losses and damages[13] to nature and people that are unequally distributed across systems, regions and sectors. Economic damages from climate change have been detected in climate-exposed sectors, such as agriculture, forestry, fishery, energy, and tourism. Individual livelihoods have been affected through, for example, destruction of homes and infrastructure, and loss of property and income, human health and food security, with adverse effects on gender and social equity. (*high confidence*) {*2.1.2*} (*Figure SPM.1*)

A.2.7 In urban areas, observed climate change has caused adverse impacts on human health, livelihoods and key infrastructure. Hot extremes have intensified in cities. Urban infrastructure, including transportation, water, sanitation and energy systems have been compromised by extreme and slow-onset events[14], with resulting economic losses, disruptions of services and negative impacts to well-being. Observed adverse impacts are concentrated amongst economically and socially marginalised urban residents. (*high confidence*) {*2.1.2*}

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13 In this report, the term 'losses and damages' refers to adverse observed impacts and/or projected risks and can be economic and/or non-economic (see Annex I: Glossary).

14 Slow-onset events are described among the climatic-impact drivers of the AR6 WGI and refer to the risks and impacts associated with e.g., increasing temperature means, desertification, decreasing precipitation, loss of biodiversity, land and forest degradation, glacial retreat and related impacts, ocean acidification, sea level rise and salinization. {*2.1.2*}

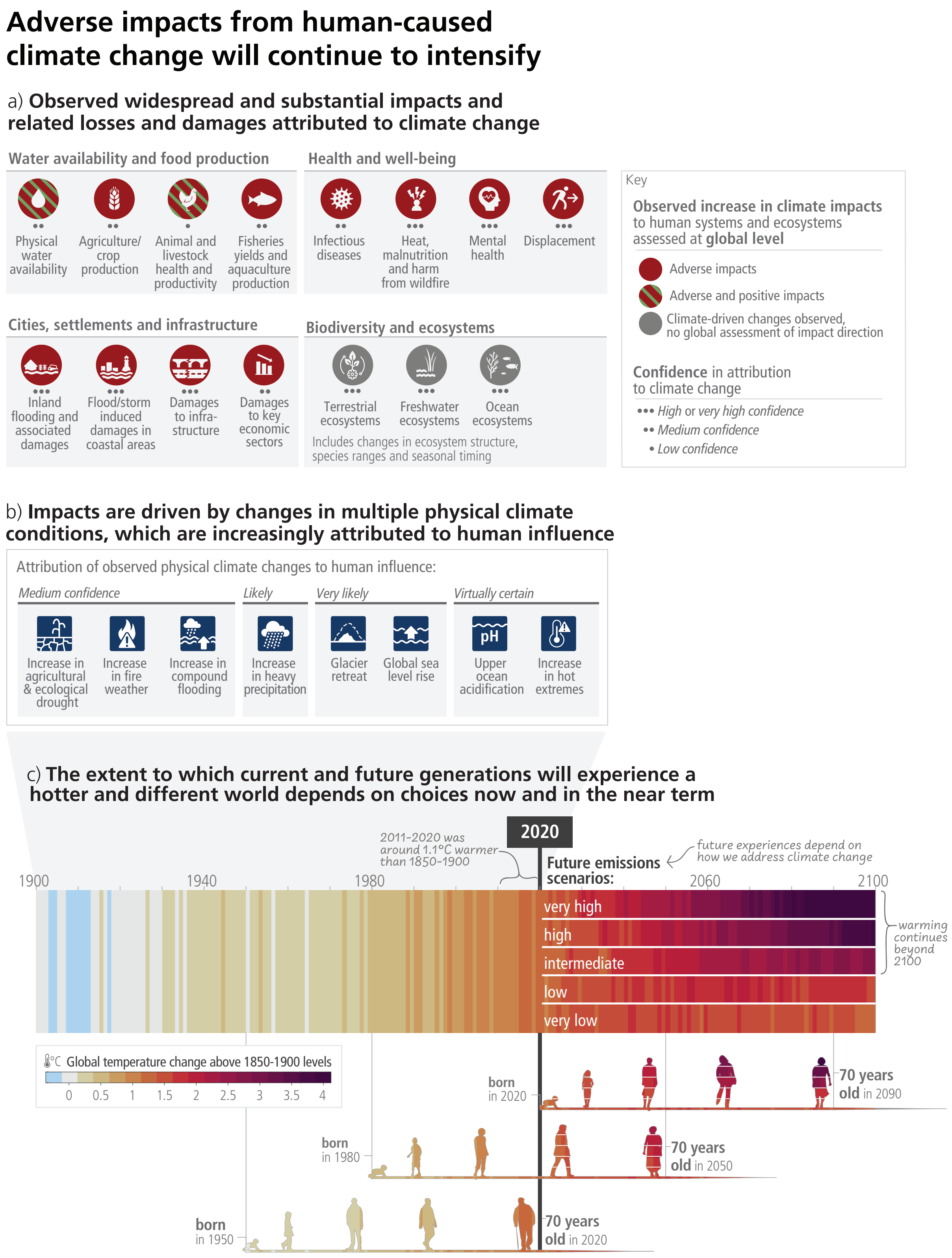

Figure SPM.1: (a) Climate change has already caused widespread impacts and related losses and damages on human systems and altered terrestrial, freshwater and ocean ecosystems worldwide. Physical water availability includes balance of water available from various sources including ground water, water quality and demand for water. Global mental health and displacement assessments reflect only assessed regions. Confidence levels reflect the assessment of attribution of the observed impact to climate change. **(b)** Observed impacts are connected to physical climate changes including many that have been attributed to human influence such as the selected climatic impact-drivers shown. Confidence and likelihood levels reflect the assessment of attribution of the observed climatic impact-driver to human influence. **(c)** Observed (1900–2020) and projected (2021–2100) changes in global surface temperature (relative to 1850-1900), which are linked to changes in climate conditions and impacts, illustrate how the climate has already changed and will change along the lifespan of three representative generations (born in 1950, 1980 and 2020). Future projections (2021–2100) of changes in global surface temperature are shown for very low (SSP1-1.9), low (SSP1-2.6), intermediate (SSP2-4.5), high (SSP3-7.0) and very high (SSP5-8.5) GHG emissions scenarios. Changes in annual global surface temperatures are presented as 'climate stripes', with future projections showing the human-caused long-term trends and continuing modulation by natural variability (represented here using observed levels of past natural variability). Colours on the generational icons correspond to the global surface temperature stripes for each year, with segments on future icons differentiating possible future experiences. {*2.1*, *2.1.2*, *Figure 2.1*, *Table 2.1*, *Figure 2.3*, *Cross-Section Box.2*, *3.1*, *Figure 3.3*, *4.1*, *4.3*} (*Box SPM.1*)

Current Progress in Adaptation and Gaps and Challenges

A.3 Adaptation planning and implementation has progressed across all sectors and regions, with documented benefits and varying effectiveness. Despite progress, adaptation gaps exist, and will continue to grow at current rates of implementation. Hard and soft limits to adaptation have been reached in some ecosystems and regions. Maladaptation is happening in some sectors and regions. Current global financial flows for adaptation are insufficient for, and constrain implementation of, adaptation options, especially in developing countries (*high confidence*). {*2.2, 2.3*}

A.3.1 Progress in adaptation planning and implementation has been observed across all sectors and regions, generating multiple benefits (*very high confidence*). Growing public and political awareness of climate impacts and risks has resulted in at least 170 countries and many cities including adaptation in their climate policies and planning processes (*high confidence*). {*2.2.3*}

A.3.2 Effectiveness[15] of adaptation in reducing climate risks[16] is documented for specific contexts, sectors and regions (*high confidence*). Examples of effective adaptation options include: cultivar improvements, on-farm water management and storage, soil moisture conservation, irrigation, agroforestry, community-based adaptation, farm and landscape level diversification in agriculture, sustainable land management approaches, use of agroecological principles and practices and other approaches that work with natural processes (*high confidence*). Ecosystem-based adaptation[17] approaches such as urban greening, restoration of wetlands and upstream forest ecosystems have been effective in reducing flood risks and urban heat (*high confidence*). Combinations of non-structural measures like early warning systems and structural measures like levees have reduced loss of lives in case of inland flooding (*medium confidence*). Adaptation options such as disaster risk management, early warning systems, climate services and social safety nets have broad applicability across multiple sectors (*high confidence*). {*2.2.3*}

A.3.3 Most observed adaptation responses are fragmented, incremental[18], sector-specific and unequally distributed across regions. Despite progress, adaptation gaps exist across sectors and regions, and will continue to grow under current levels of implementation, with the largest adaptation gaps among lower income groups. (*high confidence*) {*2.3.2*}

A.3.4 There is increased evidence of maladaptation in various sectors and regions. Maladaptation especially affects marginalised and vulnerable groups adversely. (*high confidence*) {*2.3.2*}

A.3.5 Soft limits to adaptation are currently being experienced by small-scale farmers and households along some low-lying coastal areas (*medium confidence*) resulting from financial, governance, institutional and policy constraints (*high confidence*). Some tropical, coastal, polar and mountain ecosystems have reached hard adaptation limits (*high confidence*). Adaptation does not prevent all losses and damages, even with effective adaptation and before reaching soft and hard limits (*high confidence*). {*2.3.2*}

[15] Effectiveness refers here to the extent to which an adaptation option is anticipated or observed to reduce climate-related risk. {*2.2.3*}

[16] See Annex I: Glossary. {*2.2.3*}

[17] Ecosystem-based Adaptation (EbA) is recognized internationally under the Convention on Biological Diversity (CBD14/5). A related concept is Nature-based Solutions (NbS), see Annex I: Glossary.

[18] Incremental adaptations to change in climate are understood as extensions of actions and behaviours that already reduce the losses or enhance the benefits of natural variations in extreme weather/climate events. {*2.3.2*}

A.3.6 Key barriers to adaptation are limited resources, lack of private sector and citizen engagement, insufficient mobilization of finance (including for research), low climate literacy, lack of political commitment, limited research and/or slow and low uptake of adaptation science, and low sense of urgency. There are widening disparities between the estimated costs of adaptation and the finance allocated to adaptation (*high confidence*). Adaptation finance has come predominantly from public sources, and a small proportion of global tracked climate finance was targeted to adaptation and an overwhelming majority to mitigation (*very high confidence*). Although global tracked climate finance has shown an upward trend since AR5, current global financial flows for adaptation, including from public and private finance sources, are insufficient and constrain implementation of adaptation options, especially in developing countries (*high confidence*). Adverse climate impacts can reduce the availability of financial resources by incurring losses and damages and through impeding national economic growth, thereby further increasing financial constraints for adaptation, particularly for developing and least developed countries (*medium confidence*). {*2.3.2*, *2.3.3*}

Box SPM.1 The use of scenarios and modelled pathways in the AR6 Synthesis Report

Modelled scenarios and pathways[19] are used to explore future emissions, climate change, related impacts and risks, and possible mitigation and adaptation strategies and are based on a range of assumptions, including socio-economic variables and mitigation options. These are quantitative projections and are neither predictions nor forecasts. Global modelled emission pathways, including those based on cost effective approaches contain regionally differentiated assumptions and outcomes, and have to be assessed with the careful recognition of these assumptions. Most do not make explicit assumptions about global equity, environmental justice or intra-regional income distribution. IPCC is neutral with regard to the assumptions underlying the scenarios in the literature assessed in this report, which do not cover all possible futures.[20] {*Cross-Section Box.2*}

WGI assessed the climate response to five illustrative scenarios based on Shared Socio-economic Pathways (SSPs)[21] that cover the range of possible future development of anthropogenic drivers of climate change found in the literature. High and very high GHG emissions scenarios (SSP3-7.0 and SSP5-8.5[22]) have CO_2 emissions that roughly double from current levels by 2100 and 2050, respectively. The intermediate GHG emissions scenario (SSP2-4.5) has CO_2 emissions remaining around current levels until the middle of the century. The very low and low GHG emissions scenarios (SSP1-1.9 and SSP1-2.6) have CO_2 emissions declining to net zero around 2050 and 2070, respectively, followed by varying levels of net negative CO_2 emissions. In addition, Representative Concentration Pathways (RCPs)[23] were used by WGI and WGII to assess regional climate changes, impacts and risks. In WGIII, a large number of global modelled emissions pathways were assessed, of which 1202 pathways were categorised based on their assessed global warming over the 21st century; categories range from pathways that limit warming to 1.5°C with more than 50% likelihood (noted >50% in this report) with no or limited overshoot (C1) to pathways that exceed 4°C (C8). {*Cross-Section Box.2*} (*Box SPM.1*, *Table 1*)

Global warming levels (GWLs) relative to 1850–1900 are used to integrate the assessment of climate change and related impacts and risks since patterns of changes for many variables at a given GWL are common to all scenarios considered and independent of timing when that level is reached. {*Cross-Section Box.2*}

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19 In the literature, the terms pathways and scenarios are used interchangeably, with the former more frequently used in relation to climate goals. WGI primarily used the term scenarios and WGIII mostly used the term modelled emission and mitigation pathways. The SYR primarily uses scenarios when referring to WGI and modelled emission and mitigation pathways when referring to WGIII.

20 Around half of all modelled global emission pathways assume cost-effective approaches that rely on least-cost mitigation/abatement options globally. The other half looks at existing policies and regionally and sectorally differentiated actions.

21 SSP-based scenarios are referred to as SSPx-y, where 'SSPx' refers to the Shared Socioeconomic Pathway describing the socioeconomic trends underlying the scenarios, and 'y' refers to the level of radiative forcing (in watts per square metre, or W m^{-2}) resulting from the scenario in the year 2100. {*Cross-Section Box.2*}

22 Very high emissions scenarios have become *less likely* but cannot be ruled out. Warming levels >4°C may result from very high emissions scenarios, but can also occur from lower emission scenarios if climate sensitivity or carbon cycle feedbacks are higher than the best estimate. {*3.1.1*}

23 RCP-based scenarios are referred to as RCPy, where 'y' refers to the level of radiative forcing (in watts per square metre, or W m^{-2}) resulting from the scenario in the year 2100. The SSP scenarios cover a broader range of greenhouse gas and air pollutant futures than the RCPs. They are similar but not identical, with differences in concentration trajectories. The overall effective radiative forcing tends to be higher for the SSPs compared to the RCPs with the same label (*medium confidence*). {*Cross-Section Box.2*}

Box SPM.1, Table 1: Description and relationship of scenarios and modelled pathways considered across AR6 Working Group reports. {*Cross-Section Box.2 Figure 1*}

Category in WGIII	Category description	GHG emissions scenarios (SSPx-y*) in WGI & WGII	RCPy** in WGI & WGII
C1	limit warming to 1.5°C (>50%) with no or limited overshoot***	Very low (SSP1-1.9)	
C2	return warming to 1.5°C (>50%) after a high overshoot***		
C3	limit warming to 2°C (>67%)	Low (SSP1-2.6)	RCP2.6
C4	limit warming to 2°C (>50%)		
C5	limit warming to 2.5°C (>50%)		
C6	limit warming to 3°C (>50%)	Intermediate (SSP2-4.5)	RCP 4.5
C7	limit warming to 4°C (>50%)	High (SSP3-7.0)	
C8	exceed warming of 4°C (>50%)	Very high (SSP5-8.5)	RCP 8.5

* See footnote 21 for the SSPx-y terminology.

** See footnote 23 for the RCPy terminology.

*** Limited overshoot refers to exceeding 1.5°C global warming by up to about 0.1°C, high overshoot by 0.1°C-0.3°C, in both cases for up to several decades.

Current Mitigation Progress, Gaps and Challenges

A.4 Policies and laws addressing mitigation have consistently expanded since AR5. Global GHG emissions in 2030 implied by nationally determined contributions (NDCs) announced by October 2021 make it *likely* that warming will exceed 1.5°C during the 21st century and make it harder to limit warming below 2°C. There are gaps between projected emissions from implemented policies and those from NDCs and finance flows fall short of the levels needed to meet climate goals across all sectors and regions. (*high confidence*) {*2.2, 2.3, Figure 2.5, Table 2.2*}

A.4.1 The UNFCCC, Kyoto Protocol, and the Paris Agreement are supporting rising levels of national ambition. The Paris Agreement, adopted under the UNFCCC, with near universal participation, has led to policy development and target-setting at national and sub-national levels, in particular in relation to mitigation, as well as enhanced transparency of climate action and support (*medium confidence*). Many regulatory and economic instruments have already been deployed successfully (*high confidence*). In many countries, policies have enhanced energy efficiency, reduced rates of deforestation and accelerated technology deployment, leading to avoided and in some cases reduced or removed emissions (*high confidence*). Multiple lines of evidence suggest that mitigation policies have led to several[24] Gt CO_2-eq yr^{-1} of avoided global emissions (*medium confidence*). At least 18 countries have sustained absolute production-based GHG and consumption-based CO_2 reductions[25] for longer than 10 years. These reductions have only partly offset global emissions growth (*high confidence*). {*2.2.1, 2.2.2*}

A.4.2 Several mitigation options, notably solar energy, wind energy, electrification of urban systems, urban green infrastructure, energy efficiency, demand-side management, improved forest and crop/grassland management, and reduced food waste and loss, are technically viable, are becoming increasingly cost effective and are generally supported by the

[24] At least 1.8 GtCO_2-eq yr^{-1} can be accounted for by aggregating separate estimates for the effects of economic and regulatory instruments. Growing numbers of laws and executive orders have impacted global emissions and were estimated to result in 5.9 GtCO_2-eq yr^{-1} less emissions in 2016 than they otherwise would have been. (*medium confidence*) {*2.2.2*}

[25] Reductions were linked to energy supply decarbonisation, energy efficiency gains, and energy demand reduction, which resulted from both policies and changes in economic structure (*high confidence*). {*2.2.2*}

public. From 2010 to 2019 there have been sustained decreases in the unit costs of solar energy (85%), wind energy (55%), and lithium-ion batteries (85%), and large increases in their deployment, e.g., >10× for solar and >100× for electric vehicles (EVs), varying widely across regions. The mix of policy instruments that reduced costs and stimulated adoption includes public R&D, funding for demonstration and pilot projects, and demand-pull instruments such as deployment subsidies to attain scale. Maintaining emission-intensive systems may, in some regions and sectors, be more expensive than transitioning to low emission systems. (*high confidence*) {*2.2.2, Figure 2.4*}

A.4.3 A substantial 'emissions gap' exists between global GHG emissions in 2030 associated with the implementation of NDCs announced prior to COP26[26] and those associated with modelled mitigation pathways that limit warming to 1.5°C (>50%) with no or limited overshoot or limit warming to 2°C (>67%) assuming immediate action (*high confidence*). This would make it *likely* that warming will exceed 1.5°C during the 21st century (*high confidence*). Global modelled mitigation pathways that limit warming to 1.5°C (>50%) with no or limited overshoot or limit warming to 2°C (>67%) assuming immediate action imply deep global GHG emissions reductions this decade (*high confidence*) (see SPM Box 1, Table 1, B.6)[27]. Modelled pathways that are consistent with NDCs announced prior to COP26 until 2030 and assume no increase in ambition thereafter have higher emissions, leading to a median global warming of 2.8 [2.1 to 3.4] °C by 2100 (*medium confidence*). Many countries have signalled an intention to achieve net zero GHG or net zero CO_2 by around mid-century but pledges differ across countries in terms of scope and specificity, and limited policies are to date in place to deliver on them. {*2.3.1*, *Table 2.2*, *Figure 2.5*, *Table 3.1*, *4.1*}

A.4.4 Policy coverage is uneven across sectors (*high confidence*). Policies implemented by the end of 2020 are projected to result in higher global GHG emissions in 2030 than emissions implied by NDCs, indicating an 'implementation gap' (*high confidence*). Without a strengthening of policies, global warming of 3.2 [2.2 to 3.5] °C is projected by 2100 (*medium confidence*). {*2.2.2*, *2.3.1*, *3.1.1*, *Figure 2.5*} (*Box SPM.1*, *Figure SPM.5*)

A.4.5 The adoption of low-emission technologies lags in most developing countries, particularly least developed ones, due in part to limited finance, technology development and transfer, and capacity (*medium confidence*). The magnitude of climate finance flows has increased over the last decade and financing channels have broadened but growth has slowed since 2018 (*high confidence*). Financial flows have developed heterogeneously across regions and sectors (*high confidence*). Public and private finance flows for fossil fuels are still greater than those for climate adaptation and mitigation (*high confidence*). The overwhelming majority of tracked climate finance is directed towards mitigation, but nevertheless falls short of the levels needed to limit warming to below 2°C or to 1.5°C across all sectors and regions (see C7.2) (*very high confidence*). In 2018, public and publicly mobilised private climate finance flows from developed to developing countries were below the collective goal under the UNFCCC and Paris Agreement to mobilise USD 100 billion per year by 2020 in the context of meaningful mitigation action and transparency on implementation (*medium confidence*). {*2.2.2*, *2.3.1*, *2.3.3*}

[26] Due to the literature cutoff date of WGIII, the additional NDCs submitted after 11 October 2021 are not assessed here. {*Footnote 32 in the Longer Report*}

[27] Projected 2030 GHG emissions are 50 (47–55) $GtCO_2$-eq if all conditional NDC elements are taken into account. Without conditional elements, the global emissions are projected to be approximately similar to modelled 2019 levels at 53 (50–57) $GtCO_2$-eq. {*2.3.1*, *Table 2.2*}

B. Future Climate Change, Risks, and Long-Term Responses

Future Climate Change

B.1 Continued greenhouse gas emissions will lead to increasing global warming, with the best estimate of reaching 1.5°C in the near term in considered scenarios and modelled pathways. Every increment of global warming will intensify multiple and concurrent hazards (*high confidence*). Deep, rapid, and sustained reductions in greenhouse gas emissions would lead to a discernible slowdown in global warming within around two decades, and also to discernible changes in atmospheric composition within a few years (*high confidence*). {*Cross-Section Boxes 1 and 2, 3.1, 3.3, Table 3.1, Figure 3.1, 4.3*} (*Figure SPM.2, Box SPM.1*)

B.1.1 Global warming[28] will continue to increase in the near term (2021–2040) mainly due to increased cumulative CO_2 emissions in nearly all considered scenarios and modelled pathways. In the near term, global warming *is more likely than not* to reach 1.5°C even under the very low GHG emission scenario (SSP1-1.9) and *likely* or *very likely* to exceed 1.5°C under higher emissions scenarios. In the considered scenarios and modelled pathways, the best estimates of the time when the level of global warming of 1.5°C is reached lie in the near term[29]. Global warming declines back to below 1.5°C by the end of the 21st century in some scenarios and modelled pathways (see B.7). The assessed climate response to GHG emissions scenarios results in a best estimate of warming for 2081–2100 that spans a range from 1.4°C for a very low GHG emissions scenario (SSP1-1.9) to 2.7°C for an intermediate GHG emissions scenario (SSP2-4.5) and 4.4°C for a very high GHG emissions scenario (SSP5-8.5)[30], with narrower uncertainty ranges[31] than for corresponding scenarios in AR5. {*Cross-Section Boxes 1 and 2*, *3.1.1*, *3.3.4*, *Table 3.1*, *4.3*} (*Box SPM.1*)

B.1.2 Discernible differences in trends of global surface temperature between contrasting GHG emissions scenarios (SSP1-1.9 and SSP1-2.6 vs. SSP3-7.0 and SSP5-8.5) would begin to emerge from natural variability[32] within around 20 years. Under these contrasting scenarios, discernible effects would emerge within years for GHG concentrations, and sooner for air quality improvements, due to the combined targeted air pollution controls and strong and sustained methane emissions reductions. Targeted reductions of air pollutant emissions lead to more rapid improvements in air quality within years compared to reductions in GHG emissions only, but in the long term, further improvements are projected in scenarios that combine efforts to reduce air pollutants as well as GHG emissions[33]. (*high confidence*) {*3.1.1*} (*Box SPM.1*)

B.1.3 Continued emissions will further affect all major climate system components. With every additional increment of global warming, changes in extremes continue to become larger. Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation, and very wet and very dry weather and

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[28] Global warming (see Annex I: Glossary) is here reported as running 20-year averages, unless stated otherwise, relative to 1850–1900. Global surface temperature in any single year can vary above or below the long-term human-caused trend, due to natural variability. The internal variability of global surface temperature in a single year is estimated to be about ±0.25°C (5–95% range, *high confidence*). The occurrence of individual years with global surface temperature change above a certain level does not imply that this global warming level has been reached. {*4.3, Cross-Section Box.2*}

[29] Median five-year interval at which a 1.5°C global warming level is reached (50% probability) in categories of modelled pathways considered in WGIII is 2030–2035. By 2030, global surface temperature in any individual year could exceed 1.5°C relative to 1850–1900 with a probability between 40% and 60%, across the five scenarios assessed in WGI (*medium confidence*). In all scenarios considered in WGI except the very high emissions scenario (SSP5-8.5), the midpoint of the first 20-year running average period during which the assessed average global surface temperature change reaches 1.5°C lies in the first half of the 2030s. In the very high GHG emissions scenario, the midpoint is in the late 2020s. {*3.1.1*, *3.3.1*, *4.3*} (*Box SPM.1*)

[30] The best estimates [and *very likely* ranges] for the different scenarios are: 1.4 [1.0 to 1.8]°C (SSP1-1.9); 1.8 [1.3 to 2.4]°C (SSP1-2.6); 2.7 [2.1 to 3.5]°C (SSP2-4.5); 3.6 [2.8 to 4.6]°C (SSP3-7.0); and 4.4 [3.3 to 5.7]°C (SSP5-8.5). {*3.1.1*} (*Box SPM.1*)

[31] Assessed future changes in global surface temperature have been constructed, for the first time, by combining multi-model projections with observational constraints and the assessed equilibrium climate sensitivity and transient climate response. The uncertainty range is narrower than in the AR5 thanks to improved knowledge of climate processes, paleoclimate evidence and model-based emergent constraints. {*3.1.1*}

[32] See Annex I: Glossary. Natural variability includes natural drivers and internal variability. The main internal variability phenomena include El Niño-Southern Oscillation, Pacific Decadal Variability and Atlantic Multi-decadal Variability. {*4.3*}

[33] Based on additional scenarios.

climate events and seasons (*high confidence*). In scenarios with increasing CO_2 emissions, natural land and ocean carbon sinks are projected to take up a decreasing proportion of these emissions (*high confidence*). Other projected changes include further reduced extents and/or volumes of almost all cryospheric elements[34] (*high confidence*), further global mean sea level rise (*virtually certain*), and increased ocean acidification (*virtually certain*) and deoxygenation (*high confidence*). {*3.1.1, 3.3.1, Figure 3.4*} (*Figure SPM.2*)

B.1.4 With further warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. Compound heatwaves and droughts are projected to become more frequent, including concurrent events across multiple locations (*high confidence*). Due to relative sea level rise, current 1-in-100 year extreme sea level events are projected to occur at least annually in more than half of all tide gauge locations by 2100 under all considered scenarios (*high confidence*). Other projected regional changes include intensification of tropical cyclones and/or extratropical storms (*medium confidence*), and increases in aridity and fire weather *(medium* to *high confidence*). {*3.1.1, 3.1.3*}

B.1.5 Natural variability will continue to modulate human-caused climate changes, either attenuating or amplifying projected changes, with little effect on centennial-scale global warming (*high confidence*). These modulations are important to consider in adaptation planning, especially at the regional scale and in the near term. If a large explosive volcanic eruption were to occur[35], it would temporarily and partially mask human-caused climate change by reducing global surface temperature and precipitation for one to three years (*medium confidence*). {*4.3*}

34 Permafrost, seasonal snow cover, glaciers, the Greenland and Antarctic Ice Sheets, and Arctic sea ice.

35 Based on 2500-year reconstructions, eruptions with a radiative forcing more negative than –1 W m^{-2}, related to the radiative effect of volcanic stratospheric aerosols in the literature assessed in this report, occur on average twice per century. {*4.3*}

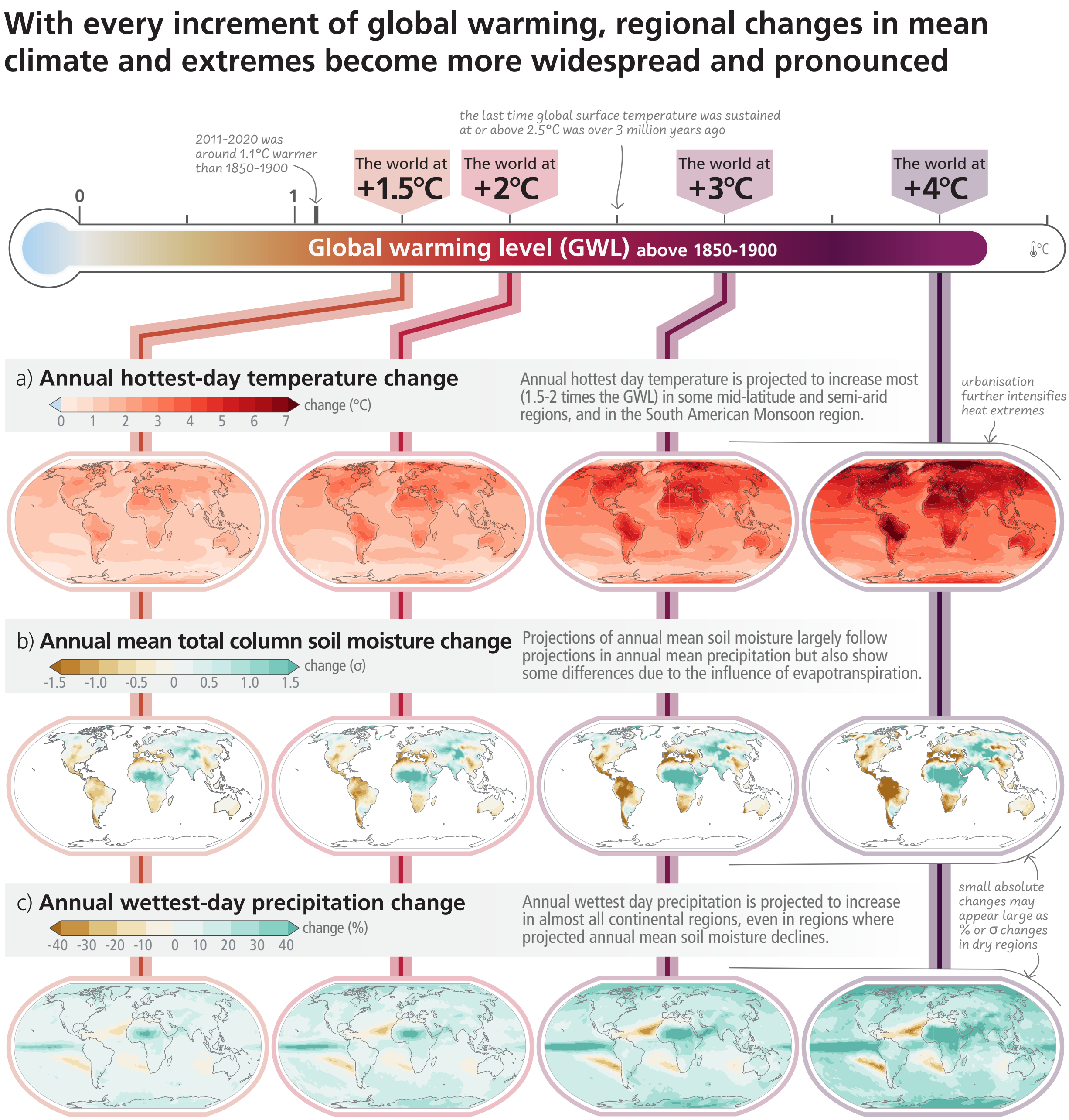

Figure SPM.2: Projected changes of annual maximum daily maximum temperature, annual mean total column soil moisture and annual maximum 1-day precipitation at global warming levels of 1.5°C, 2°C, 3°C, and 4°C relative to 1850–1900. Projected **(a)** annual maximum daily temperature change (°C), **(b)** annual mean total column soil moisture change (standard deviation), **(c)** annual maximum 1-day precipitation change (%). The panels show CMIP6 multi-model median changes. In panels (b) and (c), large positive relative changes in dry regions may correspond to small absolute changes. In panel (b), the unit is the standard deviation of interannual variability in soil moisture during 1850–1900. Standard deviation is a widely used metric in characterising drought severity. A projected reduction in mean soil moisture by one standard deviation corresponds to soil moisture conditions typical of droughts that occurred about once every six years during 1850–1900. The WGI Interactive Atlas (https://interactive-atlas.ipcc.ch/) can be used to explore additional changes in the climate system across the range of global warming levels presented in this figure. {*Figure 3.1, Cross-Section Box.2*}

Climate Change Impacts and Climate-Related Risks

B.2 For any given future warming level, many climate-related risks are higher than assessed in AR5, and projected long-term impacts are up to multiple times higher than currently observed (*high confidence*). Risks and projected adverse impacts and related losses and damages from climate change escalate with every increment of global warming (*very high confidence*). Climatic and non-climatic risks will increasingly interact, creating compound and cascading risks that are more complex and difficult to manage (*high confidence*). {*Cross-Section Box.2, 3.1, 4.3, Figure 3.3, Figure 4.3*} (*Figure SPM.3, Figure SPM.4*)

B.2.1 In the near term, every region in the world is projected to face further increases in climate hazards (*medium* to *high confidence*, depending on region and hazard), increasing multiple risks to ecosystems and humans (*very high confidence*). Hazards and associated risks expected in the near term include an increase in heat-related human mortality and morbidity (*high confidence*), food-borne, water-borne, and vector-borne diseases (*high confidence*), and mental health challenges[36] (*very high confidence*), flooding in coastal and other low-lying cities and regions (*high confidence*), biodiversity loss in land, freshwater and ocean ecosystems (*medium* to *very high confidence*, depending on ecosystem), and a decrease in food production in some regions (*high confidence*). Cryosphere-related changes in floods, landslides, and water availability have the potential to lead to severe consequences for people, infrastructure and the economy in most mountain regions (*high confidence*). The projected increase in frequency and intensity of heavy precipitation (*high confidence*) will increase rain-generated local flooding (*medium confidence*). {*Figure 3.2*, *Figure 3.3*, *4.3*, *Figure 4.3*} (*Figure SPM.3*, *Figure SPM.4*)

B.2.2 Risks and projected adverse impacts and related losses and damages from climate change will escalate with every increment of global warming (*very high confidence*). They are higher for global warming of 1.5°C than at present, and even higher at 2°C (*high confidence*). Compared to the AR5, global aggregated risk levels[37] (Reasons for Concern[38]) are assessed to become high to very high at lower levels of global warming due to recent evidence of observed impacts, improved process understanding, and new knowledge on exposure and vulnerability of human and natural systems, including limits to adaptation (*high confidence*). Due to unavoidable sea level rise (see also B.3), risks for coastal ecosystems, people and infrastructure will continue to increase beyond 2100 (*high confidence*). {*3.1.2*, *3.1.3*, *Figure 3.4*, *Figure 4.3*} (*Figure SPM.3*, *Figure SPM.4*)

B.2.3 With further warming, climate change risks will become increasingly complex and more difficult to manage. Multiple climatic and non-climatic risk drivers will interact, resulting in compounding overall risk and risks cascading across sectors and regions. Climate-driven food insecurity and supply instability, for example, are projected to increase with increasing global warming, interacting with non-climatic risk drivers such as competition for land between urban expansion and food production, pandemics and conflict. (*high confidence*) {*3.1.2*, *4.3*, *Figure 4.3*}

B.2.4 For any given warming level, the level of risk will also depend on trends in vulnerability and exposure of humans and ecosystems. Future exposure to climatic hazards is increasing globally due to socio-economic development trends including migration, growing inequality and urbanisation. Human vulnerability will concentrate in informal settlements and rapidly growing smaller settlements. In rural areas vulnerability will be heightened by high reliance on climate-sensitive livelihoods. Vulnerability of ecosystems will be strongly influenced by past, present, and future patterns of unsustainable consumption and production, increasing demographic pressures, and persistent unsustainable use and management of land, ocean, and water. Loss of ecosystems and their services has cascading and long-term impacts on people globally, especially for Indigenous Peoples and local communities who are directly dependent on ecosystems to meet basic needs. (*high confidence*) {*Cross-Section Box.2 Figure 1c*, *3.1.2*, *4.3*}

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36 In all assessed regions.

37 Undetectable risk level indicates no associated impacts are detectable and attributable to climate change; moderate risk indicates associated impacts are both detectable and attributable to climate change with at least *medium confidence*, also accounting for the other specific criteria for key risks; high risk indicates severe and widespread impacts that are judged to be high on one or more criteria for assessing key risks; and very high risk level indicates very high risk of severe impacts and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks. {*3.1.2*}

38 The Reasons for Concern (RFC) framework communicates scientific understanding about accrual of risk for five broad categories. RFC1: Unique and threatened systems: ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. RFC2: Extreme weather events: risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events. RFC3: Distribution of impacts: risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability. RFC4: Global aggregate impacts: impacts to socio-ecological systems that can be aggregated globally into a single metric. RFC5: Large-scale singular events: relatively large, abrupt and sometimes irreversible changes in systems caused by global warming. See also Annex I: Glossary. {*3.1.2, Cross-Section Box.2*}

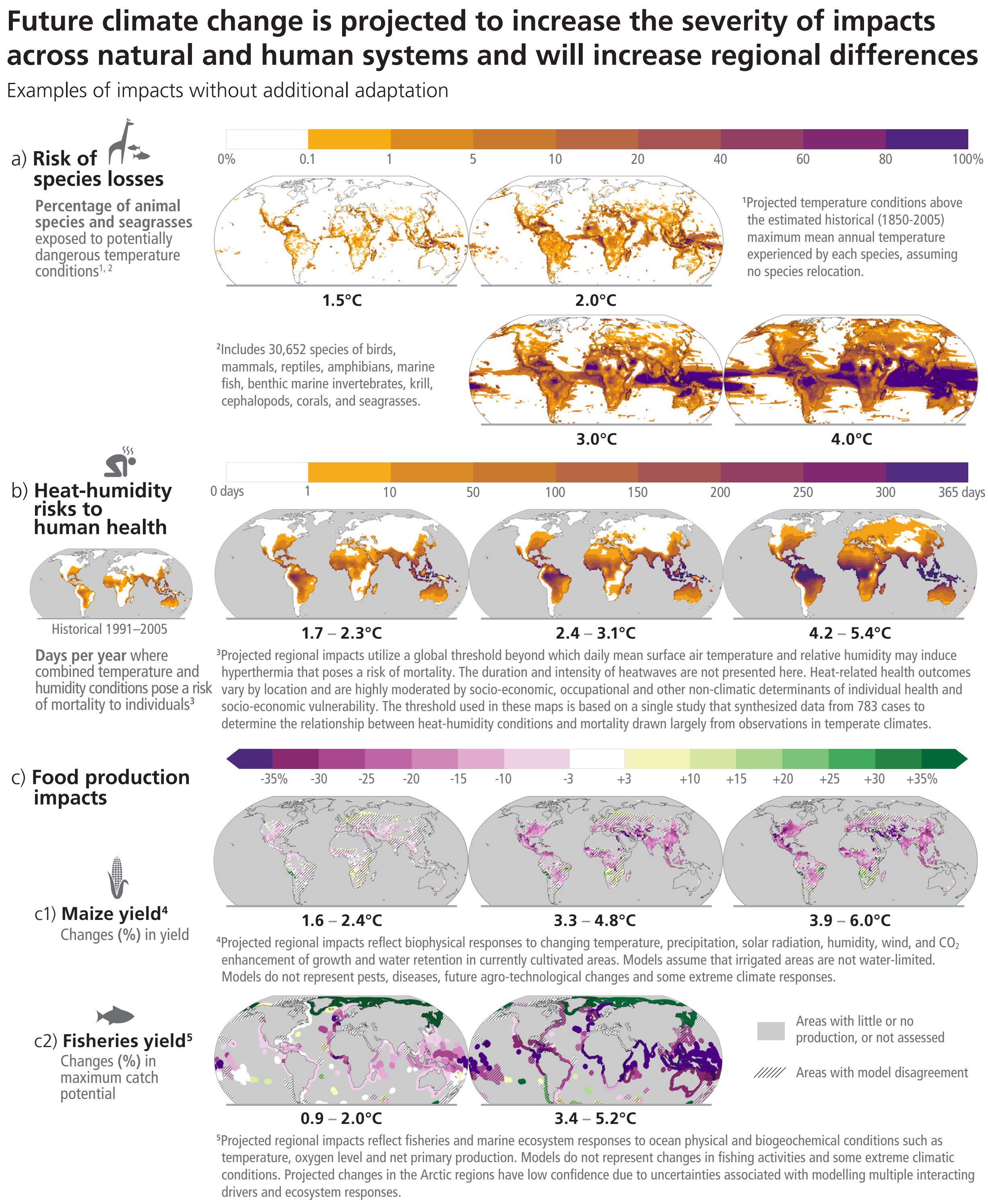

Figure SPM.3: Projected risks and impacts of climate change on natural and human systems at different global warming levels (GWLs) relative to 1850-1900 levels. Projected risks and impacts shown on the maps are based on outputs from different subsets of Earth system and impact models that were used to project each impact indicator without additional adaptation. WGII provides further assessment of the impacts on human and natural systems using these projections and additional lines of evidence. **(a)** Risks of species losses as indicated by the percentage of assessed species exposed to potentially dangerous temperature conditions, as defined by conditions beyond the estimated historical (1850–2005) maximum mean annual temperature experienced by each species, at GWLs of 1.5°C, 2°C, 3°C and 4°C. Underpinning projections of temperature are from 21 Earth system models and do not consider extreme events impacting ecosystems such as the Arctic. **(b)** Risks to human health as indicated by the days per year of population exposure to hyperthermic conditions that pose a risk of mortality from surface air temperature and humidity conditions for historical period (1991–2005) and at GWLs of 1.7°C–2.3°C (mean = 1.9°C; 13 climate models), 2.4°C–3.1°C (2.7°C; 16 climate models) and 4.2°C–5.4°C (4.7°C; 15 climate models). Interquartile ranges of GWLs by 2081–2100 under RCP2.6, RCP4.5 and RCP8.5. The presented index is consistent with common features found in many indices included within WGI and WGII assessments. **(c)** Impacts on food production: (c1) Changes in maize yield by 2080–2099 relative to 1986–2005 at projected GWLs of 1.6°C–2.4°C (2.0°C), 3.3°C–4.8°C (4.1°C) and 3.9°C–6.0°C (4.9°C). Median yield changes from an ensemble of 12 crop models, each driven by bias-adjusted outputs from 5 Earth system models, from the Agricultural Model Intercomparison and Improvement Project (AgMIP) and the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP). Maps depict

2080–2099 compared to 1986–2005 for current growing regions (>10 ha), with the corresponding range of future global warming levels shown under SSP1-2.6, SSP3-7.0 and SSP5-8.5, respectively. Hatching indicates areas where <70% of the climate-crop model combinations agree on the sign of impact. (c2) Change in maximum fisheries catch potential by 2081–2099 relative to 1986–2005 at projected GWLs of 0.9°C–2.0°C (1.5°C) and 3.4°C–5.2°C (4.3°C). GWLs by 2081–2100 under RCP2.6 and RCP8.5. Hatching indicates where the two climate-fisheries models disagree in the direction of change. Large relative changes in low yielding regions may correspond to small absolute changes. Biodiversity and fisheries in Antarctica were not analysed due to data limitations. Food security is also affected by crop and fishery failures not presented here. {*3.1.2, Figure 3.2, Cross-Section Box.2*} (*Box SPM.1*)

Risks are increasing with every increment of warming

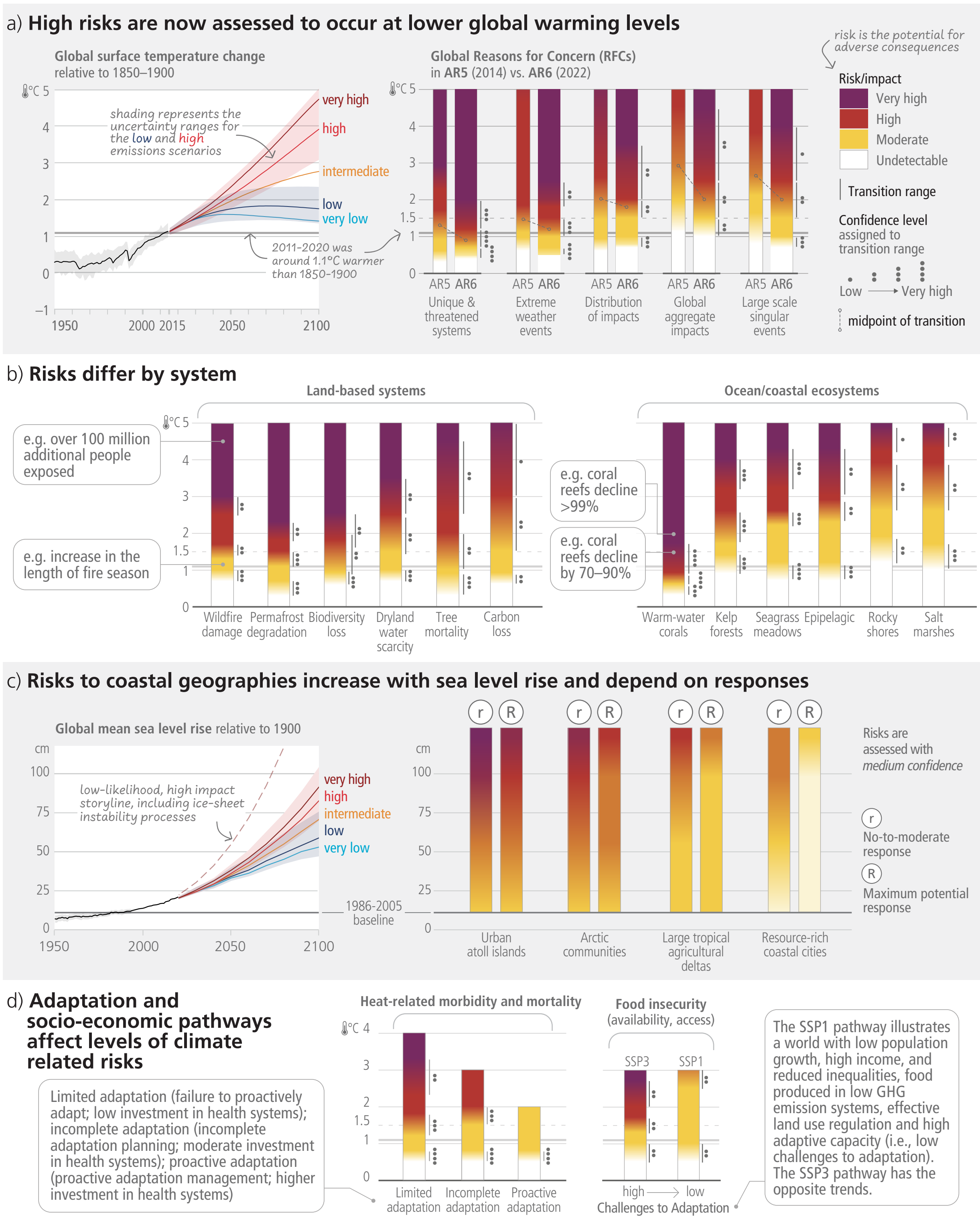

Figure SPM.4: Subset of assessed climate outcomes and associated global and regional climate risks. The burning embers result from a literature based expert elicitation. **Panel (a): Left** – Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining CMIP6 model simulations with observational constraints based on past simulated warming, as well as an updated assessment of equilibrium climate sensitivity. *Very likely* ranges are shown for the low and high GHG emissions scenarios (SSP1-2.6 and SSP3-7.0) (Cross-Section Box.2). **Right** – Global Reasons for Concern (RFC), comparing AR6 (thick embers) and AR5 (thin embers) assessments. Risk transitions have generally shifted towards lower temperatures with updated scientific understanding. Diagrams are shown for each RFC, assuming low to no adaptation. Lines connect the midpoints of the transitions from moderate to high risk across AR5 and AR6. **Panel (b)**: Selected global risks for land and ocean ecosystems, illustrating general increase of risk with global warming levels with low to no adaptation. **Panel (c): Left** - Global mean sea level change in centimetres, relative to 1900. The historical changes (black) are observed by tide gauges before 1992 and altimeters afterwards. The future changes to 2100 (coloured lines and shading) are assessed consistently with observational constraints based on emulation of CMIP, ice-sheet, and glacier models, and *likely* ranges are shown for SSP1-2.6 and SSP3-7.0. **Right** - Assessment of the combined risk of coastal flooding, erosion and salinization for four illustrative coastal geographies in 2100, due to changing mean and extreme sea levels, under two response scenarios, with respect to the SROCC baseline period (1986–2005). The assessment does not account for changes in extreme sea level beyond those directly induced by mean sea level rise; risk levels could increase if other changes in extreme sea levels were considered (e.g., due to changes in cyclone intensity). "No-to-moderate response" describes efforts as of today (i.e., no further significant action or new types of actions). "Maximum potential response" represent a combination of responses implemented to their full extent and thus significant additional efforts compared to today, assuming minimal financial, social and political barriers. (In this context, 'today' refers to 2019.) The assessment criteria include exposure and vulnerability, coastal hazards, in-situ responses and planned relocation. Planned relocation refers to managed retreat or resettlements. The term response is used here instead of adaptation because some responses, such as retreat, may or may not be considered to be adaptation. **Panel (d)**: Selected risks under different socio-economic pathways, illustrating how development strategies and challenges to adaptation influence risk. **Left** - Heat-sensitive human health outcomes under three scenarios of adaptation effectiveness. The diagrams are truncated at the nearest whole ºC within the range of temperature change in 2100 under three SSP scenarios. **Right** - Risks associated with food security due to climate change and patterns of socio-economic development. Risks to food security include availability and access to food, including population at risk of hunger, food price increases and increases in disability adjusted life years attributable to childhood underweight. Risks are assessed for two contrasted socio-economic pathways (SSP1 and SSP3) excluding the effects of targeted mitigation and adaptation policies. {*Figure 3.3*} (*Box SPM.1*)

Likelihood and Risks of Unavoidable, Irreversible or Abrupt Changes

B.3 Some future changes are unavoidable and/or irreversible but can be limited by deep, rapid, and sustained global greenhouse gas emissions reduction. The likelihood of abrupt and/or irreversible changes increases with higher global warming levels. Similarly, the probability of low-likelihood outcomes associated with potentially very large adverse impacts increases with higher global warming levels. (*high confidence*) {*3.1*}

B.3.1 Limiting global surface temperature does not prevent continued changes in climate system components that have multi-decadal or longer timescales of response (*high confidence*). Sea level rise is unavoidable for centuries to millennia due to continuing deep ocean warming and ice sheet melt, and sea levels will remain elevated for thousands of years (*high confidence*). However, deep, rapid, and sustained GHG emissions reductions would limit further sea level rise acceleration and projected long-term sea level rise commitment. Relative to 1995–2014, the *likely* global mean sea level rise under the SSP1-1.9 GHG emissions scenario is 0.15–0.23 m by 2050 and 0.28–0.55 m by 2100; while for the SSP5-8.5 GHG emissions scenario it is 0.20–0.29 m by 2050 and 0.63–1.01 m by 2100 (*medium confidence*). Over the next 2000 years, global mean sea level will rise by about 2–3 m if warming is limited to 1.5°C and 2–6 m if limited to 2°C (*low confidence*). {*3.1.3, Figure 3.4*} (*Box SPM.1*)

B.3.2 The likelihood and impacts of abrupt and/or irreversible changes in the climate system, including changes triggered when tipping points are reached, increase with further global warming (*high confidence*). As warming levels increase, so do the risks of species extinction or irreversible loss of biodiversity in ecosystems including forests (*medium confidence*), coral reefs (*very high confidence*) and in Arctic regions (*high confidence*). At sustained warming levels between 2°C and 3°C, the Greenland and West Antarctic ice sheets will be lost almost completely and irreversibly over multiple millennia, causing several metres of sea level rise *(limited evidence)*. The probability and rate of ice mass loss increase with higher global surface temperatures (*high confidence*). {*3.1.2, 3.1.3*}

B.3.3 The probability of low-likelihood outcomes associated with potentially very large impacts increases with higher global warming levels (*high confidence*). Due to deep uncertainty linked to ice-sheet processes, global mean sea level rise above the *likely* range – approaching 2 m by 2100 and in excess of 15 m by 2300 under the very high GHG emissions scenario (SSP5-8.5) (*low confidence*) – cannot be excluded. There is *medium confidence* that the Atlantic Meridional Overturning Circulation will not collapse abruptly before 2100, but if it were to occur, it would *very likely* cause abrupt shifts in regional weather patterns, and large impacts on ecosystems and human activities. {*3.1.3*} (*Box SPM.1*)

Adaptation Options and their Limits in a Warmer World

B.4 Adaptation options that are feasible and effective today will become constrained and less effective with increasing global warming. With increasing global warming, losses and damages will increase and additional human and natural systems will reach adaptation limits. Maladaptation can be avoided by flexible, multi-sectoral, inclusive, long-term planning and implementation of adaptation actions, with co-benefits to many sectors and systems. (*high confidence*) {*3.2, 4.1, 4.2, 4.3*}

B.4.1 The effectiveness of adaptation, including ecosystem-based and most water-related options, will decrease with increasing warming. The feasibility and effectiveness of options increase with integrated, multi-sectoral solutions that differentiate responses based on climate risk, cut across systems and address social inequities. As adaptation options often have long implementation times, long-term planning increases their efficiency. (*high confidence*) {*3.2*, *Figure 3.4*, *4.1*, *4.2*}

B.4.2 With additional global warming, limits to adaptation and losses and damages, strongly concentrated among vulnerable populations, will become increasingly difficult to avoid (*high confidence*). Above 1.5°C of global warming, limited freshwater resources pose potential hard adaptation limits for small islands and for regions dependent on glacier and snow melt (*medium confidence*). Above that level, ecosystems such as some warm-water coral reefs, coastal wetlands, rainforests, and polar and mountain ecosystems will have reached or surpassed hard adaptation limits and as a consequence, some Ecosystem-based Adaptation measures will also lose their effectiveness (*high confidence*). {*2.3.2*, *3.2*, *4.3*}

B.4.3 Actions that focus on sectors and risks in isolation and on short-term gains often lead to maladaptation over the long term, creating lock-ins of vulnerability, exposure and risks that are difficult to change. For example, seawalls effectively reduce impacts to people and assets in the short term but can also result in lock-ins and increase exposure to climate risks in the long term unless they are integrated into a long-term adaptive plan. Maladaptive responses can worsen existing inequities especially for Indigenous Peoples and marginalised groups and decrease ecosystem and biodiversity resilience. Maladaptation can be avoided by flexible, multi-sectoral, inclusive, long-term planning and implementation of adaptation actions, with co-benefits to many sectors and systems. (*high confidence*) {*2.3.2*, *3.2*}

Carbon Budgets and Net Zero Emissions

B.5 Limiting human-caused global warming requires net zero CO_2 emissions. Cumulative carbon emissions until the time of reaching net zero CO_2 emissions and the level of greenhouse gas emission reductions this decade largely determine whether warming can be limited to 1.5°C or 2°C (*high confidence*). Projected CO_2 emissions from existing fossil fuel infrastructure without additional abatement would exceed the remaining carbon budget for 1.5°C (50%) (*high confidence*). {*2.3, 3.1, 3.3, Table 3.1*}

B.5.1 From a physical science perspective, limiting human-caused global warming to a specific level requires limiting cumulative CO_2 emissions, reaching at least net zero CO_2 emissions, along with strong reductions in other greenhouse gas emissions. Reaching net zero GHG emissions primarily requires deep reductions in CO_2, methane, and other GHG emissions, and implies net negative CO_2 emissions[39]. Carbon dioxide removal (CDR) will be necessary to achieve net negative CO_2 emissions (see B.6). Net zero GHG emissions, if sustained, are projected to result in a gradual decline in global surface temperatures after an earlier peak. (*high confidence*) {*3.1.1*, *3.3.1*, *3.3.2*, *3.3.3*, *Table 3.1*, *Cross-Section Box.1*}

B.5.2 For every 1000 $GtCO_2$ emitted by human activity, global surface temperature rises by 0.45°C (best estimate, with a *likely* range from 0.27°C to 0.63°C). The best estimates of the remaining carbon budgets from the beginning of 2020 are 500 $GtCO_2$ for a 50% likelihood of limiting global warming to 1.5°C and 1150 $GtCO_2$ for a 67% likelihood of limiting warming to 2°C[40]. The stronger the reductions in non-CO_2 emissions, the lower the resulting temperatures are for a given remaining carbon budget or the larger remaining carbon budget for the same level of temperature change[41]. {*3.3.1*}

[39] Net zero GHG emissions defined by the 100-year global warming potential. See footnote 9.

[40] Global databases make different choices about which emissions and removals occurring on land are considered anthropogenic. Most countries report their anthropogenic land CO_2 fluxes including fluxes due to human-caused environmental change (e.g., CO_2 fertilisation) on 'managed' land in their national GHG inventories. Using emissions estimates based on these inventories, the remaining carbon budgets must be correspondingly reduced. {*3.3.1*}

[41] For example, remaining carbon budgets could be 300 or 600 $GtCO_2$ for 1.5°C (50%), respectively for high and low non-CO_2 emissions, compared to 500 $GtCO_2$ in the central case. {*3.3.1*}

B.5.3 If the annual CO_2 emissions between 2020–2030 stayed, on average, at the same level as 2019, the resulting cumulative emissions would almost exhaust the remaining carbon budget for 1.5°C (50%), and deplete more than a third of the remaining carbon budget for 2°C (67%). Estimates of future CO_2 emissions from existing fossil fuel infrastructures without additional abatement[42] already exceed the remaining carbon budget for limiting warming to 1.5°C (50%) (*high confidence*). Projected cumulative future CO_2 emissions over the lifetime of existing and planned fossil fuel infrastructure, if historical operating patterns are maintained and without additional abatement[43], are approximately equal to the remaining carbon budget for limiting warming to 2°C with a likelihood of 83%[44] (*high confidence*). {*2.3.1*, *3.3.1*, *Figure 3.5*}

B.5.4 Based on central estimates only, historical cumulative net CO_2 emissions between 1850 and 2019 amount to about four fifths[45] of the total carbon budget for a 50% probability of limiting global warming to 1.5°C (central estimate about 2900 $GtCO_2$), and to about two thirds[46] of the total carbon budget for a 67% probability to limit global warming to 2°C (central estimate about 3550 $GtCO_2$). {*3.3.1*, *Figure 3.5*}

Mitigation Pathways

B.6 All global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, and those that limit warming to 2°C (>67%), involve rapid and deep and, in most cases, immediate greenhouse gas emissions reductions in all sectors this decade. Global net zero CO_2 emissions are reached for these pathway categories, in the early 2050s and around the early 2070s, respectively. (*high confidence*) {*3.3, 3.4, 4.1, 4.5, Table 3.1*} (*Figure SPM.5, Box SPM.1*)

B.6.1 Global modelled pathways provide information on limiting warming to different levels; these pathways, particularly their sectoral and regional aspects, depend on the assumptions described in Box SPM.1. Global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot or limit warming to 2°C (>67%) are characterized by deep, rapid, and, in most cases, immediate GHG emissions reductions. Pathways that limit warming to 1.5 °C (>50%) with no or limited overshoot reach net zero CO_2 in the early 2050s, followed by net negative CO_2 emissions. Those pathways that reach net zero GHG emissions do so around the 2070s. Pathways that limit warming to 2 °C (>67%) reach net zero CO_2 emissions in the early 2070s. Global GHG emissions are projected to peak between 2020 and at the latest before 2025 in global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot and in those that limit warming to 2°C (>67%) and assume immediate action. (*high confidence*) {*3.3.2*, *3.3.4*, *4.1*, *Table 3.1*, *Figure 3.6*} (*Table SPM.1*)

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[42] Abatement here refers to human interventions that reduce the amount of greenhouse gases that are released from fossil fuel infrastructure to the atmosphere.

[43] Ibid.

[44] WGI provides carbon budgets that are in line with limiting global warming to temperature limits with different likelihoods, such as 50%, 67% or 83%. {*3.3.1*}

[45] Uncertainties for total carbon budgets have not been assessed and could affect the specific calculated fractions.

[46] Ibid.

Table SPM.1: Greenhouse gas and CO_2 emission reductions from 2019, median and 5-95 percentiles. {*3.3.1*, *4.1*, *Table 3.1*, *Figure 2.5*, *Box SPM.1*}

		Reductions from 2019 emission levels (%)			
		2030	2035	2040	2050
Limit warming to1.5°C (>50%) with no or limited overshoot	GHG	43 [34-60]	60 [49-77]	69 [58-90]	84 [73-98]
	CO_2	48 [36-69]	65 [50-96]	80 [61-109]	99 [79-119]
Limit warming to 2°C (>67%)	GHG	21 [1-42]	35 [22-55]	46 [34-63]	64 [53-77]
	CO_2	22 [1-44]	37 [21-59]	51 [36-70]	73 [55-90]

B.6.2 Reaching net zero CO_2 or GHG emissions primarily requires deep and rapid reductions in gross emissions of CO_2, as well as substantial reductions of non-CO_2 GHG emissions (*high confidence*). For example, in modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, global methane emissions are reduced by 34 [21–57] % by 2030 relative to 2019. However, some hard-to-abate residual GHG emissions (e.g., some emissions from agriculture, aviation, shipping, and industrial processes) remain and would need to be counterbalanced by deployment of CDR methods to achieve net zero CO_2 or GHG emissions (*high confidence*). As a result, net zero CO_2 is reached earlier than net zero GHGs (*high confidence*). {*3.3.2*, *3.3.3*, *Table 3.1*, *Figure 3.5*} (*Figure SPM.5*)

B.6.3 Global modelled mitigation pathways reaching net zero CO_2 and GHG emissions include transitioning from fossil fuels without carbon capture and storage (CCS) to very low- or zero-carbon energy sources, such as renewables or fossil fuels with CCS, demand-side measures and improving efficiency, reducing non-CO_2 GHG emissions, and CDR[47]. In most global modelled pathways, land-use change and forestry (via reforestation and reduced deforestation) and the energy supply sector reach net zero CO_2 emissions earlier than the buildings, industry and transport sectors. (*high confidence*) {*3.3.3, 4.1*, *4.5*, *Figure 4.1*} (*Figure SPM.5, Box SPM.1*)

B.6.4 Mitigation options often have synergies with other aspects of sustainable development, but some options can also have trade-offs. There are potential synergies between sustainable development and, for instance, energy efficiency and renewable energy. Similarly, depending on the context[48], biological CDR methods like reforestation, improved forest management, soil carbon sequestration, peatland restoration and coastal blue carbon management can enhance biodiversity and ecosystem functions, employment and local livelihoods. However, afforestation or production of biomass crops can have adverse socio-economic and environmental impacts, including on biodiversity, food and water security, local livelihoods and the rights of Indigenous Peoples, especially if implemented at large scales and where land tenure is insecure. Modelled pathways that assume using resources more efficiently or that shift global development towards sustainability include fewer challenges, such as less dependence on CDR and pressure on land and biodiversity. (*high confidence*) {*3.4.1*}

[47] CCS is an option to reduce emissions from large-scale fossil-based energy and industry sources provided geological storage is available. When CO_2 is captured directly from the atmosphere (DACCS), or from biomass (BECCS), CCS provides the storage component of these CDR methods. CO_2 capture and subsurface injection is a mature technology for gas processing and enhanced oil recovery. In contrast to the oil and gas sector, CCS is less mature in the power sector, as well as in cement and chemicals production, where it is a critical mitigation option. The technical geological storage capacity is estimated to be on the order of 1000 $GtCO_2$, which is more than the CO_2 storage requirements through 2100 to limit global warming to 1.5°C, although the regional availability of geological storage could be a limiting factor. If the geological storage site is appropriately selected and managed, it is estimated that the CO_2 can be permanently isolated from the atmosphere. Implementation of CCS currently faces technological, economic, institutional, ecological-environmental and socio-cultural barriers. Currently, global rates of CCS deployment are far below those in modelled pathways limiting global warming to 1.5°C to 2°C. Enabling conditions such as policy instruments, greater public support and technological innovation could reduce these barriers. (*high confidence*) {*3.3.3*}

[48] The impacts, risks, and co-benefits of CDR deployment for ecosystems, biodiversity and people will be highly variable depending on the method, site-specific context, implementation and scale (*high confidence*).

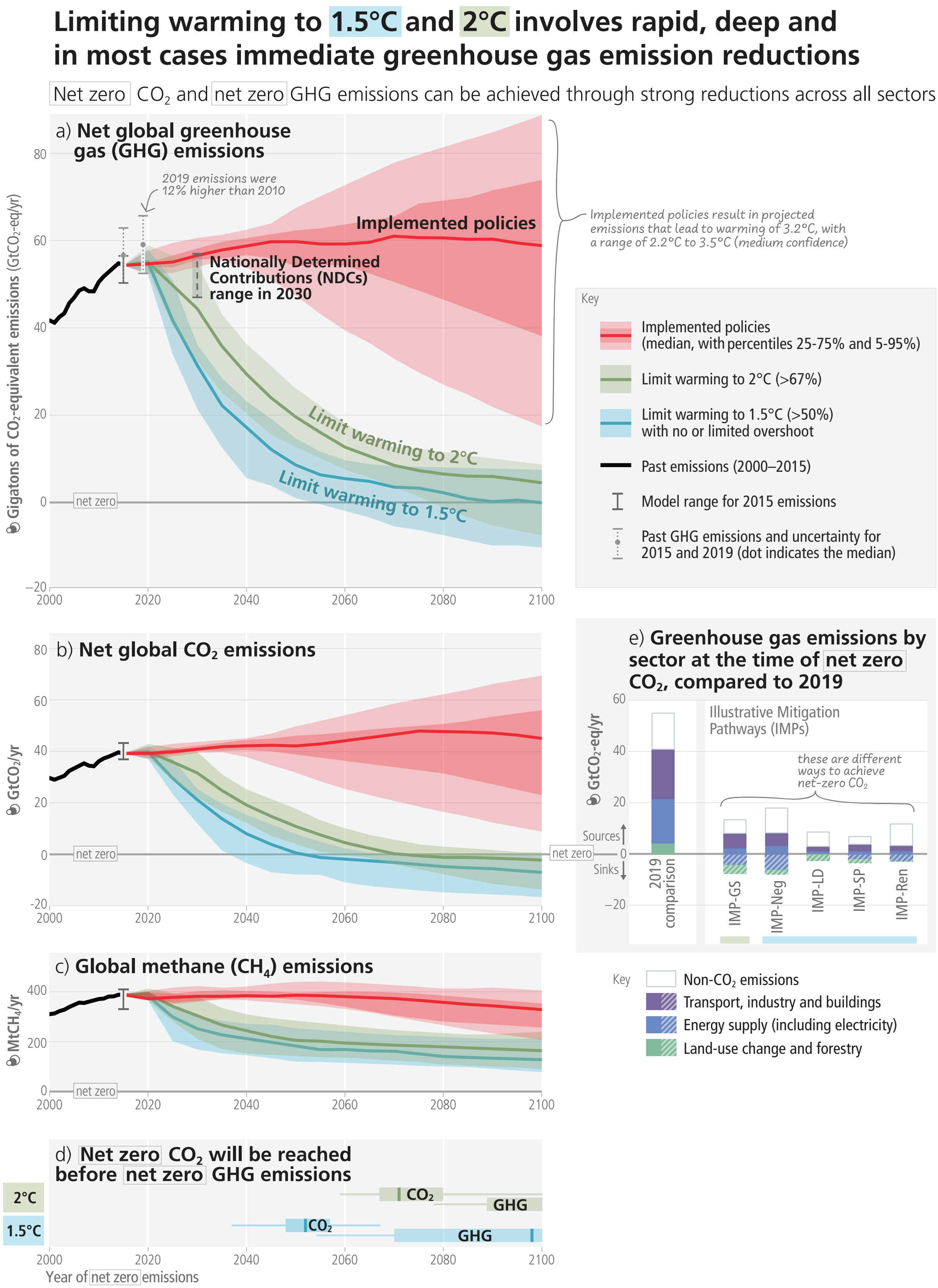
Limiting warming to 1.5°C and 2°C involves rapid, deep and in most cases immediate greenhouse gas emission reductions
Net zero CO2 and net zero GHG emissions can be achieved through strong reductions across all sectors
a) Net global greenhouse gas (GHG) emissions
Gigatons of CO2-equivalent emissions (GtCO2-eq/yr)
2019 emissions were 12% higher than 2010
Implemented policies
Nationally Determined Contributions (NDCs) range in 2030
Limit warming to 2°C
Limit warming to 1.5°C
net zero
Implemented policies result in projected emissions that lead to warming of 3.2°C, with a range of 2.2°C to 3.5°C (medium confidence)
Key
Implemented policies (median, with percentiles 25-75% and 5-95%)
Limit warming to 2°C (>67%)
Limit warming to 1.5°C (>50%) with no or limited overshoot
Past emissions (2000–2015)
Model range for 2015 emissions
Past GHG emissions and uncertainty for 2015 and 2019 (dot indicates the median)
b) Net global CO2 emissions
GtCO2/yr
c) Global methane (CH4) emissions
MtCH4/yr
d) Net zero CO2 will be reached before net zero GHG emissions
2°C
1.5°C
CO2
GHG
Year of net zero emissions
e) Greenhouse gas emissions by sector at the time of net zero CO2, compared to 2019
GtCO2-eq/yr
Sources
Sinks
2019 comparison
Illustrative Mitigation Pathways (IMPs)
these are different ways to achieve net-zero CO2
IMP-GS
IMP-Neg
IMP-LD
IMP-SP
IMP-Ren
Key
Non-CO2 emissions
Transport, industry and buildings
Energy supply (including electricity)
Land-use change and forestry

Figure SPM.5: Global emissions pathways consistent with implemented policies and mitigation strategies. Panels (a), (b) and **(c)** show the development of global GHG, CO_2 and methane emissions in modelled pathways, while **panel (d)** shows the associated timing of when GHG and CO_2 emissions reach net zero. Coloured ranges denote the 5th to 95th percentile across the global modelled pathways falling within a given category as described in Box SPM.1. The red ranges depict emissions pathways assuming policies that were implemented by the end of 2020. Ranges of modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot are shown in light blue (category C1) and pathways that limit warming to 2°C (>67%) are shown in green (category C3). Global emission pathways that would limit warming to 1.5°C (>50%) with no or limited overshoot and also reach net zero GHG in the second half of the century do so between 2070–2075. **Panel (e)** shows the sectoral contributions of CO_2 and non-CO_2 emissions sources and sinks at the time when net zero CO_2 emissions are reached in illustrative mitigation pathways (IMPs) consistent with limiting warming to 1.5°C with a high reliance on net negative emissions (IMP-Neg) ("high overshoot"), high resource efficiency (IMP-LD), a focus on sustainable development (IMP-SP), renewables (IMP-Ren) and limiting warming to 2°C with less rapid mitigation initially followed by a gradual strengthening (IMP-GS). Positive and negative emissions for different IMPs are compared to GHG emissions from the year 2019. Energy supply (including electricity) includes bioenergy with carbon dioxide capture and storage and direct air carbon dioxide capture and storage. CO_2 emissions from land-use change and forestry can only be shown as a net number as many models do not report emissions and sinks of this category separately. {*Figure 3.6, 4.1*} (*Box SPM.1*)

Overshoot: Exceeding a Warming Level and Returning

B.7 If warming exceeds a specified level such as 1.5°C, it could gradually be reduced again by achieving and sustaining net negative global CO_2 emissions. This would require additional deployment of carbon dioxide removal, compared to pathways without overshoot, leading to greater feasibility and sustainability concerns. Overshoot entails adverse impacts, some irreversible, and additional risks for human and natural systems, all growing with the magnitude and duration of overshoot. (*high confidence*) {*3.1, 3.3, 3.4, Table 3.1, Figure 3.6*}

B.7.1 Only a small number of the most ambitious global modelled pathways limit global warming to 1.5°C (>50%) by 2100 without exceeding this level temporarily. Achieving and sustaining net negative global CO_2 emissions, with annual rates of CDR greater than residual CO_2 emissions, would gradually reduce the warming level again (*high confidence*). Adverse impacts that occur during this period of overshoot and cause additional warming via feedback mechanisms, such as increased wildfires, mass mortality of trees, drying of peatlands, and permafrost thawing, weakening natural land carbon sinks and increasing releases of GHGs would make the return more challenging (*medium confidence*). {*3.3.2, 3.3.4*, *Table 3.1*, *Figure 3.6*} (*Box SPM.1*)

B.7.2 The higher the magnitude and the longer the duration of overshoot, the more ecosystems and societies are exposed to greater and more widespread changes in climatic impact-drivers, increasing risks for many natural and human systems. Compared to pathways without overshoot, societies would face higher risks to infrastructure, low-lying coastal settlements, and associated livelihoods. Overshooting 1.5°C will result in irreversible adverse impacts on certain ecosystems with low resilience, such as polar, mountain, and coastal ecosystems, impacted by ice-sheet melt, glacier melt, or by accelerating and higher committed sea level rise. (*high confidence*) {*3.1.2*, *3.3.4*}

B.7.3 The larger the overshoot, the more net negative CO_2 emissions would be needed to return to 1.5°C by 2100. Transitioning towards net zero CO_2 emissions faster and reducing non-CO_2 emissions such as methane more rapidly would limit peak warming levels and reduce the requirement for net negative CO_2 emissions, thereby reducing feasibility and sustainability concerns, and social and environmental risks associated with CDR deployment at large scales. (*high confidence*) {*3.3.3*, *3.3.4*, *3.4.1*, *Table 3.1*}

C. Responses in the Near Term

Urgency of Near-Term Integrated Climate Action

C.1 Climate change is a threat to human well-being and planetary health (*very high confidence*). There is a rapidly closing window of opportunity to secure a liveable and sustainable future for all (*very high confidence*). Climate resilient development integrates adaptation and mitigation to advance sustainable development for all, and is enabled by increased international cooperation including improved access to adequate financial resources, particularly for vulnerable regions, sectors and groups, and inclusive governance and coordinated policies (*high confidence*). The choices and actions implemented in this decade will have impacts now and for thousands of years (*high confidence*). {*3.1, 3.3, 4.1, 4.2, 4.3, 4.4, 4.7, 4.8, 4.9, Figure 3.1, Figure 3.3, Figure 4.2*} (*Figure SPM.1, Figure SPM.6*)

C.1.1 Evidence of observed adverse impacts and related losses and damages, projected risks, levels and trends in vulnerability and adaptation limits, demonstrate that worldwide climate resilient development action is more urgent than previously assessed in AR5. Climate resilient development integrates adaptation and GHG mitigation to advance sustainable development for all. Climate resilient development pathways have been constrained by past development, emissions and climate change and are progressively constrained by every increment of warming, in particular beyond 1.5°C. (*very high confidence*) {*3.4*, *3.4.2*, *4.1*}

C.1.2 Government actions at sub-national, national and international levels, with civil society and the private sector, play a crucial role in enabling and accelerating shifts in development pathways towards sustainability and climate resilient development (*very high confidence*). Climate resilient development is enabled when governments, civil society and the private sector make inclusive development choices that prioritize risk reduction, equity and justice, and when decision-making processes, finance and actions are integrated across governance levels, sectors, and timeframes (*very high confidence*). Enabling conditions are differentiated by national, regional and local circumstances and geographies, according to capabilities, and include: political commitment and follow-through, coordinated policies, social and international cooperation, ecosystem stewardship, inclusive governance, knowledge diversity, technological innovation, monitoring and evaluation, and improved access to adequate financial resources, especially for vulnerable regions, sectors and communities (*high confidence*). {*3.4*, *4.2*, *4.4*, *4.5*, *4.7*, *4.8*} (*Figure SPM.6*)

C.1.3 Continued emissions will further affect all major climate system components, and many changes will be irreversible on centennial to millennial time scales and become larger with increasing global warming. Without urgent, effective, and equitable mitigation and adaptation actions, climate change increasingly threatens ecosystems, biodiversity, and the livelihoods, health and well-being of current and future generations. (*high confidence*) {*3.1.3*, *3.3.3*, *3.4.1*, *Figure 3.4*, *4.1*, *4.2*, *4.3*, *4.4*} (*Figure SPM.1*, *Figure SPM.6*)

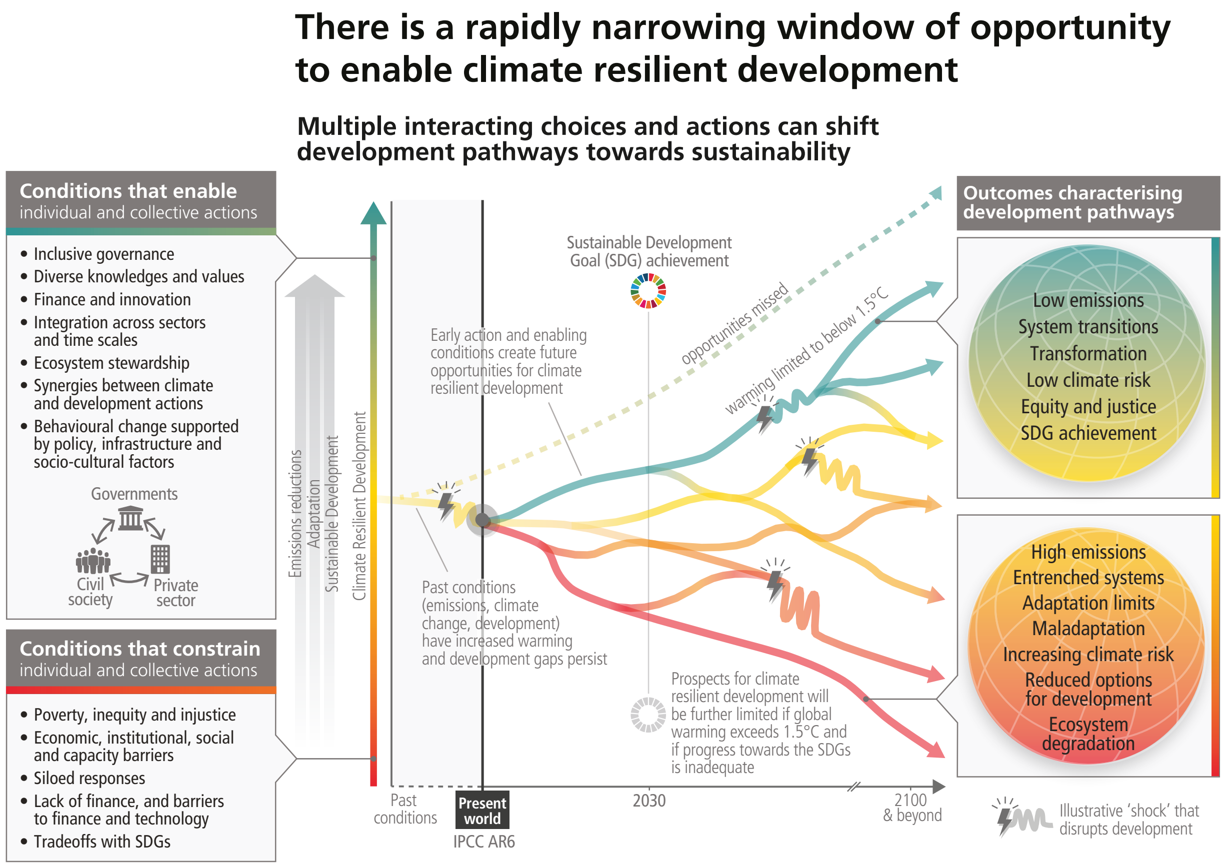

Figure SPM.6: The illustrative development pathways (red to green) and associated outcomes (right panel) show that there is a rapidly narrowing window of opportunity to secure a liveable and sustainable future for all. Climate resilient development is the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development. Diverging pathways illustrate that interacting choices and actions made by diverse government, private sector and civil society actors can advance climate resilient development, shift pathways towards sustainability, and enable lower emissions and adaptation. Diverse knowledge and values include cultural values, Indigenous Knowledge, local knowledge, and scientific knowledge. Climatic and non-climatic events, such as droughts, floods or pandemics, pose more severe shocks to pathways with lower climate resilient development (red to yellow) than to pathways with higher climate resilient development (green). There are limits to adaptation and adaptive capacity for some human and natural systems at global warming of 1.5°C, and with every increment of warming, losses and damages will increase. The development pathways taken by countries at all stages of economic development impact GHG emissions and mitigation challenges and opportunities, which vary across countries and regions. Pathways and opportunities for action are shaped by previous actions (or inactions and opportunities missed; dashed pathway) and enabling and constraining conditions (left panel), and take place in the context of climate risks, adaptation limits and development gaps. The longer emissions reductions are delayed, the fewer effective adaptation options. {*Figure 4.2, 3.1, 3.2, 3.4, 4.2, 4.4, 4.5, 4.6, 4.9*}

The Benefits of Near-Term Action

C.2 Deep, rapid, and sustained mitigation and accelerated implementation of adaptation actions in this decade would reduce projected losses and damages for humans and ecosystems (*very high confidence*), and deliver many co-benefits, especially for air quality and health (*high confidence*). Delayed mitigation and adaptation action would lock in high-emissions infrastructure, raise risks of stranded assets and cost-escalation, reduce feasibility, and increase losses and damages (*high confidence*). Near-term actions involve high up-front investments and potentially disruptive changes that can be lessened by a range of enabling policies (*high confidence*). {*2.1, 2.2, 3.1, 3.2, 3.3, 3.4, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8*}

C.2.1 Deep, rapid, and sustained mitigation and accelerated implementation of adaptation actions in this decade would reduce future losses and damages related to climate change for humans and ecosystems (*very high confidence*). As adaptation options often have long implementation times, accelerated implementation of adaptation in this decade is important to close adaptation gaps (*high confidence*). Comprehensive, effective, and innovative responses integrating adaptation and mitigation can harness synergies and reduce trade-offs between adaptation and mitigation (*high confidence*). {*4.1, 4.2, 4.3*}

C.2.2 Delayed mitigation action will further increase global warming and losses and damages will rise and additional human and natural systems will reach adaptation limits. Challenges from delayed adaptation and mitigation actions include the risk of cost escalation, lock-in of infrastructure, stranded assets, and reduced feasibility and effectiveness of adaptation and mitigation options. Without rapid, deep and sustained mitigation and accelerated adaptation actions, losses and damages will continue to increase, including projected adverse impacts in Africa, LDCs, SIDS, Central and South America[49], Asia and the Arctic, and will disproportionately affect the most vulnerable populations. *(high confidence)* {*2.1.2*, *3.1.2*, *3.2*, *3.3.1*, *3.3.3*, *4.1*, *4.2*, *4.3*} (*Figure SPM.3*, *Figure SPM.4*)

C.2.3 Accelerated climate action can also provide co-benefits (see also C.4) (*high confidence*). Many mitigation actions would have benefits for health through lower air pollution, active mobility (e.g., walking, cycling), and shifts to sustainable healthy diets (*high confidence*). Strong, rapid and sustained reductions in methane emissions can limit near-term warming and improve air quality by reducing global surface ozone (*high confidence*). Adaptation can generate multiple additional benefits such as improving agricultural productivity, innovation, health and well-being, food security, livelihood, and biodiversity conservation (*very high confidence*). {*4.2*, *4.5.4*, *4.5.5*, *4.6*}

C.2.4 Cost-benefit analysis remains limited in its ability to represent all avoided damages from climate change (*high confidence*). The economic benefits for human health from air quality improvement arising from mitigation action can be of the same order of magnitude as mitigation costs, and potentially even larger (*medium confidence*). Even without accounting for all the benefits of avoiding potential damages, the global economic and social benefit of limiting global warming to 2°C exceeds the cost of mitigation in most of the assessed literature (*medium confidence*)[50]. More rapid climate change mitigation, with emissions peaking earlier, increases co-benefits and reduces feasibility risks and costs in the long-term, but requires higher up-front investments (*high confidence*). {*3.4.1*, *4.2*}

C.2.5 Ambitious mitigation pathways imply large and sometimes disruptive changes in existing economic structures, with significant distributional consequences within and between countries. To accelerate climate action, the adverse consequences of these changes can be moderated by fiscal, financial, institutional and regulatory reforms and by integrating climate actions with macroeconomic policies through (i) economy-wide packages, consistent with national circumstances, supporting sustainable low-emission growth paths; (ii) climate resilient safety nets and social protection; and (iii) improved access to finance for low-emissions infrastructure and technologies, especially in developing countries. (*high confidence*) {*4.2*, *4.4*, *4.7*, *4.8.1*}

[49] The southern part of Mexico is included in the climatic subregion South Central America (SCA) for WGI. Mexico is assessed as part of North America for WGII. The climate change literature for the SCA region occasionally includes Mexico, and in those cases WGII assessment makes reference to Latin America. Mexico is considered part of Latin America and the Caribbean for WGIII.

[50] The evidence is too limited to make a similar robust conclusion for limiting warming to 1.5°C. Limiting global warming to 1.5°C instead of 2°C would increase the costs of mitigation, but also increase the benefits in terms of reduced impacts and related risks, and reduced adaptation needs (*high confidence*).

There are multiple opportunities for scaling up climate action

a) **Feasibility of climate responses and adaptation, and potential of mitigation options in the near term**

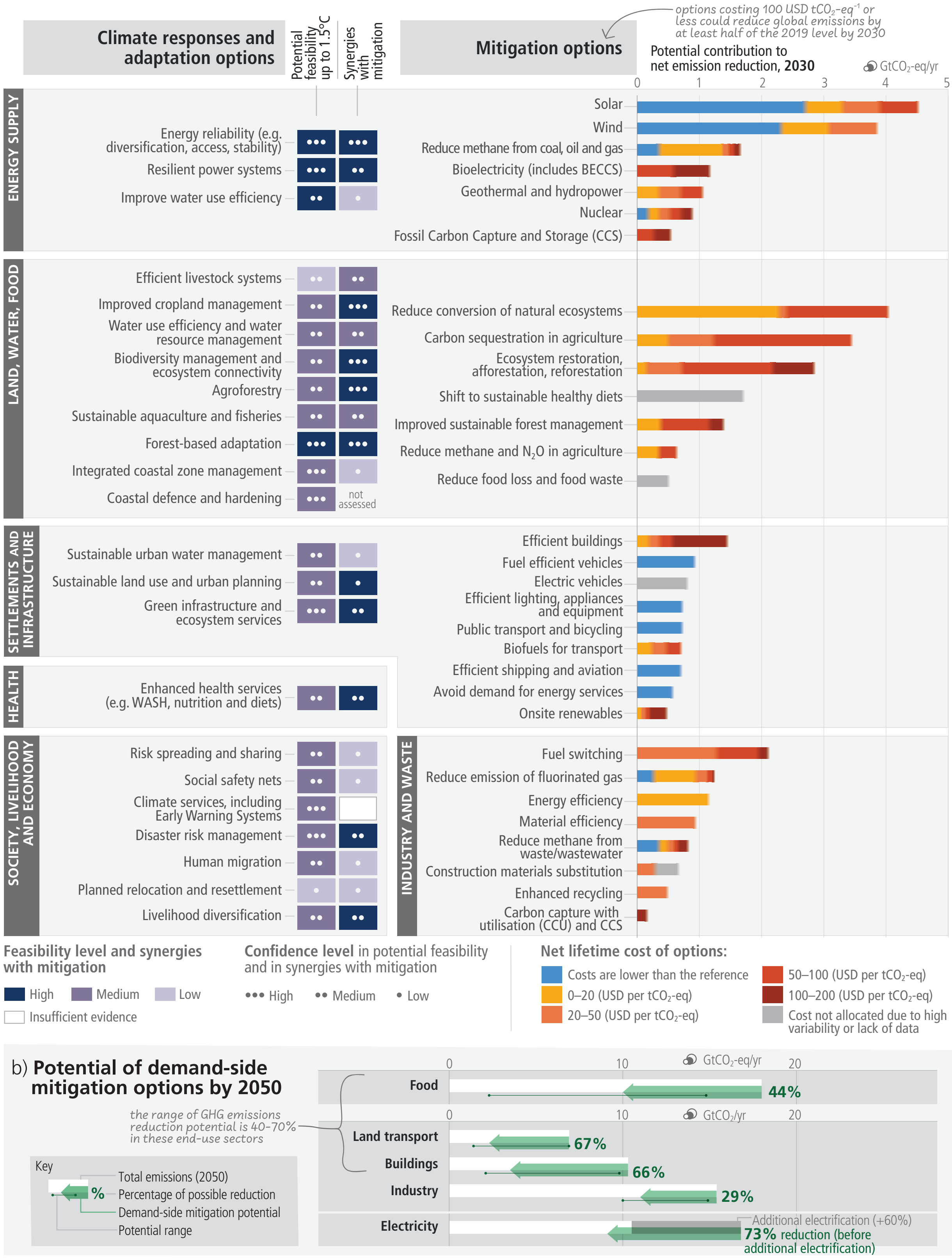

Figure SPM.7: Multiple Opportunities for scaling up climate action. Panel (a) presents selected mitigation and adaptation options across different systems. The left-hand side of panel a shows climate responses and adaptation options assessed for their multidimensional feasibility at global scale, in the near term and up to 1.5°C global warming. As literature above 1.5°C is limited, feasibility at higher levels of warming may change, which is currently not possible to assess robustly. The term response is used here in addition to adaptation because some responses, such as migration, relocation and resettlement may or may not be considered to be adaptation. Forest based adaptation includes sustainable forest management, forest conservation and restoration, reforestation and afforestation. WASH refers to water, sanitation and hygiene. Six feasibility dimensions (economic, technological, institutional, social, environmental and geophysical) were used to calculate the potential feasibility of climate responses and adaptation options, along with their synergies with mitigation. For potential feasibility and feasibility dimensions, the figure shows high, medium, or low feasibility. Synergies with mitigation are identified as high, medium, and low. The right-hand side of Panel a provides an overview of selected mitigation options and their estimated costs and potentials in 2030. Costs are net lifetime discounted monetary costs of avoided GHG emissions calculated relative to a reference technology. Relative potentials and costs will vary by place, context and time and in the longer term compared to 2030. The potential (horizontal axis) is the net GHG emission reduction (sum of reduced emissions and/or enhanced sinks) broken down into cost categories (coloured bar segments) relative to an emission baseline consisting of current policy (around 2019) reference scenarios from the AR6 scenarios database. The potentials are assessed independently for each option and are not additive. Health system mitigation options are included mostly in settlement and infrastructure (e.g., efficient healthcare buildings) and cannot be identified separately. Fuel switching in industry refers to switching to electricity, hydrogen, bioenergy and natural gas. Gradual colour transitions indicate uncertain breakdown into cost categories due to uncertainty or heavy context dependency. The uncertainty in the total potential is typically 25–50%. **Panel (b)** displays the indicative potential of demand-side mitigation options for 2050. Potentials are estimated based on approximately 500 bottom-up studies representing all global regions. The baseline (white bar) is provided by the sectoral mean GHG emissions in 2050 of the two scenarios (IEA-STEPS and IP_ModAct) consistent with policies announced by national governments until 2020. The green arrow represents the demand-side emissions reductions potentials. The range in potential is shown by a line connecting dots displaying the highest and the lowest potentials reported in the literature. Food shows demand-side potential of socio-cultural factors and infrastructure use, and changes in land-use patterns enabled by change in food demand. Demand-side measures and new ways of end-use service provision can reduce global GHG emissions in end-use sectors (buildings, land transport, food) by 40–70% by 2050 compared to baseline scenarios, while some regions and socioeconomic groups require additional energy and resources. The last row shows how demand-side mitigation options in other sectors can influence overall electricity demand. The dark grey bar shows the projected increase in electricity demand above the 2050 baseline due to increasing electrification in the other sectors. Based on a bottom-up assessment, this projected increase in electricity demand can be avoided through demand-side mitigation options in the domains of infrastructure use and socio-cultural factors that influence electricity usage in industry, land transport, and buildings (green arrow). {*Figure 4.4*}

Mitigation and Adaptation Options across Systems

C.3 Rapid and far-reaching transitions across all sectors and systems are necessary to achieve deep and sustained emissions reductions and secure a liveable and sustainable future for all. These system transitions involve a significant upscaling of a wide portfolio of mitigation and adaptation options. Feasible, effective, and low-cost options for mitigation and adaptation are already available, with differences across systems and regions. (*high confidence*) {*4.1, 4.5, 4.6*} (*Figure SPM.7*)

C.3.1 The systemic change required to achieve rapid and deep emissions reductions and transformative adaptation to climate change is unprecedented in terms of scale, but not necessarily in terms of speed (*medium confidence*). Systems transitions include: deployment of low- or zero-emission technologies; reducing and changing demand through infrastructure design and access, socio-cultural and behavioural changes, and increased technological efficiency and adoption; social protection, climate services or other services; and protecting and restoring ecosystems (*high confidence*). Feasible, effective, and low-cost options for mitigation and adaptation are already available (*high confidence*). The availability, feasibility and potential of mitigation and adaptation options in the near term differs across systems and regions (*very high confidence*). {*4.1, 4.5.1 to 4.5.6*} (*Figure SPM.7*)

Energy Systems

C.3.2 Net zero CO_2 energy systems entail: a substantial reduction in overall fossil fuel use, minimal use of unabated fossil fuels[51], and use of carbon capture and storage in the remaining fossil fuel systems; electricity systems that emit no net CO_2; widespread electrification; alternative energy carriers in applications less amenable to electrification; energy conservation and efficiency; and greater integration across the energy system (*high confidence*). Large contributions to emissions reductions with costs less than USD 20 tCO_2-eq^{-1} come from solar and wind energy, energy efficiency improvements, and methane emissions reductions (coal mining, oil and gas, waste) (*medium confidence*). There are feasible adaptation options that support infrastructure resilience, reliable power systems and efficient water use for existing and new energy generation systems (*very high confidence*). Energy generation diversification (e.g., via wind, solar, small scale hydropower) and demand-side management (e.g., storage and energy efficiency improvements) can increase energy reliability and reduce vulnerabilities to climate change (*high confidence*). Climate responsive energy markets, updated design standards on energy assets according to current and projected climate change, smart-grid technologies, robust transmission systems and improved capacity to respond to supply deficits have high feasibility in the medium to long term, with mitigation co-benefits (*very high confidence*). {*4.5.1*} (*Figure SPM.7*)

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51 In this context, 'unabated fossil fuels' refers to fossil fuels produced and used without interventions that substantially reduce the amount of GHG emitted throughout the life cycle; for example, capturing 90% or more CO_2 from power plants, or 50–80% of fugitive methane emissions from energy supply.

Industry and Transport

C.3.3 Reducing industry GHG emissions entails coordinated action throughout value chains to promote all mitigation options, including demand management, energy and materials efficiency, circular material flows, as well as abatement technologies and transformational changes in production processes (*high confidence*). In transport, sustainable biofuels, low-emissions hydrogen, and derivatives (including ammonia and synthetic fuels) can support mitigation of CO_2 emissions from shipping, aviation, and heavy-duty land transport but require production process improvements and cost reductions (*medium confidence*). Sustainable biofuels can offer additional mitigation benefits in land-based transport in the short and medium term (*medium confidence*). Electric vehicles powered by low-GHG emissions electricity have large potential to reduce land-based transport GHG emissions, on a life cycle basis (*high confidence*). Advances in battery technologies could facilitate the electrification of heavy-duty trucks and compliment conventional electric rail systems (*medium confidence*). The environmental footprint of battery production and growing concerns about critical minerals can be addressed by material and supply diversification strategies, energy and material efficiency improvements, and circular material flows (*medium confidence*). {*4.5.2, 4.5.3*} (*Figure SPM.7*)

Cities, Settlements and Infrastructure

C.3.4 Urban systems are critical for achieving deep emissions reductions and advancing climate resilient development (*high confidence*). Key adaptation and mitigation elements in cities include considering climate change impacts and risks (e.g., through climate services) in the design and planning of settlements and infrastructure; land use planning to achieve compact urban form, co-location of jobs and housing; supporting public transport and active mobility (e.g., walking and cycling); the efficient design, construction, retrofit, and use of buildings; reducing and changing energy and material consumption; sufficiency[52]; material substitution; and electrification in combination with low emissions sources (*high confidence*). Urban transitions that offer benefits for mitigation, adaptation, human health and well-being, ecosystem services, and vulnerability reduction for low-income communities are fostered by inclusive long-term planning that takes an integrated approach to physical, natural and social infrastructure (*high confidence*). Green/natural and blue infrastructure supports carbon uptake and storage and either singly or when combined with grey infrastructure can reduce energy use and risk from extreme events such as heatwaves, flooding, heavy precipitation and droughts, while generating co-benefits for health, well-being and livelihoods (*medium confidence*). {*4.5.3*}

Land, Ocean, Food, and Water

C.3.5 Many agriculture, forestry, and other land use (AFOLU) options provide adaptation and mitigation benefits that could be upscaled in the near term across most regions. Conservation, improved management, and restoration of forests and other ecosystems offer the largest share of economic mitigation potential, with reduced deforestation in tropical regions having the highest total mitigation potential. Ecosystem restoration, reforestation, and afforestation can lead to trade-offs due to competing demands on land. Minimizing trade-offs requires integrated approaches to meet multiple objectives including food security. Demand-side measures (shifting to sustainable healthy diets[53] and reducing food loss/waste) and sustainable agricultural intensification can reduce ecosystem conversion, and methane and nitrous oxide emissions, and free up land for reforestation and ecosystem restoration. Sustainably sourced agricultural and forest products, including long-lived wood products, can be used instead of more GHG-intensive products in other sectors. Effective adaptation options include cultivar improvements, agroforestry, community-based adaptation, farm and landscape diversification, and urban agriculture. These AFOLU response options require integration of biophysical, socioeconomic and other enabling factors. Some options, such as conservation of high-carbon ecosystems (e.g., peatlands, wetlands, rangelands, mangroves and forests), deliver immediate benefits, while others, such as restoration of high-carbon ecosystems, take decades to deliver measurable results. (*high confidence*) {*4.5.4*} (*Figure SPM.7*)

C.3.6 Maintaining the resilience of biodiversity and ecosystem services at a global scale depends on effective and equitable conservation of approximately 30% to 50% of Earth's land, freshwater and ocean areas, including currently near-natural ecosystems (*high confidence*). Conservation, protection and restoration of terrestrial, freshwater, coastal and

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52 A set of measures and daily practices that avoid demand for energy, materials, land, and water while delivering human well-being for all within planetary boundaries. {*4.5.3*}

53 'Sustainable healthy diets' promote all dimensions of individuals' health and well-being; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable, as described in FAO and WHO. The related concept of 'balanced diets' refers to diets that feature plant-based foods, such as those based on coarse grains, legumes, fruits and vegetables, nuts and seeds, and animal-sourced food produced in resilient, sustainable and low-GHG emission systems, as described in SRCCL.

ocean ecosystems, together with targeted management to adapt to unavoidable impacts of climate change reduces the vulnerability of biodiversity and ecosystem services to climate change (*high confidence*), reduces coastal erosion and flooding (*high confidence*), and could increase carbon uptake and storage if global warming is limited (*medium confidence*). Rebuilding overexploited or depleted fisheries reduces negative climate change impacts on fisheries (*medium confidence*) and supports food security, biodiversity, human health and well-being (*high confidence*). Land restoration contributes to climate change mitigation and adaptation with synergies via enhanced ecosystem services and with economically positive returns and co-benefits for poverty reduction and improved livelihoods (*high confidence*). Cooperation, and inclusive decision making, with Indigenous Peoples and local communities, as well as recognition of inherent rights of Indigenous Peoples, is integral to successful adaptation and mitigation across forests and other ecosystems (*high confidence*). {*4.5.4, 4.6*} (*Figure SPM.7*)

Health and Nutrition

C.3.7 Human health will benefit from integrated mitigation and adaptation options that mainstream health into food, infrastructure, social protection, and water policies (*very high confidence*). Effective adaptation options exist to help protect human health and well-being, including: strengthening public health programs related to climate-sensitive diseases, increasing health systems resilience, improving ecosystem health, improving access to potable water, reducing exposure of water and sanitation systems to flooding, improving surveillance and early warning systems, vaccine development (*very high confidence*), improving access to mental healthcare, and Heat Health Action Plans that include early warning and response systems (*high confidence*). Adaptation strategies which reduce food loss and waste or support balanced, sustainable healthy diets contribute to nutrition, health, biodiversity and other environmental benefits (*high confidence*). {*4.5.5*} (*Figure SPM.7*)

Society, Livelihoods, and Economies

C.3.8 Policy mixes that include weather and health insurance, social protection and adaptive social safety nets, contingent finance and reserve funds, and universal access to early warning systems combined with effective contingency plans, can reduce vulnerability and exposure of human systems. Disaster risk management, early warning systems, climate services and risk spreading and sharing approaches have broad applicability across sectors. Increasing education including capacity building, climate literacy, and information provided through climate services and community approaches can facilitate heightened risk perception and accelerate behavioural changes and planning. (*high confidence*) {*4.5.6*}

Synergies and Trade-Offs with Sustainable Development

C.4 Accelerated and equitable action in mitigating and adapting to climate change impacts is critical to sustainable development. Mitigation and adaptation actions have more synergies than trade-offs with Sustainable Development Goals. Synergies and trade-offs depend on context and scale of implementation. (*high confidence*) {*3.4, 4.2, 4.4, 4.5, 4.6, 4.9, Figure 4.5*}

C.4.1 Mitigation efforts embedded within the wider development context can increase the pace, depth and breadth of emission reductions (*medium confidence*). Countries at all stages of economic development seek to improve the well-being of people, and their development priorities reflect different starting points and contexts. Different contexts include but are not limited to social, economic, environmental, cultural, political circumstances, resource endowment, capabilities, international environment, and prior development (*high confidence*). In regions with high dependency on fossil fuels for, among other things, revenue and employment generation, mitigating risk for sustainable development requires policies that promote economic and energy sector diversification and considerations of just transitions principles, processes and practices (*high confidence*). Eradicating extreme poverty, energy poverty, and providing decent living standards in low-emitting countries / regions in the context of achieving sustainable development objectives, in the near term, can be achieved without significant global emissions growth (*high confidence*). {*4.4, 4.6, Annex I: Glossary*}

C.4.2 Many mitigation and adaptation actions have multiple synergies with Sustainable Development Goals (SDGs) and sustainable development generally, but some actions can also have trade-offs. Potential synergies with SDGs exceed potential trade-offs; synergies and trade-offs depend on the pace and magnitude of change and the development context including inequalities with consideration of climate justice. Trade-offs can be evaluated and minimised by giving emphasis to capacity building, finance, governance, technology transfer, investments, development, context specific gender-based and other social equity considerations with meaningful participation of Indigenous Peoples, local communities and vulnerable populations. (*high confidence*) {*3.4.1, 4.6, Figure 4.5, 4.9*}

C.4.3 Implementing both mitigation and adaptation actions together and taking trade-offs into account supports co-benefits and synergies for human health and well-being. For example, improved access to clean energy sources and technologies generates health benefits especially for women and children; electrification combined with low-GHG energy, and shifts to active mobility and public transport can enhance air quality, health, employment, and can elicit energy security and deliver equity. (*high confidence*) {*4.2*, *4.5.3*, *4.5.5*, *4.6*, *4.9*}

Equity and Inclusion

C.5 Prioritising equity, climate justice, social justice, inclusion and just transition processes can enable adaptation and ambitious mitigation actions and climate resilient development. Adaptation outcomes are enhanced by increased support to regions and people with the highest vulnerability to climatic hazards. Integrating climate adaptation into social protection programs improves resilience. Many options are available for reducing emission-intensive consumption, including through behavioural and lifestyle changes, with co-benefits for societal well-being. (*high confidence*) {*4.4, 4.5*}

C.5.1 Equity remains a central element in the UN climate regime, notwithstanding shifts in differentiation between states over time and challenges in assessing fair shares. Ambitious mitigation pathways imply large and sometimes disruptive changes in economic structure, with significant distributional consequences, within and between countries. Distributional consequences within and between countries include shifting of income and employment during the transition from high- to low-emissions activities. (*high confidence*) {*4.4*}

C.5.2 Adaptation and mitigation actions that prioritise equity, social justice, climate justice, rights-based approaches, and inclusivity, lead to more sustainable outcomes, reduce trade-offs, support transformative change and advance climate resilient development. Redistributive policies across sectors and regions that shield the poor and vulnerable, social safety nets, equity, inclusion and just transitions, at all scales can enable deeper societal ambitions and resolve trade-offs with sustainable development goals. Attention to equity and broad and meaningful participation of all relevant actors in decision making at all scales can build social trust which builds on equitable sharing of benefits and burdens of mitigation that deepen and widen support for transformative changes. (*high confidence*) {*4.4*}

C.5.3 Regions and people (3.3 to 3.6 billion in number) with considerable development constraints have high vulnerability to climatic hazards (see A.2.2). Adaptation outcomes for the most vulnerable within and across countries and regions are enhanced through approaches focusing on equity, inclusivity and rights-based approaches. Vulnerability is exacerbated by inequity and marginalisation linked to e.g., gender, ethnicity, low incomes, informal settlements, disability, age, and historical and ongoing patterns of inequity such as colonialism, especially for many Indigenous Peoples and local communities. Integrating climate adaptation into social protection programs, including cash transfers and public works programs, is highly feasible and increases resilience to climate change, especially when supported by basic services and infrastructure. The greatest gains in well-being in urban areas can be achieved by prioritising access to finance to reduce climate risk for low-income and marginalised communities including people living in informal settlements. (*high confidence*) {*4.4*, *4.5.3*, *4.5.5*, *4.5.6*}

C.5.4 The design of regulatory instruments and economic instruments and consumption-based approaches, can advance equity. Individuals with high socio-economic status contribute disproportionately to emissions, and have the highest potential for emissions reductions. Many options are available for reducing emission-intensive consumption while improving societal well-being. Socio-cultural options, behaviour and lifestyle changes supported by policies, infrastructure, and technology can help end-users shift to low-emissions-intensive consumption, with multiple co-benefits. A substantial share of the population in low-emitting countries lack access to modern energy services. Technology development, transfer, capacity building and financing can support developing countries / regions leapfrogging or transitioning to low-emissions transport systems thereby providing multiple co-benefits. Climate resilient development is advanced when actors work in equitable, just and inclusive ways to reconcile divergent interests, values and worldviews, toward equitable and just outcomes. (*high confidence*) {*2.1*, *4.4*}

Governance and Policies

C.6 Effective climate action is enabled by political commitment, well-aligned multilevel governance, institutional frameworks, laws, policies and strategies and enhanced access to finance and technology. Clear goals, coordination across multiple policy domains, and inclusive governance processes facilitate effective climate action. Regulatory and economic instruments can support deep emissions reductions and climate resilience if scaled up and applied widely. Climate resilient development benefits from drawing on diverse knowledge. (*high confidence*) {*2.2, 4.4, 4.5, 4.7*}

C.6.1 Effective climate governance enables mitigation and adaptation. Effective governance provides overall direction on setting targets and priorities and mainstreaming climate action across policy domains and levels, based on national circumstances and in the context of international cooperation. It enhances monitoring and evaluation and regulatory certainty, prioritising inclusive, transparent and equitable decision-making, and improves access to finance and technology (see C.7). (*high confidence*) {*2.2.2, 4.7*}

C.6.2 Effective local, municipal, national and subnational institutions build consensus for climate action among diverse interests, enable coordination and inform strategy setting but require adequate institutional capacity. Policy support is influenced by actors in civil society, including businesses, youth, women, labour, media, Indigenous Peoples, and local communities. Effectiveness is enhanced by political commitment and partnerships between different groups in society. (*high confidence*) {*2.2, 4.7*}

C.6.3 Effective multilevel governence for mitigation, adaptation, risk management, and climate resilient development is enabled by inclusive decision processes that prioritise equity and justice in planning and implementation, allocation of appropriate resources, institutional review, and monitoring and evaluation. Vulnerabilities and climate risks are often reduced through carefully designed and implemented laws, policies, participatory processes, and interventions that address context specific inequities such as those based on gender, ethnicity, disability, age, location and income. (*high confidence*) {*4.4, 4.7*}

C.6.4 Regulatory and economic instruments could support deep emissions reductions if scaled up and applied more widely (*high confidence*). Scaling up and enhancing the use of regulatory instruments can improve mitigation outcomes in sectoral applications, consistent with national circumstances (*high confidence*). Where implemented, carbon pricing instruments have incentivized low-cost emissions reduction measures but have been less effective, on their own and at prevailing prices during the assessment period, to promote higher-cost measures necessary for further reductions (*medium confidence*). Equity and distributional impacts of such carbon pricing instruments, e.g., carbon taxes and emissions trading, can be addressed by using revenue to support low-income households, among other approaches. Removing fossil fuel subsidies would reduce emissions[54] and yield benefits such as improved public revenue, macroeconomic and sustainability performance; subsidy removal can have adverse distributional impacts, especially on the most economically vulnerable groups which, in some cases can be mitigated by measures such as redistributing revenue saved, all of which depend on national circumstances (*high confidence*). Economy-wide policy packages, such as public spending commitments and pricing reforms, can meet short-term economic goals while reducing emissions and shifting development pathways towards sustainability (*medium confidence*). Effective policy packages would be comprehensive, consistent, balanced across objectives, and tailored to national circumstances (*high confidence*). {*2.2.2, 4.7*}

C.6.5 Drawing on diverse knowledges and cultural values, meaningful participation and inclusive engagement processes—including Indigenous Knowledge, local knowledge, and scientific knowledge—facilitates climate resilient development, builds capacity and allows locally appropriate and socially acceptable solutions. (*high confidence*) {*4.4, 4.5.6, 4.7*}

[54] Fossil fuel subsidy removal is projected by various studies to reduce global CO_2 emission by 1 to 4%, and GHG emissions by up to 10% by 2030, varying across regions (*medium confidence*).

Finance, Technology and International Cooperation

C.7 Finance, technology and international cooperation are critical enablers for accelerated climate action. If climate goals are to be achieved, both adaptation and mitigation financing would need to increase many-fold. There is sufficient global capital to close the global investment gaps but there are barriers to redirect capital to climate action. Enhancing technology innovation systems is key to accelerate the widespread adoption of technologies and practices. Enhancing international cooperation is possible through multiple channels. (*high confidence*) {*2.3, 4.8*}

C.7.1 Improved availability of and access to finance[55] would enable accelerated climate action (*very high confidence*). Addressing needs and gaps and broadening equitable access to domestic and international finance, when combined with other supportive actions, can act as a catalyst for accelerating adaptation and mitigation, and enabling climate resilient development (*high confidence*). If climate goals are to be achieved, and to address rising risks and accelerate investments in emissions reductions, both adaptation and mitigation finance would need to increase many-fold (*high confidence*). {*4.8.1*}

C.7.2 Increased access to finance can build capacity and address soft limits to adaptation and avert rising risks, especially for developing countries, vulnerable groups, regions and sectors (*high confidence*). Public finance is an important enabler of adaptation and mitigation, and can also leverage private finance (*high confidence*). Average annual modelled mitigation investment requirements for 2020 to 2030 in scenarios that limit warming to 2°C or 1.5°C are a factor of three to six greater than current levels[56], and total mitigation investments (public, private, domestic and international) would need to increase across all sectors and regions (*medium confidence*). Even if extensive global mitigation efforts are implemented, there will be a need for financial, technical, and human resources for adaptation (*high confidence*). {*4.3, 4.8.1*}

C.7.3 There is sufficient global capital and liquidity to close global investment gaps, given the size of the global financial system, but there are barriers to redirect capital to climate action both within and outside the global financial sector and in the context of economic vulnerabilities and indebtedness facing developing countries. Reducing financing barriers for scaling up financial flows would require clear signalling and support by governments, including a stronger alignment of public finances in order to lower real and perceived regulatory, cost and market barriers and risks and improving the risk-return profile of investments. At the same time, depending on national contexts, financial actors, including investors, financial intermediaries, central banks and financial regulators can shift the systemic underpricing of climate-related risks, and reduce sectoral and regional mismatches between available capital and investment needs. (*high confidence*) {*4.8.1*}

C.7.4 Tracked financial flows fall short of the levels needed for adaptation and to achieve mitigation goals across all sectors and regions. These gaps create many opportunities and the challenge of closing gaps is largest in developing countries. Accelerated financial support for developing countries from developed countries and other sources is a critical enabler to enhance adaptation and mitigation actions and address inequities in access to finance, including its costs, terms and conditions, and economic vulnerability to climate change for developing countries. Scaled-up public grants for mitigation and adaptation funding for vulnerable regions, especially in Sub-Saharan Africa, would be cost-effective and have high social returns in terms of access to basic energy. Options for scaling up mitigation in developing countries include: increased levels of public finance and publicly mobilised private finance flows from developed to developing countries in the context of the USD 100 billion-a-year goal; increased use of public guarantees to reduce risks and leverage private flows at lower cost; local capital markets development; and building greater trust in international cooperation processes. A coordinated effort to make the post-pandemic recovery sustainable over the longer-term can accelerate climate action, including in developing regions and countries facing high debt costs, debt distress and macroeconomic uncertainty. (*high confidence*) {*4.8.1*}

C.7.5 Enhancing technology innovation systems can provide opportunities to lower emissions growth, create social and environmental co-benefits, and achieve other SDGs. Policy packages tailored to national contexts and technological characteristics have been effective in supporting low-emission innovation and technology diffusion. Public policies can

[55] Finance originates from diverse sources: public or private, local, national or international, bilateral or multilateral, and alternative sources. It can take the form of grants, technical assistance, loans (concessional and non-concessional), bonds, equity, risk insurance and financial guarantees (of different types).

[56] These estimates rely on scenario assumptions.

support training and R&D, complemented by both regulatory and market-based instruments that create incentives and market opportunities. Technological innovation can have trade-offs such as new and greater environmental impacts, social inequalities, overdependence on foreign knowledge and providers, distributional impacts and rebound effects[57], requiring appropriate governance and policies to enhance potential and reduce trade-offs. Innovation and adoption of low-emission technologies lags in most developing countries, particularly least developed ones, due in part to weaker enabling conditions, including limited finance, technology development and transfer, and capacity building. (*high confidence*) {*4.8.3*}

C.7.6 International cooperation is a critical enabler for achieving ambitious climate change mitigation, adaptation, and climate resilient development (*high confidence*). Climate resilient development is enabled by increased international cooperation including mobilising and enhancing access to finance, particularly for developing countries, vulnerable regions, sectors and groups and aligning finance flows for climate action to be consistent with ambition levels and funding needs (*high confidence*). Enhancing international cooperation on finance, technology and capacity building can enable greater ambition and can act as a catalyst for accelerating mitigation and adaptation, and shifting development pathways towards sustainability (*high confidence*). This includes support to NDCs and accelerating technology development and deployment (*high confidence*). Transnational partnerships can stimulate policy development, technology diffusion, adaptation and mitigation, though uncertainties remain over their costs, feasibility and effectiveness (*medium confidence*). International environmental and sectoral agreements, institutions and initiatives are helping, and in some cases may help, to stimulate low GHG emissions investments and reduce emissions (*medium confidence*). {*2.2.2, 4.8.2*}

[57] Leading to lower net emission reductions or even emission increases.

United Nations | Secretary-General

Interlaken, Switzerland

20 March 2023

Secretary-General's video message for press conference to launch the Synthesis Report of the Intergovernmental Panel on Climate Change

Watch the video here.

Dear friends,

Humanity is on thin ice – and that ice is melting fast.

As today's report of the Intergovernmental Panel on Climate Change (IPCC) details, humans are responsible for virtually all global heating over the last 200 years.

The rate of temperature rise in the last half century is the highest in 2,000 years.

Concentrations of carbon dioxide are at their highest in at least two million years.

The climate time-bomb is ticking.

But today's IPCC report is a how-to guide to defuse the climate time-bomb.

It is a survival guide for humanity.

As it shows, the 1.5-degree limit is achievable.

But it will take a quantum leap in climate action.

This report is a clarion call to massively fast-track climate efforts by every country and every sector and on every timeframe.

In short, our world needs climate action on all fronts -- everything, everywhere, all at once.

I have proposed to the G20 a Climate Solidarity Pact – in which all big emitters make extra efforts to cut emissions, and wealthier countries mobilize financial and technical resources to support emerging economies in a common effort to keep 1.5 degrees alive.

Today, I am presenting a plan to super-charge efforts to achieve this Climate Solidarity Pact through an all-hands-on-deck Acceleration Agenda.

It starts with parties immediately hitting the fast-forward button on their net zero deadlines to get to global net zero by 2050 – in line with the principle of common but differentiated responsibilities and respective capabilities, in light of different national circumstances.

Specifically, leaders of developed countries must commit to reaching net zero as close as possible to 2040, the limit they should all aim to respect.

This can be done. Some have already set a target as early as 2035.

Leaders in emerging economies must commit to reaching net zero as close as possible to 2050 – again, the limit they should all aim to respect.

A number have already made the 2050 commitment.

This is the moment for all G20 members to come together in a joint effort, pooling their resources and scientific capacities as well as their proven and affordable technologies through the public and private sectors to make carbon neutrality a reality by 2050.

Every country must be part of the solution.

Demanding others move first only ensures humanity comes last.

The Acceleration Agenda calls for a number of other actions.

Specifically:
No new coal and the phasing out of coal by 2030 in OECD countries and 2040 in all other countries.

Ending all international public and private funding of coal.

Ensuring net zero electricity generation by 2035 for all developed countries and 2040 for the rest of the world.

Ceasing all licensing or funding of new oil and gas – consistent with the findings of the International Energy Agency.

Stopping any expansion of existing oil and gas reserves.

Shifting subsidies from fossil fuels to a just energy transition.

Establishing a global phase down of existing oil and gas production compatible with the 2050 global net zero target.

I urge all governments to prepare energy transition plans consistent with these actions and ready for investors.

I am also calling on CEOs of all oil and gas companies to be part of the solution.

They should present credible, comprehensive and detailed transition plans in line with the recommendations of my High-Level Expert Group on net zero pledges.

These plans must clearly detail actual emission cuts for 2025 and 2030, and efforts to change business models to phase out fossil fuels and scale up renewable energy.

This acceleration has already started in some sectors, but investors now need crystal clear signals.

And all governments need the assurance that business leaders will help them deliver on extra efforts – but governments must also create an enabling policy and regulatory environment.

Shipping, aviation, steel, cement, aluminum, agriculture – every sector must be aligned with net zero by 2050 with clear plans including interim targets to get there.

At the same time, we need to seize the opportunity to invest in credible innovations that can contribute to reaching our global targets.

We must also speed-up efforts to deliver climate justice to those on the frontlines of many crises – none of them they caused.

We can do this by:
Safeguarding the most vulnerable communities, and scaling up finance and capacities for adaptation and loss and damage.

Promoting reforms to ensure Multilateral Development Banks provide more grants and concessional loans and fully mobilize private finance.

Delivering on the financial commitments made in Copenhagen, Paris and Glasgow.

Replenishing the Green Climate Fund this year and developing a roadmap to double adaptation finance before 2025.

Protecting everyone with early warning systems against natural disasters in four years.

Implementing the new loss and damage fund this year.

The longer we wait on any of these crucial issues, the harder it will become.

In less than nine months, leaders will gather at COP28 for the first global stocktake of the Paris Agreement.

They will also launch the process to prepare the next cycle of national climate plans – or Nationally Determined Contributions -- due in 2025.

These new climate plans must reflect the acceleration we need now, over this decade and the next.

By the end of COP28, I count on all G20 leaders to have committed to ambitious new economy-wide nationally determined contributions encompassing all greenhouse gases and indicating their absolute emissions cuts targets for 2035 and 2040.

The transition must cover the entire economy.

Partial pledges won't cut it.

I look forward to welcoming "first movers" on the Acceleration Agenda at the Climate Ambition Summit in September in New York.

Once again, I thank the Intergovernmental Panel on Climate Change for showing the fact-based, science-grounded way out of the climate mess.

We have never been better equipped to solve the climate challenge – but we must move into warp speed climate action now.

We don't have a moment to lose.

Thank you.

- Former Secretaries-General
- Official Travels

THE TEAM

- Deputy Secretary-General
- Senior Management Group
- Global Leadership
- Messengers of Peace

RESOURCES

- Annual Report on the Work of the Organization
- Coordinator for Multilingualism
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Earth Syst. Sci. Data, 15, 2295–2327, 2023
https://doi.org/10.5194/essd-15-2295-2023

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Indicators of Global Climate Change 2022: annual update of large-scale indicators of the state of the climate system and human influence

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Received: 2 May 2023 – Discussion started: 5 May 2023
Revised: 25 May 2023 – Accepted: 27 May 202 – Published: 8 June 2023

Abstract. Intergovernmental Panel on Climate Change (IPCC) assessments are the trusted source of scientific evidence for climate negotiations taking place under the United Nations Framework Convention on Climate Change (UNFCCC), including the first global stocktake under the Paris Agreement that will conclude at COP28 in December 2023. Evidence-based decision-making needs to be informed by up-to-date and timely information on key indicators of the state of the climate system and of the human influence on the global climate system. However, successive IPCC reports are published at intervals of 5–10 years, creating potential for an information gap between report cycles.

We follow methods as close as possible to those used in the IPCC Sixth Assessment Report (AR6) Working Group One (WGI) report. We compile monitoring datasets to produce estimates for key climate indicators related to forcing of the climate system: emissions of greenhouse gases and short-lived climate forcers, greenhouse gas concentrations, radiative forcing, surface temperature changes, the Earth's energy imbalance, warming attributed to human activities, the remaining carbon budget, and estimates of global temperature extremes. The purpose of this effort, grounded in an open data, open science approach, is to make annually updated reliable global climate indicators available in the public domain (https://doi.org/10.5281/zenodo.8000192, Smith et al., 2023a). As they are traceable to IPCC report methods, they can be trusted by all parties involved in UNFCCC negotiations and help convey wider understanding of the latest knowledge of the climate system and its direction of travel.

The indicators show that human-induced warming reached 1.14 [0.9 to 1.4] °C averaged over the 2013–2022 decade and 1.26 [1.0 to 1.6] °C in 2022. Over the 2013–2022 period, human-induced warming has been increasing at an unprecedented rate of over 0.2 °C per decade. This high rate of warming is caused by a combination of greenhouse gas emissions being at an all-time high of 54 ± 5.3 $GtCO_2e$ over the last decade, as well as reductions in the strength of aerosol cooling. Despite this, there is evidence that increases in greenhouse gas emissions have slowed, and depending on societal choices, a continued series of these annual updates over the critical 2020s decade could track a change of direction for human influence on climate.

1 Introduction

Increased greenhouse gas concentrations combined with reductions in aerosol pollution have led to rapid increases in human-induced effective radiative forcing, which has in turn led to atmosphere, land, cryosphere and ocean warming (Gulev et al., 2021). This in turn has led to an intensification of many weather and climate extremes, particularly more frequent and more intense hot extremes, and heavy precipitation across most regions of the world (Seneviratne et al., 2021). Given the speed of recent change, and the need for evidence-based decision-making, this Indicators of Global Climate Change (IGCC) update assembles the latest scientific understanding on the current state and evolution of the climate system and of human influence to support policymakers whilst the next Intergovernmental Panel on Climate Change (IPCC) assessment is under preparation. This first annual update is focused on indicators related to heating of the climate system, building from greenhouse gas emissions towards estimates of human-induced warming and the remaining carbon budget. In future years, this effort could be expanded to encompass other indicators, including global precipitation changes and related extremes.

We adopt the Global Carbon Budget ethos of a community-wide inclusive effort that synthesises work from across a large and diverse global scientific community in a timely fashion (Friedlingstein et al., 2022a). Like the Global Carbon Budget, this initiative arises from the international science community to establish a knowledge base to support policy debate and action to meet the Paris Agreement temperature goal.

This update complements other international efforts under the auspices of the Global Climate Observing System (GCOS) and the World Meteorological Organization (WMO). Annual state-of-the-climate reports are released by the WMO which use much of the same data analysed here for surface temperature and energy budget trends. The Bulletin of American Meteorological Society (BAMS) releases annual state-of-the-climate reports covering many essential variables including temperature and greenhouse gas concentrations. However, these reports focus on statistics from the previous year and make slightly different choices over datasets and analysis compared to the IPCC (see Sect. 5). The Global Carbon Project publishes updated carbon dioxide datasets which are used directly in this report. There is no similarly structured activity that provides all the necessary datasets to update the assessment of human influence on global surface temperature annually.

The update is based on methodologies for key climate indicators assessed by the IPCC Sixth Assessment Report (AR6) of the physical science basis of climate change (Working Group One (WGI) report; IPCC, 2021a) as well as Chap. 2 of the WGIII report (Dhakal et al., 2022) and is aligned with the efforts initiated in AR6 to implement FAIR (Findable, Accessible, Interoperable, Reusable) principles for reproducibility and reusability (Pirani et al., 2022; Iturbide et al., 2022). IPCC reports make a much wider assessment of the science and methodologies – we do not attempt to reproduce the comprehensive nature of these IPCC assessments here.

The IPCC Special Report on Global Warming of 1.5 °C (SR1.5), published in 2018, provided an assessment of the level of human-induced warming and cumulative emissions to date (Allen et al., 2018) and the remaining carbon budget (Rogelj et al., 2018) to support the evidence base on how the world is progressing in terms of meeting aspects of the Paris Agreement. The AR6 WGI Report, published in 2021, assessed past, current and future changes of these and other key global climate indicators, as well as undertaking an assessment of the Earth's energy budget. It also updated its approach for estimating human-induced warming and global warming level. In AR6 WGI and here, reaching a level of global warming is defined as the global surface temperature change, averaged over a 20-year period, exceeding a particular level of global warming, for example, 1.5 °C global warming. Given the current rates of change and the likelihood of reaching 1.5 °C of global warming in the first half of the 2030s (Lee et al., 2021, 2023; Riahi et al., 2022), it is important to have robust, trusted and also timely climate indicators in the public domain to form an evidence base for effective science-based decision-making.

When making their assessments, authors of IPCC reports assess published literature but also apply established published analysis methods to assessed datasets, such as the dataset produced by the latest climate model intercomparison projects (Lee et al., 2021). The authors combine and analyse both model and observational data as part of their expert assessment, making assessments of the trustworthiness and error characteristics of different datasets. It is this synthetic analysis by IPCC authors that derives the estimates of key climate indicators. Wherever possible, these same assessed methodological approaches are implemented here to provide the updates with variations clearly flagged and documented. The same approach, using the same datasets (updated by 2 years) and methods as employed in WGI, was used in the AR6 Synthesis Report (2023) (AR6 SYR; Lee et al., 2023) to provide an updated assessment of the latest atmospheric well-mixed greenhouse gas concentrations (up to 2021) and decadal average change in global surface temperature (+1.15 °C [1.00–1.25 °C] in 2013–2022 for global surface temperature). However, the assessment of human-induced warming was not updated (and therefore only covers warming up to the decade 2010–2019), nor was the remaining carbon budget updated, so the related information in the AR6 SYR report remained based on data up to the end of 2019.

The indicators in this first annual update give important insights into the magnitude and the pace of global warming. This paper provides the basis for a dashboard of climate indicators grounded in IPCC methodologies and directly traceable to reports published as part of the AR6 cycle. We employ datasets that can be updated on a regular basis between the publication of IPCC reports. Note that there are other similar initiatives underway to update other AR6 cycle products; for example, the evolution of the WGI Interactive Atlas (Gutiérrez et al., 2021) is being developed under the Copernicus Climate Change Service (C3S) and has potential connections and synergies with this initiative that will be explored in the future.

Our longer-term ambition is to rigorously track both climate system change and methodological improvements between IPCC report cycles, thereby building consistency and awareness. An example of why tracking methodological change is important was the updated estimate for historic warming (the increase in global surface temperature from 1850–1900 to 1986–2005). This was 0.08 [−0.01 to 0.12] °C higher in the AR6 than in the fifth assessment report (AR5) and SR1.5. Datasets and methods of evaluating global temperature changes altered between the AR5 and AR6, leading to a small shift in the historical temperature. This was reflected in changes between AR5 and AR6, whereas SR1.5 mostly relied on methodologies from AR5 (see AR6 WGI Cross Chap. Box 2.3, Gulev et al., 2021). Annual updates provide indications of possible future methodological shifts that subsequent IPCC reports may make as science advances and can detail their impact on perceived trends.

The update is organised as follows: emissions (Sect. 2) and greenhouse gas (GHG) concentrations (Sect. 3) are used to develop updated estimates of effective radiative forcing (Sect. 4). Observations of global surface temperature change (Sect. 5) and Earth's energy imbalance (Sect. 6) are key global indicators of a warming world. The global surface temperature change is formally attributed to human activity in Sect. 7, which tracks human-induced warming. Section 8 updates the remaining carbon budget to policy-relevant temperature thresholds. Section 9 gives an example of global-scale indicators associated with climate extremes of maximum land surface temperatures.

An important purpose of the exercise is to make these indicators widely available and understood. Plans for a web dashboard are discussed in Sect. 10 and code and data availability in Sect. 11, and conclusions are presented in Sect. 12. Data are available at https://doi.org/10.5281/zenodo.8000192 (Smith et al., 2023a).

2 Emissions

Historic emissions from human activity were assessed in both AR6 WGI and WGIII. Chapter 5 of WGI assessed CO_2 and CH_4 emissions in the context of the carbon cycle (Canadell et al., 2021). Chapter 6 of WGI assessed emissions in the context of understanding the climate and air quality impacts of short-lived climate forcers (Szopa et al., 2021). Chapter 2 of WGIII, published 1 year later (Dhakal et al., 2022), looked at the sectoral sources of emissions and gave the most up-to-date understanding of the current level of emissions. This section bases its methods and data on those employed in this WGIII chapter.

2.1 Methods of estimating greenhouse gas emissions changes

Like in AR6 WGIII, net GHG emissions in this paper refer to releases of GHGs from anthropogenic sources minus removals by anthropogenic sinks, for those species of gases that are reported under the common reporting format of the UNFCCC. This includes CO_2 emissions from fossil fuels and industry (CO_2-FFI); net CO_2 emissions from land use, land-use change and forestry (CO_2-LULUCF); CH_4; N_2O; and fluorinated gas (F-gas) emissions. CO_2-FFI mainly comprises fossil-fuel combustion emissions, as well as emissions from industrial processes such as cement production. This excludes biomass and biofuel use by industry. CO_2-LULUCF is mainly driven by deforestation but also includes anthropogenic removals on land from afforestation and reforestation, emissions from logging and forest degradation, and emissions and removals in shifting cultivation cycles, as well as emissions and removals from other land-use change and land management activities, including peat burning and drainage. The non-CO_2 GHGs – CH_4, N_2O and F-gas emissions – are linked to the fossil-fuel extraction, agriculture, industry and waste sectors.

Global regulatory conventions have led to a twofold categorisation of F-gas emissions (also known as halogenated gases). Under UNFCCC accounting, countries record emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6) and nitrogen trifluoride (NF3) – hereinafter "UNFCCC F-gases". However, national inventories tend to exclude halons, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) – hereinafter "ODS (ozone-depleting substance) F-gases" – as they have been initially regulated under the Montreal Protocol and its amendments. In line with the WGIII assessment, ODS F-gases and other substances, including ozone and aerosols, are not included in our GHG emissions reporting but are included in subsequent assessments of concentrations, effective radiative forcing, human-induced warming, carbon budgets and climate impacts in line with the WGI assessment.

There are also varying conventions used to quantify CO_2-LULUCF fluxes. These include the use of bookkeeping models, dynamic global vegetation models (DGVMs) and the national inventory approach (Pongratz et al., 2021). Each differs in terms of their applied system boundaries and definitions and is not directly comparable. However, efforts to "translate" between bookkeeping estimates and national inventories using DGVMs have demonstrated a degree of consistency between the varying approaches (Friedlingstein et al., 2022a; Grassi et al., 2023).

Each category of GHG emissions included here is covered by varying primary sources and datasets. Although many datasets cover individual categories, few extend across multiple categories, and only a minority have frequent and timely update schedules. Notable datasets include the Global Carbon Budget (GCB; Friedlingstein et al., 2022b), which covers CO_2-FFI and CO_2-LULUCF; the Emissions Database for Global Atmospheric Research (EDGAR; Crippa et al., 2022) and the Potsdam Real-time Integrated Model for probabilistic Assessment of emissions Paths (PRIMAP-hist; Gütschow et al., 2016; Gütschow and Pflüger 2023), which cover CO_2-FFI, CH_4, N_2O and UNFCCC F-gases; and the Community Emissions Data System (CEDS; O'Rourke et al., 2021), which covers CO_2-FFI, CH_4, and N_2O. As detailed below, not all these datasets were employed in this update.

In AR6 WGIII, total net GHG emissions were calculated as the sum of CO_2-FFI, CH_4, N_2O and UNFCCC F-gases from EDGAR and net CO_2-LULUCF emissions from the GCB. Net CO_2-LULUCF emissions followed the GCB convention and were derived from the average of three bookkeeping models (Hansis et al., 2015; Houghton and Nassikas, 2017; Gasser et al., 2020). Version 6 of EDGAR was used (with a fast-track methodology applied for the final year of data – 2019), alongside the 2020 version of the GCB (Friedlingstein et al., 2020). CO_2-equivalent emissions were calculated using global warming potentials with a 100-year time horizon from AR6 WGI Chap. 7 (Forster et al., 2021). Uncertainty ranges were based on a comparative assessment of available data and expert judgement, corresponding to a 90 % confidence interval (Minx et al., 2021): ±8 % for CO_2-FFI, ±70 % for CO_2-LULUCF, ±30 % for CH_4 and F-gases, and ±60 % for N_2O (note that the GCB assesses 1 standard deviation uncertainty for CO_2-FFI as ±5 % and for CO_2-LULUCF as ±2.6 $GtCO_2$; Friedlingstein et al., 2022a). The total uncertainty was summed in quadrature, assuming independence of estimates per species/source. Reflecting these uncertainties, AR6 WGIII reported emissions to two significant figures only. Uncertainties in GWP100 metrics were not applied (Minx et al., 2021).

This analysis tracks the same compilation of GHGs as in AR6 WGIII. We follow the same approach for estimating uncertainties and CO_2-equivalent emissions. We also use the same type of data sources but make important changes to the specific selection of data sources to further improve the quality of the data, as suggested in the knowledge gap discussion of the WGIII report (Dhakal et al., 2022). Instead of using EDGAR data (which are now available as version 7), we use GCB data for CO_2-FFI, PRIMAP-hist data for CH_4 and N_2O, and atmospheric concentrations with best-estimate lifetimes for UNFCCC F-gas emissions (Hodnebrog et al., 2020). As in AR6 WGIII we use GCB for net CO_2-LULUCF emissions, taking the average of three bookkeeping models.

There are three reasons for these specific data choices. First, national greenhouse gas emissions inventories tend to use improved, higher-tier methods for estimating emissions fluxes than global inventories such as EDGAR or CEDS (Dhakal et al., 2022; Minx et al., 2021). As GCB and PRIMAP-hist integrate the most recent national inventory submissions to the UNFCCC, selecting these databases makes best use of country-level improvements in data-gathering infrastructures. Second, comprehensive reporting of F-gas emissions has remained challenging in national inventories and may exclude some military applications (see Minx et al., 2021; Dhakal et al., 2022). However, F-gases are entirely anthropogenic substances, and their concentrations can be measured effectively and reliably in the atmosphere. We therefore follow the AR6 WGI approach in making use of direct atmospheric observations. Third, the choice of GCB data for CO_2-FFI means we can integrate its projection of that year's CO_2 emissions at the time of publication (i.e. for 2022). No other dataset except GCB provides projections of CO_2 emissions on this time frame. At this point in the publication cycle (mid-year), the other chosen sources provide data points with a 2-year time lag (i.e. for 2021). While these data choices inform our overall assessment of GHG emissions, we provide a comparison across datasets for each emissions category, as well as between our estimates and an estimate derived from AR6 WGIII-like databases (i.e. EDGAR for CO_2-FFI and non-CO_2 GHG emissions, GCB for CO_2-LULUCF).

2.2 Updated global greenhouse gas emissions

Total global GHG emissions reached 55 ± 5.2 $GtCO_2e$ in 2021. The main contributing sources were CO_2-FFI (37 ± 3 $GtCO_2$), CO_2-LULUCF (3.9 ± 2.8 $GtCO_2$), CH_4 (8.9 ± 2.7 $GtCO_2e$), N_2O (2.9 ± 1.8 $GtCO_2e$) and F-gas emissions (2 ± 0.59 $GtCO_2e$). GHG emissions rebounded in 2021, following a single-year decline during the COVID-19-induced lockdowns of 2020. Prior to this event in 2019, emissions were 55 ± 5.4 $GtCO_2e$ – i.e. almost the same level as in 2021. Initial projections indicate that CO_2 emissions from fossil fuel and industry and land-use change remained similar in 2022, at 37 ± 3 and 3.9 ± 2.8 $GtCO_2$, respectively (Friedlingstein et al., 2022a). Note that ODS F-gases such as chlorofluorocarbons and hydrochlorofluorocarbons are excluded from national GHG emissions inventories. For consistency with AR6, they are also excluded here. Including them here would increase total global GHG emissions by 1.6 $GtCO_2e$ in 2021.

Average GHG emissions for the decade 2012–2021 were 54 ± 5.3 $GtCO_2e$. Average decadal GHG emissions have increased steadily since the 1970s across all major groups of GHGs, driven primarily by increasing CO_2 emissions from fossil fuel and industry but also rising emissions of CH_4 and N_2O. UNFCCC F-gas emissions have grown more rapidly than other greenhouse gases reported under the UNFCCC but from low levels. By contrast, ODS F-gas emissions have declined substantially since the 1990s. Both the magnitude and trend of CO_2 emissions from land-use change remain highly uncertain, with the latest data indicating an average net flux between 4–5 $GtCO_2\,yr^{-1}$ for the past few decades.

AR6 WGIII reported total net anthropogenic emissions of 59 ± 6.6 $GtCO_2e$ in 2019 and decadal average emissions of 56 ± 6.0 $GtCO_2e$ from 2010–2019. By comparison, our estimates here for the AR6 period sum to 55 ± 5.4 $GtCO_2e$ in 2019 and 53 ± 5.3 $GtCO_2e$ for the same decade (2010–2019). The difference between these figures, including the reduced relative uncertainty range, is partly driven by the substantial revision in GCB CO_2-LULUCF estimates between the 2020 version (used in AR6 WGIII) of 6.6 $GtCO_2$ and the 2022 version (used here) of 4.6 $GtCO_2$. The main reason for this downward revision comes from updated estimates of agricultural areas by the FAO and uses multi-annual land-cover maps from satellite remote sensing, leading to lower emissions from cropland expansion, particularly in the tropical regions. It is important to note that this change is not a reflection of changed and improved methodology per se but an update of the resulting estimation due to updates in the available input data. Second, there are relatively small changes resulting from improvements in datasets since AR6, with the direction of changes depending on the considered gases. CH_4 accounts for the largest of these at -1.8 $GtCO_2e$ in 2019, which is related to the switch from EDGAR in AR6 to PRIMAP-hist in this study. EDGAR estimates considerably higher CH_4 emissions – from fugitive fossil sources, as well as the livestock, rice cultivation and waste sectors – compared to country-reported data using higher tier methods, as compiled in PRIMAP-hist. Generally, uncertainty in these sectors is relatively high as calculations are based on activity data and assumed emissions factors which are hard to determine and vary greatly over countries. Differences in the remaining gases for 2019 are relatively small in magnitude (increases in N_2O ($+0.18$ $GtCO_2e$) and UNFCCC-F-gases ($+0.48$ $GtCO_2e$) and decreases in CO2-FFI (-0.8 $GtCO_2e$)). Overall, excluding the change due to CO_2-LULUCF and CH_4, they impact the total GHG emissions estimate by -0.14 $GtCO_2e$.

New literature not available at the time of the AR6 suggests that increases in atmospheric methane concentrations are also driven by methane emissions from wetland changes resulting from climate change (e.g. Basu et al., 2022; Peng et al., 2022; Nisbet et al., 2023; Zhang et al., 2023). Such carbon cycle feedbacks are not considered here, as we focus on estimates of emissions resulting directly from human activities.

2.3 Non-methane short-lived climate forcers

In addition to GHG emissions, we provide an update of anthropogenic emissions of non-methane short-lived climate forcers (SLCFs) (SO_2, black carbon (BC), organic carbon (OC), NO_x, volatile organic compounds (VOCs), CO and NH_3). HFCs are considered in Sect. 2.2. Updating emissions of many short-lived climate forcing agents to 2022 based on established datasets is not possible as compiling global data can take several years. Yet, as SLCF emissions are needed in this paper to update effective radiative forcing (ERF) estimates through 2022, updated emission datasets, where they are available, are combined with projected data to make SLCF emission time series complete.

As in Dhakal et al. (2022), sectoral emissions of SLCFs are derived from two sources. For fossil fuel, industrial, waste and agricultural sectors, we use the CEDS dataset that provided SLCF emissions for the Coupled Model Intercomparison Project Phase 6 (CMIP6) (Hoesly et al., 2018). CEDS provides global emissions totals from 1750 to 2019 in its most recent version (O'Rourke et al., 2021). No CEDS emissions data are available yet beyond 2019. As a first estimate, the SLCF emissions time series are extrapolated to 2022 using the "two-year blip" scenario (Forster et al., 2020) of global emissions suppressed by the economic slowdown due to COVID-19. These projections are proxy estimates from Google and Apple mobility data over 2020 and assume a slow return to pre-pandemic emissions activity levels by 2022. Other near-real-time emissions estimates covering the COVID-19 pandemic era tend to show less of an emissions reduction than the two-year blip scenario (Guevara et al., 2023). It should be stressed that accurate quantification of SLCF emissions during this period is not possible.

We do not explicitly account for the introduction of strict fuel sulfur controls brought in by the International Maritime Organization on 1 January 2020, which was expected to reduce SO_2 emissions from the global shipping sector by 8.5 Tg against a pre-COVID baseline (around 10 % of 2019 total SO_2 emissions). SO_2 reductions from shipping are partly accounted for in the proxy activity dataset, and including a specific shipping adjustment may double-count emissions reductions.

For biomass-burning SLCF emissions, we follow AR6 WGIII (Dhakal et al., 2022) and use the Global Fire Emissions Dataset (GFED; Randerson et al., 2017) for 1997 to 2022, with the dataset extended back to 1750 for CMIP6 (van Marle et al., 2017). Estimates from 2017 to 2022 are provisional. The potential for both sources of emissions data to be updated in future versions exists, particularly in light of a forthcoming update to CEDS and quantification of shipping sector SO_2 reductions. Other natural emissions, which are important for gauging some SLCF concentrations, are considered as constant in the context of calculating concentrations and ERF.

Estimated emissions used here are based on a combination of GFED emissions for biomass-burning emissions and CEDS up until 2019 extended with the two-year blip scenario for fossil, agricultural, industrial and waste sectors. Under this scenario, emissions of all SLCFs are reduced in 2022 relative to 2019 (Table 2). As described in Sect. 4, this has implications for several categories of anthropogenic radiative forcing. Trends in SLCFs emissions are spatially heterogeneous (Szopa et al., 2021), with strong shifts in the

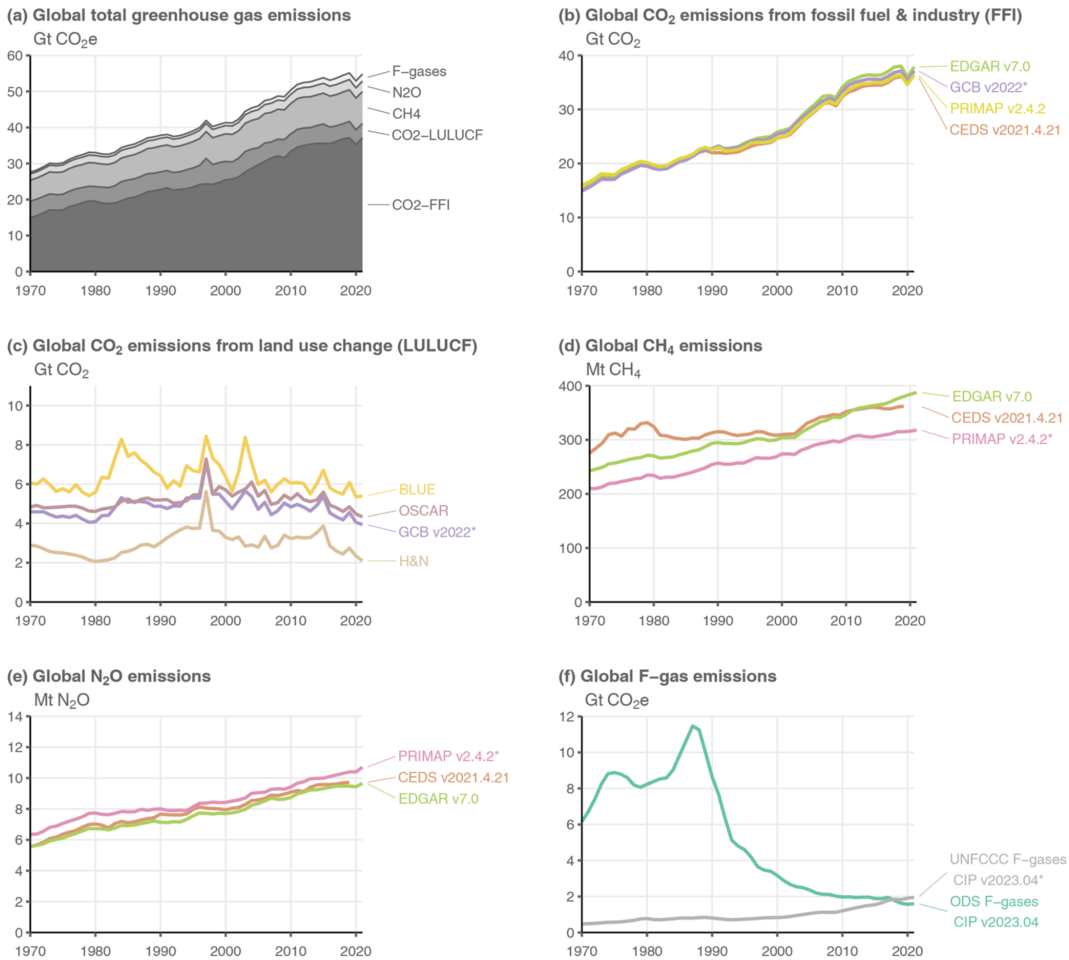

Figure 1. Annual global anthropogenic greenhouse gas emissions by source, 1970–2021. Refer to Sect. 2.1 for a list of datasets. Datasets with an asterisk (*) indicate the sources used to compile global total greenhouse gas emissions in **(a)**. CO_2-equivalent emissions in **(a)** and **(f)** are calculated using global warming potentials (GWPs) with a 100-year time horizon from the AR6 WGI Chap. 7 (Forster et al., 2021). F-gas emissions in **(a)** comprise only UNFCCC F-gas emissions (see Sect. 2.1 for a list of species).

Table 1. Global anthropogenic greenhouse gas emissions by source and decade.

Gt CO_2e	1970–1979	1980–1989	1990–1999	2000–2009	2010–2019	2012–2021	2021	2022 (projection)
GHGs	30 ± 4	35 ± 4.4	39 ± 4.9	45 ± 5.1	53 ± 5.3	54 ± 5.3	55 ± 5.2	
CO_2-FFI	17 ± 1.4	20 ± 1.6	24 ± 1.9	29 ± 2.3	36 ± 2.8	36 ± 2.9	37 ± 3	37 ± 3
CO_2-LULUCF	4.4 ± 3.1	4.8 ± 3.4	5.3 ± 3.7	5 ± 3.5	4.7 ± 3.3	4.5 ± 3.2	3.9 ± 2.8	3.9 ± 2.8
CH_4	6.2 ± 1.9	6.6 ± 2	7.3 ± 2.2	8 ± 2.4	8.6 ± 2.6	8.7 ± 2.6	8.9 ± 2.7	
N_2O	1.9 ± 1.1	2.1 ± 1.3	2.2 ± 1.3	2.4 ± 1.5	2.7 ± 1.6	2.8 ± 1.7	2.9 ± 1.8	
UNFCCC F-gases	0.58 ± 0.17	0.78 ± 0.23	0.77 ± 0.23	1 ± 0.3	1.5 ± 0.46	1.7 ± 0.5	2 ± 0.59	

All numbers refer to decadal averages, except for annual estimates in 2021 and 2022. CO_2-equivalent emissions are calculated using GWP with a 100-year time horizon from AR6 WGI Chap. 7 (Forster et al., 2021). Projections of non-CO_2 GHG emissions in 2022 remain unavailable at the time of publication. Uncertainties are ±8 % for CO_2-FFI, ±70 % for CO_2-LULUCF, ±30 % for CH_4 and F-gases, and ±60 % for N_2O, corresponding to a 90 % confidence interval. ODS F-gases are excluded, as noted in Sect. 2.1.

geographical distribution of emissions over the 2010–2019 decade. Very different lockdown measures have been applied for COVID around the world, resulting in various lengths and intensities of activity reductions and effects on air pollutant emissions (Sokhi et al., 2021). SLCF emissions have been seen to return to their pre-COVID levels by 2022 in some regions, sometimes with a rebound effect, but not in all (Putaud et al., 2023; Lonsdale and Sun, 2023), but quantification at the global scale is not yet available.

Uncertainties associated with these emission estimates are difficult to quantify. From the non-biomass-burning sectors they are estimated to be smallest for SO_2 (±14 %), largest for black carbon (BC) (a factor of 2) and intermediate for other species (Smith et al., 2011; Bond et al., 2013; Hoesly et al., 2018). Uncertainties are also likely to increase both backwards in time (Hoesly et al., 2018) and again in the most recent years. The estimates of non-biomass-burning emissions for 2020, 2021 and 2022 are highly uncertain, owing to the use of proxy activity data, scenario extension and the impact of sulfur controls in the shipping sector. Future updates of CEDS are expected to include uncertainties (Hoesly et al., 2018). Even though trends over recent years are uncertain, the general decline in some SLCF emissions derived is supported by aerosol optical depth measurements (e.g. Quaas et al., 2022).

3 Well-mixed greenhouse gas concentrations

AR6 WGI assessed well-mixed GHG concentrations in Chap. 2 (Gulev et al., 2021) and additionally provided a dataset of concentrations of 52 well-mixed GHGs from 1750 to 2019 in its Annex III (IPCC, 2021c). Footnotes in AR6 SYR updated CO_2, CH_4 and N_2O concentrations to 2021 (Lee et al., 2023). In this update, we extended the record to 2022 for all 52 gases.

Ozone is an important greenhouse gas with strong regional variation both in the stratosphere and troposphere (Szopa et al., 2021). Its ERF arising from its regional distribution is assessed in Sect. 4 but following AR6 convention is not included with the GHGs discussed here. Other non-methane SLCFs are heterogeneously distributed in the atmosphere and are also not typically reported in terms of a globally averaged concentration. Globally averaged concentrations for these are normally model-derived, supplemented by local monitoring networks and satellite data (Szopa et al., 2021).

As in AR6, CO_2 concentrations are taken from the NOAA Global Monitoring Laboratory (GML) and updated through 2022 (Lan et al., 2023a). Here, CO_2 is reported on the updated WMO-CO2-X2019 scale, whereas in AR6, values were reported on the WMO-CO2-X2007 scale. This improved calibration increases CO_2 concentrations by around 0.2 ppm (Hall et al., 2021). In AR6, CH_4 and N_2O were reported as the average from NOAA and the Advanced Global Atmospheric Gases Experiment (AGAGE) global networks. For 2022, as updated AGAGE data are not currently available, we used only NOAA data (Lan et al., 2023b) and multiplied N_2O by 1.0007 to be consistent with a NOAA–AGAGE average. NOAA CH_4 in 2022 was used without adjustment since the NOAA and AGAGE global CH_4 means are consistent within 2 ppb. Mixing ratio uncertainties for 2022 are assumed to be similar to 2019, and we adopt the same uncertainties as assessed in AR6 WGI.

Many halogenated greenhouse gases are reported on a global mean basis from NOAA and/or AGAGE until 2020 or 2021 (SF_6 is available in the NOAA dataset up to 2022). Where both NOAA and AGAGE data are used for the same gas, we take a mean of the two datasets. Where both networks are used and the last full year of data availability is different, the difference between the dataset mean and the dataset with the longer time series in this last year is used as an additive offset to the dataset with the longer time series. Some obvious inconsistencies are removed such as sudden changes in concentrations when missing data are reported as zero.

Some of the more minor halogenated gases are not part of the NOAA or AGAGE operational network and are currently only reported in literature sources until 2019 or possibly 2015 (Droste et al., 2020; Laube et al., 2014; Schoenenberger et al., 2015; Simmonds et al., 2017; Vollmer et al., 2018). Concentrations of gases where 2022 data are not yet available are extrapolated forwards to 2022 using the average growth rate over the last 5 years of available data. These assumptions have an imperceptible effect on the total ERF assessed in Sect. 4, whereas excluding these gases would have an impact.

The global surface mean mixing ratios of CO_2, CH_4 and N_2O in 2022 were 417.1 [±0.4] ppm, 1911.9 [±3.3] ppb and 335.9 [±0.4] ppb. Concentrations of all three major GHGs have increased from 2019 values reported in AR6 WGI, which were 410.1 [±0.36] ppm for CO_2, 1866.3 [±3.2] ppb for CH_4 and 332.1 [±0.7] ppb for N_2O. CO_2 concentrations in 2019 are updated to 410.3 ppm using the new WMO-CO2-X2019 scale adopted here. Concentrations of most categories of halogenated GHGs have increased from 2019 to 2022: from 109.4 to 114.2 ppt on a CF_4-equivalent scale for PFCs, 237.1 to 287.2 ppt on an HFC-134a-equivalent scale for HFCs, 9.9 to 11.0 ppt for SF_6 and 2.1 to 2.8 ppt for NF_3. Only Montreal Protocol halogenated GHGs have decreased in concentration, from 1031.9 ppt in 2019 to 1016.6 ppt in 2022 on a CFC-12-equivalent scale, demonstrating the continued success of the Montreal Protocol. Although even here, concentrations of some minor CFCs are rising (see also Western et al., 2023). In this update we employ AR6-derived uncertainty estimates and do not perform a new assessment. Table S1 in Sect. S3 of the Supplement shows specific updated concentrations for all the GHGs considered.

Table 2. Emissions of the major SLCFs in 1750, 2019 and 2022.

Compound species	1750 emissions ($Tg\,yr^{-1}$)	2019 emissions ($Tg\,yr^{-1}$)	2022 emissions ($Tg\,yr^{-1}$)
Sulfur dioxide (SO_2) + sulfate (SO_4^{2-})	0.3	85.9	76.9
Black carbon (BC)	2.1	7.8	6.7
Organic carbon (OC)	15.4	34.7	26.0
Ammonia (NH_3)	6.6	66.5	65.3
Oxides of nitrogen (NO_x)	19.4	142.9	131.8
Volatile organic compounds (VOCs)	60.6	227.2	189.6
Carbon monoxide (CO)	348.4	937.8	764.1

Emissions of SO_2+SO_4^{2-} use SO_2 molecular weights. Emissions of NO_x use NO_2 molecular weights. VOCs are for the total mass.

4 Effective radiative forcing (ERF)

ERFs were principally assessed in Chap. 7 of AR6 WGI (Forster et al., 2021). Chapter 7 focussed on assessing ERF from changes in atmospheric concentrations; it also supported estimates of ERF in Chap. 6 that attributed forcing to specific precursor emissions (Szopa et al., 2021) and also generated the time history of ERF shown in AR6 WGI Fig. 2.10 and discussed in Chap. 2 (Gulev et al., 2021). Only the concentration-based estimates are updated this year. The emission-based estimates relied on specific chemistry climate model integrations, and a consistent method of applying updates to these would need to be developed in the future.

Each IPCC report has successively updated both the method of calculation and the time history of different warming and cooling contributions, measured as ERFs. Both types of updates have contributed to a significantly changed forcing estimate between successive reports. For example, Forster et al. (2021) updated the methodology to exclude adjustments related to land surface temperature from the forcing calculation, which generally increased estimates. At the same time GHG levels increased, and the time history of aerosol forcing was revised, overall leading to a higher total ERF estimate in AR6 compared to AR5. These IPCC updates flow from an assessment of varied literature and also rely on updates to concentrations and/or emissions.

There is no published regularly updated total ERF indicator outside of the IPCC process, although the European Copernicus programme has trialled such a product (Bellouin et al., 2020). For radiative forcing, NOAA annually updates estimates for the main GHGs, calculating radiative forcing (RF) using the set of formulas to estimate RFs from concentrations (Montzka, 2022). Updated RF formulas were employed in AR6 (Forster et al., 2021), and these updated expressions are also employed here in the Supplement, Sect. S4.

The ERF calculation follows the methodology used in AR6 WGI (Smith et al., 2021). For each category of forcing, a 100 000-member probabilistic Monte Carlo ensemble is sampled to span the assessed uncertainty range in each forcing. All uncertainties are reported as 5 %–95 % ranges and provided in square brackets. The only significant methodological change compared to AR6 is for the volcanic ERF estimate. Firstly, the pre-industrial baseline data have been improved by switching to a new longer record of stratospheric aerosol optical depth before 1750 (Sigl et al., 2022). Secondly, choices have also been made to include the January 2022 eruption of Hunga Tonga–Hunga Ha'apai as an exceptional positive ERF perturbation from the increase in stratospheric water vapour (Millán et al., 2022; Sellito et al., 2022; Jenkins et al., 2023). The methods are all detailed in the Supplement, Sect. S4.

The summary results for the anthropogenic constituents of ERF and solar irradiance in 2022 relative to 1750 are shown in Fig. 2a. In Table 3 these are summarised alongside the equivalent ERFs from AR6 (1750–2019) and AR5 (1750–2011). Figure 2b shows the time evolution of ERF from 1750 to 2022.

Total anthropogenic ERF has increased to 2.91 [2.19 to 3.63] $W\,m^{-2}$ in 2022 relative to 1750, compared to 2.72 [1.96 to 3.48] $W\,m^{-2}$ for 2019 relative to 1750 in AR6. The main contributions to this increase are from increases in greenhouse gas concentrations and a reduction in the magnitude of aerosol forcing. Decadal trends in ERF have increased markedly and are now over 0.6 $W\,m^{-2}$ per decade. These are discussed further in the discussion and conclusions (Sect. 12).

The ERF from well-mixed GHGs is 3.45 [3.14 to 3.75] $W\,m^{-2}$ for 1750–2022, of which 2.25 $W\,m^{-2}$ is from CO_2, 0.56 $W\,m^{-2}$ from CH_4, 0.22 $W\,m^{-2}$ from N_2O and 0.41 $W\,m^{-2}$ from halogenated gases. This is an increase from 3.32 [3.03 to 3.61] $W\,m^{-2}$ for 1750–2019 in AR6. ERFs from CO_2, CH_4 and N_2O have all increased since the AR6 WG1 assessment for 1750–2019, owing to increases in atmospheric concentrations.

The total aerosol ERF (sum of the ERF from aerosol–radiation interactions (ERFari) and aerosol–cloud interactions (ERFaci)) for 1750–2022 is −0.98 [−1.58 to −0.40] $W\,m^{-2}$ compared to −1.06 [−1.71 to −0.41] $W\,m^{-2}$ assessed for 1750–2019 in AR6 WG1. This continues a

Table 3. Contributions to anthropogenic effective radiative forcing (ERF) for 1750–2022 assessed in this section.

Forcer	1750–2022 $W\,m^{-2}$	1750–2019 (AR6) $W\,m^{-2}$	1750–2011 (AR5) $W\,m^{-2}$	Reason for change from AR6
CO_2	2.25 [1.98 to 2.52]	2.16 [1.90 to 2.41]	1.82 [1.63 to 2.01]	Increases in GHG concentrations
CH_4	0.56 [0.45 to 0.67]	0.54 [0.43 to 0.65]	0.48 [0.43 to 0.53]	
N_2O	0.22 [0.19 to 0.25]	0.21 [0.18 to 0.24]	0.17 [0.14 to 0.20]	
Halogenated GHGs	0.41 [0.33 to 0.49]	0.41 [0.33 to 0.49]	0.36 [0.32 to 0.40]	
Ozone	0.48 [0.24 to 0.72]	0.47 [0.24 to 0.71]	0.35 [0.21 to 0.67]	Changes in precursor emissions and chemically active GHGs; net effect almost cancels out
Stratospheric water vapour	0.05 [0.00 to 0.10]	0.05 [0.00 to 0.10]	0.07 [0.02 to 0.12]	
Aerosol–radiation interactions	−0.21 [−0.42 to 0.00]	−0.22 [−0.47 to 0.04]	−0.45 [−0.95 to 0.05]	Reduction in aerosol and aerosol precursor emissions
Aerosol–cloud interactions	−0.77 [−1.33 to −0.23]	−0.84 [−1.45 to −0.25]	−0.45 [−1.2 to 0.0]	
Land use	−0.20 [−0.30 to −0.10]	−0.20 [−0.30 to −0.10]	−0.15 [−0.25 to −0.05]	
Light-absorbing particles on snow and ice	0.06 [0.00 to 0.14]	0.08 [0.00 to 0.18]	0.04 [0.02 to 0.09]	Reduction in BC emissions
Contrails and aviation-induced cirrus	0.05 [0.02 to 0.09]	0.06 [0.02 to 0.10]	0.05 [0.02 to 0.15]	As of 2022, global aviation activity has not yet returned to pre-COVID-19 levels
Total anthropogenic	2.91 [2.19 to 3.63]	2.72 [1.96 to 3.48]	2.3 [1.1 to 3.3]	Increase in GHG concentrations and reduction in aerosol emissions
Solar irradiance	0.01 [−0.06 to 0.08]	0.01 [−0.06 to 0.08]	0.05 [0.0 to 0.10]	

All values are in watts per square metre ($W\,m^{-2}$), and 5 %–95 % ranges are in square brackets. As a comparison, the equivalent assessments from AR6 (1750–2019) and AR5 (1750–2011; Myhre et al., 2013) are shown. Solar ERF is included and unchanged from AR6, based on the most recent solar cycle (2009–2019), thus differing from the single-year estimate in Fig. 2a. Volcanic ERF is excluded due to the sporadic nature of eruptions.

trend of weakening aerosol forcing due to reductions in precursor emissions. Most of this reduction is from ERFaci, which is determined to be −0.77 [−1.33 to −0.23] $W\,m^{-2}$ compared to −0.84 [−1.45 to −0.25] $W\,m^{-2}$ in AR6 for 1750–2019. ERFari for 1750–2022 is −0.21 [−0.42 to 0.00] $W\,m^{-2}$, marginally weaker than the −0.22 [−0.47 to 0.04] $W\,m^{-2}$ assessed for 1750–2019 in AR6 WG1 (Forster et al., 2021). The largest contributions to ERFari are from SO_2 (primary source of sulfate aerosol; −0.21 $W\,m^{-2}$), BC (+0.12 $W\,m^{-2}$), OC (−0.04 $W\,m^{-2}$) and NH_3 (primary source of nitrate aerosol; −0.03 $W\,m^{-2}$). ERFari is not weakening as fast as ERFaci due to reductions in the warming influence of BC cancelling out some of the reduced sulfate cooling. ERFari also includes terms from CH_4, N_2O and NH_3 which are small but have all increased.

Ozone ERF is determined to be 0.48 [0.24 to 0.72] $W\,m^{-2}$ for 1750–2022, similar to the AR6 assessment of 0.47 [0.24 to 0.71] $W\,m^{-2}$ for 1750–2019. Land-use forcing and stratospheric water vapour from methane oxidation are unchanged (to two decimal places) since AR6. The decline in BC emissions from 2019 to 2022 has reduced ERF from light-absorbing particles on snow and ice from 0.08 [0.00 to 0.18] $W\,m^{-2}$ for 1750–2019 to 0.06 [0.00 to 0.14] $W\,m^{-2}$ for 1750–2022. We determine from provisional data that aviation activity in 2022 had not yet returned to pre-COVID levels. Therefore, ERF from contrails and contrail-induced cirrus is

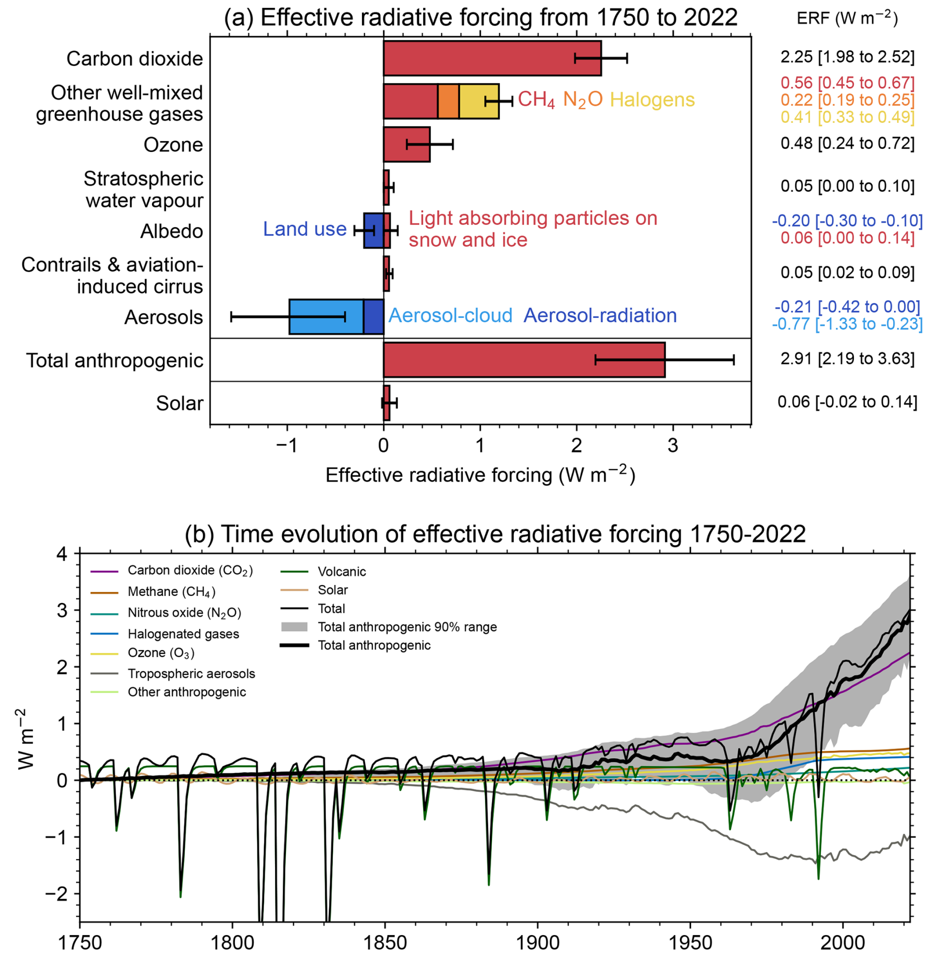

Figure 2. Effective radiative forcing from 1750–2022. **(a)** 1750–2022 change in ERF, showing best estimates (bars) and 5 %–95 % uncertainty ranges (lines) from major anthropogenic components to ERF, total anthropogenic ERF and solar forcing. **(b)** Time evolution of ERF from 1750 to 2022. Best estimates from major anthropogenic categories are shown along with solar and volcanic forcing (thin coloured lines), total (thin black line), and anthropogenic total (thick black line). The 5 %–95 % uncertainty in the anthropogenic forcing is shown by grey shading. Note that solar forcing in 2022 is a single-year estimate.

lower than AR6, at 0.05 [0.02 to 0.09] $W\,m^{-2}$ in 2022 compared to 0.06 [0.02 to 0.10] $W\,m^{-2}$ in 2019.

The headline assessment of solar ERF is unchanged, at 0.01 [−0.06 to +0.08] $W\,m^{-2}$ from pre-industrial to the 2009–2019 solar cycle mean. Separate to the assessment of solar forcing over complete solar cycles, we provide a single-year solar ERF for 2022 of 0.06 [−0.02 to +0.14] $W\,m^{-2}$. This is higher than the single-year estimate of solar ERF for 2019 (a solar minimum) of −0.02 [−0.08 to 0.06] $W\,m^{-2}$.

For volcanic ERF, updating of the pre-industrial dataset for stratospheric aerosol optical depth (sAOD) increased the sAOD over 500 BCE to 1749 CE, resulting in a larger difference to post-1750 sAOD and resulting in a volcanic ERF difference of +0.015 $W\,m^{-2}$ compared to AR6 (see Sect. S4 in the Supplement). In addition, the earlier Holocene was more volcanically active than the period after 500 BCE, further increasing the mean sAOD baseline. Taking the longer baseline period into account in the new pre-industrial dataset, post-1750 ERF is further increased by 0.031 $W\,m^{-2}$. The net effect is that volcanic forcing after 1750 has increased by +0.046 $W\,m^{-2}$ compared to AR6 due to dataset updates and by account of the fact that the post-1750 period was less volcanically active on average than the Early Holocene, which is now used in the ERF calculation.

5 Global surface temperature

AR6 WGI Chap. 2 assessed the 2001–2020 globally averaged surface temperature change above an 1850–1900 baseline to be 0.99 [0.84 to 1.10] °C and 1.09 [0.95 to 1.20] °C for 2011–2020 (Gulev et al., 2021). Updated estimates to 2022 were also given in AR6 SYR (Lee et al., 2023). The AR6 SYR estimates match those given here. We describe the update in detail and provide further quantification and comparisons.

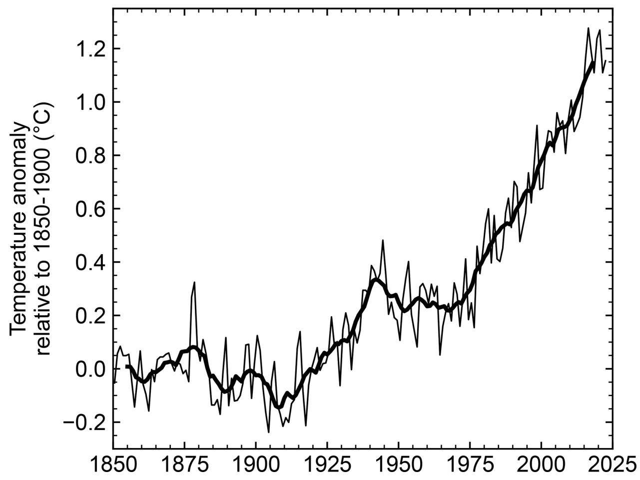

Figure 3. Annual (thin line) and decadal (thick line) means of global surface temperature (expressed as a change from the 1850–1900 reference period).

There are choices around the methods used to aggregate surface temperatures into a global average, how to correct for systematic errors in measurements, methods of infilling missing data, and whether surface measurements or atmospheric temperatures just above the surface are used. These choices, and others, affect temperature change estimates and contribute to uncertainty (IPCC AR6 WGI Chap. 2, Cross Chap. Box 2.3, Gulev et al., 2021). The methods chosen here closely follow AR6 WGI and are presented in the Supplement, Sect. S5. Confidence intervals are taken from AR6 as only one of the employed datasets regularly updates ensembles (see Supplement, Sect. S5).

Based on the updates available as of February 2023 (which were reported in the AR6 SYR), the change in global surface temperature from 1850–1900 to 2013–2022, using the same underlying datasets and methodology as AR6, is 1.15 [1.00–1.25] °C, an increase of 0.06 °C within 2 years from the 2011–2020 value reported in AR6 WGI (Table 4). The change from 1850–1900 to 2003–2022 was 1.03 [0.87–1.13] °C, 0.04 °C higher than the earlier value reported in AR6 WGI. These changes are broadly consistent with typical warming rates over the last few decades, which were assessed in AR6 as 0.76 °C over the 1980–2020 period (using ordinary-least-square linear trends) or 0.019 °C per year (Gulev et al., 2021). They are also broadly consistent with projected warming rates from 2001–2020 to 2021–2040 reported in AR6, which are in the order of 0.025 °C per year under most scenarios (Lee et al., 2021).

Note that the temperatures for single years include considerable variability and are influenced by natural forcings such as the El Niño–Southern Oscillation and sporadic volcanic eruptions that might either cool or warm the climate for short periods (Jenkins et al., 2023). At current warming rates, individual years may exceed warming of 1.5 °C several years before a long-term mean exceeds this level (Trewin, 2022).

6 Earth energy imbalance

The Earth energy imbalance (EEI), assessed in Chap. 7 of AR6 WGI (Forster et al., 2021), provides a measure of accumulated additional energy (heating) in the climate system and hence plays a critical role in our understanding of climate change. It represents the difference between the radiative forcing acting to warm the climate and Earth's radiative response, which acts to oppose this warming. On annual and longer timescales, the Earth heat inventory changes associated with EEI are dominated by the changes in global ocean heat content (OHC), which accounts for about 90 % of global heating since the 1970s (Forster et al., 2021). This planetary heating results in changes to the Earth system such as sea level rise, ocean warming, ice loss, rise in temperature and water vapour in the atmosphere, and permafrost thawing (e.g. Cheng et al., 2022; von Schuckmann et al., 2023a), with adverse impacts for ecosystems and human systems (Douville et al., 2021; IPCC, 2022).

On decadal timescales, changes in global surface temperatures (Sect. 5) can become decoupled from EEI by ocean heat rearrangement processes (e.g. Palmer and McNeall, 2014; Allison et al., 2020). Therefore, the increase in the Earth heat inventory provides a more robust indicator of the rate of global change on interannual-to-decadal timescales (Cheng et al., 2019; Forster et al., 2021; von Schuckmann et al., 2023a). AR6 WGI found increased confidence in the assessment of changes in the Earth heat inventory compared to previous IPCC reports due to observational advances and closure of the energy and global sea level budgets (Forster et al., 2021; Fox-Kemper et al., 2021).

AR6 estimated with that EEI increased from 0.50 [0.32–0.69] W m^{-2} during the period 1971–2006 to 0.79 [0.52–1.06] W m^{-2} during the period 2006–2018 (Forster et al., 2021). The contributions to increases in the Earth heat inventory throughout 1971–2018 remained stable: 91 % for the full-depth ocean, 5 % for the land, 3 % for the cryosphere and about 1 % for the atmosphere (Forster et al., 2021). The increase in EEI (Fig. 4) has also been reported by Cheng et al. (2019), von Schuckmann et al. (2020, 2023a), Loeb et al. (2021), Hakuba et al. (2021), Kramer et al. (2021) and Raghuraman et al. (2021). Drivers for the most recent period (i.e. past 2 decades) are both the increases in effective radiative forcing (Sect. 4) and climate feedbacks, such as cloud and sea ice changes. The degree of contribution from the different drivers is uncertain and still under active investigation.

While changes in EEI have been effectively monitored at the top of the atmosphere by satellites since the mid-2000s, we rely on estimates of OHC change to determine the absolute magnitude of EEI and its evolution on inter-annual to multi-decadal time series. The AR6 assessment of ocean

Table 4. Estimates of global surface temperature change from 1850–1900 [*very likely* (90 %–100 % probability) ranges] for IPCC AR6 and the present study.

Time period	Temperature change from 1850–1900 (°C)	
	IPCC AR6	This study
Global, most recent 10 years	1.09 [0.95 to 1.20] (to 2011–2020)	1.15 [1.00 to 1.25] (to 2013–2022)
Global, most recent 20 years	0.99 [0.84 to 1.10] (to 2001–2020)	1.03 [0.87 to 1.13] (to 2003–2022)
Land, most recent 10 years	1.59 [1.34 to 1.83] (to 2011–2020)	1.65 [1.36 to 1.90] (to 2013–2022)
Ocean, most recent 10 years	0.88 [0.68 to 1.01] (to 2011–2020)	0.93 [0.73 to 1.04] (to 2013–2022)

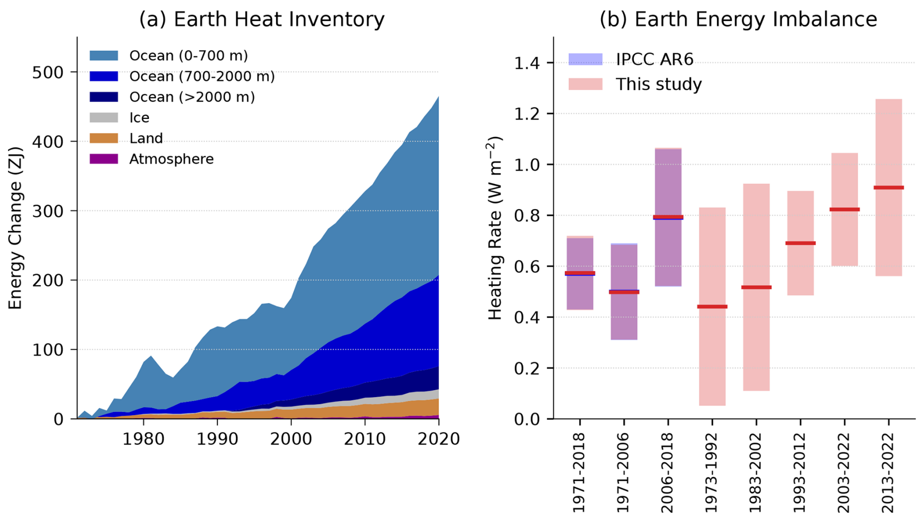

Figure 4. (a) Observed changes in the Earth heat inventory for the period 1971–2020, with component contributions as indicated in the figure legend. **(b)** Estimates of the Earth energy imbalance for IPCC AR6 assessment periods, for consecutive 20-year periods and the most recent decade. Shaded regions indicate the *very likely* range (90 % to 100 % probability). Data use and approach are based on the AR6 methods and further described in Sect. 6.

heat content change for the 0–2000 m layer was based on global annual mean time series from five ocean heat content datasets: IAP (Cheng et al., 2017), Domingues et al. (2008), EN4 (Good et al., 2013), Ishii et al. (2017) and NCEI (Levitus et al., 2012). Four of these datasets routinely provide updated OHC time series for the BAMS State of the Climate report, and all are used for the GCOS Earth heat inventory (von Schuckmann et al., 2020, 2023a) and the annual WMO global state of the climate. The uncertainty assessment for the 0–2000 m layer used the ensemble method described by Palmer et al. (2021) that separately accounts for *parametric* and *structural* uncertainty. The OHC change >2000 m and associated uncertainty were assessed based on trend analysis of the available hydrographic data following Purkey and Johnson (2010). All five of the datasets used for the 0–2000 m OHC assessment are now updated at least annually and should in principle support an AR6 assessment time series update within the first few months of each year. There is potential to increase the observational ensemble used in the assessment by supplementing this set with additional data products that are also available annually for future updates. There is also a potential to update the uncertainty estimate after a more comprehensive understanding of the error sources.

Estimates of EEI should also account for the other elements of the Earth heat inventory, i.e. the atmospheric warming, the latent heat of global ice loss and heating of the continental land surface (Forster et al., 2021; Cuesta-Valero et al., 2021, 2023a; Steiner et al., 2020; Nitzbon et al., 2022a; Vanderkelen et al., 2020; Adusumilli et al., 2022). Some of these components of the Earth heat inventory are routinely updated by a community-based initiative reported in von Schuck-

Table 5. Estimates of the Earth energy imbalance (EEI) for AR6 and the present study.

Time period	Earth energy imbalance ($W m^{-2}$) Square brackets show [90 % confidence intervals].	
	IPCC AR6	This study
1971–2018	0.57 [0.43 to 0.72]	0.57 [0.43 to 0.72]
1971–2006	0.50 [0.32 to 0.69]	0.50 [0.31 to 0.68]
2006–2018	0.79 [0.52 to 1.06]	0.79 [0.52 to 1.07]
1975–2022	–	0.65 [0.48 to 0.81]
2010–2022	–	0.89 [0.63 to 1.15]

mann et al. (2020, 2023a). However, in the absence of annual updates to all heat inventory components, a pragmatic approach is to use recent OHC change as a proxy for EEI, scaling the value up as required based on historical partitioning between Earth system components.

We carry out an update to the AR6 estimate of changes in the Earth heat inventory based on updated observational time series for the period 1971–2020 (Table 5 and Fig. 4). Time series of heating associated with loss of ice and warming of the atmosphere and continental land surface are obtained from the recent Global Climate Observing System (GCOS) initiative (von Schuckmann et al., 2023b; Adusumilli et al., 2022; Cuesta-Valero et al., 2023b; Vanderkelen and Thiery, 2022; Nitzbon et al., 2022b; Kirchengast et al., 2022). We use the original AR6 time series ensemble OHC time series for the period 1971–2018 and then switch to a smaller four-member ensemble for the period 2019–2022. We "splice" the two sets of time series by adding an offset as needed to ensure that the 2018 values are identical. The AR6 heating rates and uncertainties for the ocean below 2000 m are assumed to be constant through the period. The time evolution of the Earth heat inventory is determined as a simple summation of time series of atmospheric heating; continental land heating; heating of the cryosphere; and heating of the ocean over three depth layers, 0–700, 700–2000 and below 2000 m (Fig. 4a). While von Schuckmann et al. (2023a) have also quantified heating of permafrost and inland lakes and reservoirs, these additional terms are very small and are omitted here for consistency with AR6 (Forster et al., 2021).

A full propagation of uncertainties across all heat inventory components depends on the specific choice of time period, and different estimates are not directly comparable. Therefore, we take a simple pragmatic approach, using the total ocean heat content uncertainty as a proxy for the total uncertainty, since this term is 2 orders of magnitude larger than the other terms (Forster et al., 2021). To provide estimates of the EEI up to the year 2022, we scale up the values of OHC change in 2021 and 2022 to reflect the about 90 % contribution of the ocean to changes in the Earth heat inventory. The EEI is then simply computed as the difference in global energy inventory over each period, converted to units of watts per square metre ($W m^{-2}$) using the surface area of the Earth and the elapsed time. The uncertainties in the global energy inventory for the end-point years are assumed to be independent and added in quadrature, following the approach used in AR6 (Forster et al., 2021).

In our updated analysis, we find successive increases in EEI for each 20-year period since 1973, with an estimated value of 0.44 [0.05 to 0.83] $W m^{-2}$ during 1973–1992 that almost doubled to 0.82 [0.60 to 1.04] $W m^{-2}$ during 2003–2022 (Fig. 4b). In addition, there is some evidence that the warming signal is propagating into the deeper ocean over time, as seen by a robust increase of deep (700–2000 m) ocean warming since the 1990s (Cheng et al., 2019, 2022). The model simulations qualitatively agree with the observational evidence (e.g. Gleckler et al., 2016; Cheng et al., 2019), further suggesting that more than half of the OHC increase since the late 1800s occurs after the 1990s. For 1973–1992, the contribution by ocean vertical layer was 66 %, 28 % and 1 % for 0–700, 700–2000 and >2000 m, respectively. During 2013–2022, the corresponding layer contributions were 50 %, 33 % and 8 %.

The update of the AR6 assessment periods to end in 2022 results in systematic increases of EEI of 0.08 $W m^{-2}$ for 1975–2022 relative to 1971–2018 and 0.10 $W m^{-2}$ for 2010–2022 relative to 2006–2018 (Table 5).

7 Human-induced global warming

Human-induced warming, also known as anthropogenic warming, refers to the component of observed global surface temperature increase over a specific period (for instance, from 1850–1900 as a proxy for pre-industrial climate to the last decade) attributable to both the direct and indirect effects of human activities, which are typically grouped as follows: well-mixed greenhouse gases (consisting of CO_2, CH_4, N_2O and F-gases) and other human forcings (consisting of aerosol–radiation interaction, aerosol–cloud interaction, black carbon on snow, contrails, ozone, stratospheric H_2O and land use) (Eyring et al., 2021). While *total warming*, the actual observed temperature change potentially resulting from both natural climate variability (internal variability of the climate system and the climate response to natural forcing) and human influences, is the quantity directly related to climate impacts and therefore relevant for adaptation, mitigation efforts focus on human-induced warming as the more relevant indicator for tracking progress against climate stabilisation targets. Further, as the attribution analysis allows human-induced warming to be disentangled from possible contributions from solar and volcanic forcing and internal variability (e.g. related to El Niño/La Nina events), it avoids misperception about short-term fluctuations in temperature. An assessment of human-induced warming was therefore provided in two reports within the IPCC's 6th assessment cycle: first in SR1.5 in 2018 (Chap. 1 Sect. 1.2.1.3 and Fig. 1.2

(Allen et al., 2018), summarised in the Summary for Policymakers (SPM) Sect. A.1 and Fig. SPM.1 (IPCC, 2018)) and second in AR6 in 2021 (WGI Chap. 3 Sect. 3.3.1.1.2 and Fig. 3.8 (Eyring et al., 2021), summarised in WGI SPM A.1.3 and Fig. SPM.2 (IPCC, 2021b)).

7.1 Definitions

7.1.1 Warming period definitions in the IPCC Sixth Assessment cycle

AR6 defined the current human-induced warming relative to the 1850–1900 baseline as the decade average of the previous 10-year period (see AR6 WGI Chap. 3). This paper provides an update of the 2010–2019 period used in the AR6 to the 2013–2022 decade. SR1.5 defined current human-induced warming as the average of a 30-year period centred on the current year, assuming the recent rate of warming continues (see SR1.5 Chap. 1). This definition is currently almost identical to the present-day single-year value of human-induced warming, differing by about 0.01 °C (see results in Sect. 7.4); the attribution assessment in SR1.5 was therefore provided as a single-year warming. This section also updates the SR1.5 single-year approach by providing a year 2022 value.

7.1.2 Estimates of global surface temperature: GMST and GSAT

AR6 WGI (Chap. 2 Cross-Chap. Box 2.3, Gulev et al., 2021) described how global mean surface air temperature (GSAT), as is typically diagnosed from climate models, is physically distinct from the global mean surface temperature (GMST) estimated from observations, which generally combine measurements of near-surface temperature over land and in some cases over ice, with measurements of sea surface temperature over the ocean. Based on conflicting lines of evidence from climate models, which show stronger warming of GSAT compared to GMST, and observations, which tend to show the opposite, Gulev et al. (2021) assessed with *high confidence* that long-term trends in the two indicators differ by less than 10 % but that there is *low confidence* in the sign of the difference in trends. Therefore, with *medium* confidence, in AR6 WGI Chap. 3 (Eyring et al., 2021), the best estimates and *likely* ranges for attributable warming expressed in terms of GMST were assessed to be equal to those for GSAT, with the consequence that the AR6 warming attribution results can be interpreted as both GMST and GSAT. While, based on the WGI Chap. 2 (Gulev et al., 2021) assessment, WGI Chap. 3 (Eyring et al., 2021) treated estimates of attributable warming in GSAT and GMST from the literature together, without any rescaling, we note that climate-model-based estimates of attributable warming in GSAT are expected to be systematically higher than corresponding estimates of attributable warming in GMST (see e.g. Cowtan et al., 2015; Richardson et al., 2018; Beusch et al., 2020; Gillett et al., 2021). Therefore, given an opportunity to update these analyses from AR6, it is more consistent and more comparable with observations of GMST to report attributable changes in GMST using all three methods (described in Sect. 7.2). The SR1.5 assessment of attributable warming was given in terms of GMST, which is continued here. In line with Sect. 2 and AR6 WGI, we adopt GMST as the estimate of global surface temperature.

7.2 Methods

Both SR1.5 and AR6 drew on evidence from a range of literature for their assessments of human-induced warming, before selecting results from a smaller subset to produce a quantified estimate. While both the SR1.5 and AR6 assessments used the latest Global Warming Index (GWI) results (Haustein et al., 2017), AR6 also incorporated results from two other methods, regularised optimal fingerprinting (ROF) (as in Gillett et al., 2021) and kriging for climate change (KCC) (as in Ribes et al., 2021). In AR6, all three methods gave results consistent not only with each other but also results from AR6 WGI Chap. 7 (see WGI Chap. 7 Supplementary Material (Smith et al., 2021) and Fig. 3.8 of AR6 WGI Chap. 3 (Eyring et al., 2021) and Supplement, Sect. S7 and Fig. S2), though the results from Chap. 7 were not included in the AR6 WGI final calculation because they were not statistically independent. Of the methods used, two (Gillett et al., 2021; Ribes et al., 2021) relied on CMIP6 DAMIP (Gillett et al., 2016) simulations which ended in 2020 and hence require modifications to update to the most recent years. The other two methods (Haustein et al., 2017; Smith et al., 2021) are updatable and can also be made consistent with other aspects of the AR6 assessment and methods. The three methods used in the final assessment of contributions to warming in AR6 are used again with revisions for this annual update and are presented in the Supplement, Sect. S7, with any updates to their approaches described in Sect. 7.2.

7.3 Updated estimates of human-induced warming to date

7.3.1 Updated estimate using the AR6 WGI methodology

Factoring in results from all three methods, AR6 WGI Chap. 3 (Erying et al., 2021) defined the *likely* (66 %–100 % probability interval) range for each warming component as the smallest 0.1 °C precision range that enveloped the 5th to 95th percentile ranges of each method. In addition, a best estimate was provided for the human-induced (Ant) warming component, calculated as the mean of the 50th percentile values for each method. Best estimates were not provided in AR6 for the other components (well-mixed greenhouse gases (GHGs), other human forcings (OHFs) and natural forcings (Nat)), with their values in AR6 WGI Fig. SPM.2(b) simply being given as the midpoint between the lower and upper

Table 6. Updates to assessments in the IPCC 6th assessment cycle of warming attributable to multiple influences. Estimates of warming attributable to multiple influences, in °C, relative to the 1850–1900 baseline period. Results are given as best estimates, with the *likely* range in brackets, and reported as global mean surface temperature.

	Definition					
	(a) IPCC AR6-attributable warming update Average value for previous 10-year period			**(b)** IPCC SR1.5-attributable warming update Value for single-year period		
	Period					
Component	(i) 2010–2019 Quoted from AR6 Chap. 3 Sect. 3.3.1.1.2 Table 3.1	(ii) 2010–2019 Repeat calculation using the updated methods and datasets	(iii) 2013–2022 Updated value using updated methods and datasets	(i) 2017 Quoted from SR1.5 Chap. 1 Sect. 1.2.1.3	(ii) 2017 Repeat calculation using the updated methods and datasets	(iii) 2022 Updated value using updated methods and datasets
Observed	1.06 (0.88 to 1.21)	1.07 (0.89 to 1.22)*	1.15 (1.00 to 1.25)*			
Anthropogenic	1.07 (0.8 to 1.3)	1.07 (0.8 to 1.3)	1.14 (0.9 to 1.4)	1.0 (0.8 to 1.2)	1.13 (0.9 to 1.4)	1.26 (1.0 to 1.6)
Well-mixed greenhouse gases	1.40** (1.0 to 2.0)	1.33 (1.0 to 1.8)	1.40 (1.1 to 1.8)	NA	1.38 (1.1 to 1.8)	1.49 (1.1 to 2.0)
Other human forcings	−0.32** (−0.8 to 0.0)	−0.26 (−0.7 to 0.1)	−0.25 (−0.7 to 0.1)	NA	−0.25 (−0.7 to 0.1)	−0.24 (−0.7 to 0.1)
Natural forcings	0.03** (−0.1 to 0.1)	0.05 (−0.1 to 0.1)	0.04 (−0.1 to 0.1)	NA	0.04 (−0.1 to 0.2)	0.03 (−0.1 to 0.1)

Results from the IPCC 6th assessment cycle, for both AR6 and SR1.5, are quoted in columns labelled (i) and are compared with repeat calculations in columns labelled (ii) for the same period using the updated methods and datasets to see how methodological and dataset updates alone would change previous assessments. Assessments for the updated periods are reported in columns labelled (iii). * Updated GMST observations, quoted from Sect. 5 of this update, are marked with an asterisk, with "very likely" ranges given in brackets. ** In AR6 WGI, best-estimate values were not provided for warming attributable to well-mixed greenhouse gases, other human forcings and natural forcings (though they did receive a "likely" range, as discussed in Sect. 7.3.1); for comparison, best estimates (marked with two asterisks) have been retrospectively calculated in an identical way to the best estimate that AR6 provided for anthropogenic warming.
NA: not available.

bound of the *likely* range and therefore not directly comparable with the central values given for human-induced and observed warming. In order to make a meaningful and consistent comparison, and provide meaningful insight into interannual changes, an improvement is made in this update: the multi-method-mean best-estimate approach is extended for all warming components.

7.3.2 Updated estimate using the SR1.5 methodology applied to the AR6 WGI datasets

While a variety of literature was drawn upon for the assessment of human-induced warming in SR1.5 Chap. 1 (Allen et al., 2018), only one method, the Global Warming Index (GWI), was used to provide a quantitative assessment of the 2017, "present-day", level of human-induced warming. The latest results for this method were provided by Haustein et al. (2017), who gave a central estimate for human-induced warming in 2017 of 1.01 °C with a 5 %–95 % range of (0.87 to 1.22 °C). SR1.5 then accounted for methodological uncertainty by rounding this value to 0.1 °C precision for its final assessment of 1.0 °C and assessing the 0.8 to 1.2 °C range as a *likely* range. No assessment of the contributions from other components was provided due to limitations in the GWI approach at the time.

While it is possible to continue the SR1.5 assessment approach of using a single method (GWI) rounded to 0.1 °C precision, for the purpose of providing annual updates this is insufficient; (i) 0.1 °C precision is too coarse to capture meaningful inter-annual changes to the level of present-day warming, (ii) using different selections of methods prevents meaningful comparison between the results for *decadal mean* and *present-day* warming calculations, and (iii) using the mean of multiple methods increases the robustness of the results. These points are simultaneously addressed in this update by adopting the latest multi-method assessment approach, as established in WGI AR6, for both the AR6 *decadal mean* warming update and the SR1.5 *present-day single-year* warming update. Further, where SR1.5 only provided an assessment for human-induced warming, updates in available attribution methods since SR1.5 mean that it is now also possible to provide a fully consistent assessment for all warming components. As with the attribution assessment in SR1.5, this update reports values in Table 6b for *single-year present-day* attributable warming (as discussed in Sect. 7.1.1), with a comparison to results calculated using the SR1.5 trend-based definition also provided below in Sect. 7.4.

7.4 Results

Results are summarised in Table 6 and Fig. 5. WGI AR6 results for 2010–2019 are quoted in Table 6a, compared with a repeat calculation using updated methods and datasets,

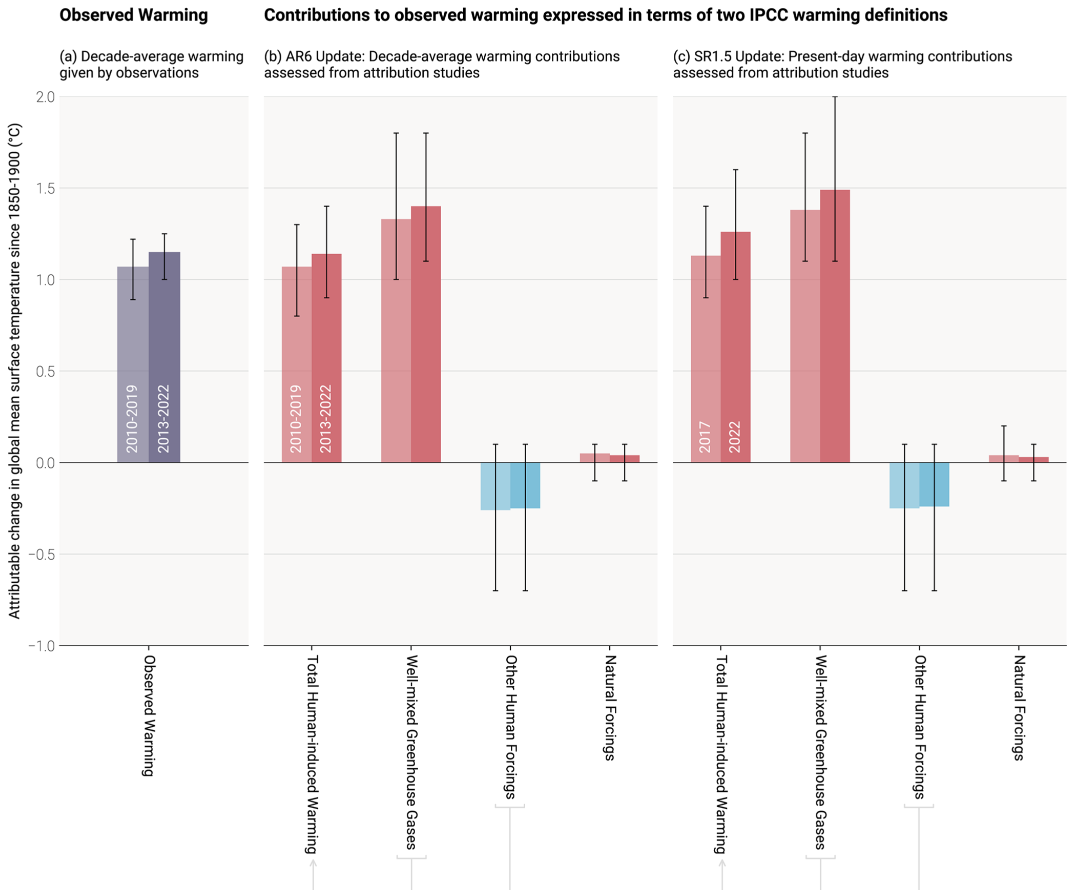

Figure 5. Updated assessed contributions to observed warming relative to 1850–1900; see AR6 WGI SPM.2. Results for all time periods in this figure are calculated using updated datasets and methods. The 2010–2019 *decade-average*-assessed results repeat the AR6 2010–2019 assessment, and the 2017 *single-year*-assessed results repeat the SR1.5 2017 assessment. For each double bar, the lighter and darker shading refers to the earlier and later period, respectively. The 2013–2022 *decade-average* and 2022 *single-year* results are the updated assessments for AR6 and SR1.5, respectively. Panel **(a)** shows updated observed global warming from Sect. 5, expressed as total GMST, due to both anthropogenic and natural influences. Whiskers give the *very likely* range. Panels **(b)** and **(c)** show updated assessed contributions to warming, expressed as global mean surface temperature, from natural forcings and total human-induced forcings, which in turn consist of contributions from well-mixed greenhouse gases and other human forcings. Whiskers give the *likely* range.

and finally updated for the 2013–2022 period. Results from SR1.5 are quoted in Table 6b for the 2017 level of human-induced warming, compared with a repeat calculation using the updated selection of methods and datasets (see Sect. 7.2) and the WGI AR6 multi-method assessment approach (see Sect. 7.3.2), and finally updated for 2022. Method-specific contributions to the assessment results, along with time series, are given in the Supplement, Sect. S7.

The repeat calculations for attributable warming in 2010–2019 exhibit good correspondence with the results in WGI AR6 for the same period (see also Supplement, Sect. S7), with an exact correspondence in the best estimate and *likely* (66 % to 100 % probability) range of human-induced warming (Ant).

The repeat calculation for the level of attributable anthropogenic warming in 2017 is about 0.1 °C larger than the estimate provided in SR1.5 for the same period, resulting from changes in methods and observational data (see above). The updated results for warming contributions in 2022 are also higher than in 2017 due to 5 additional years of anthropogenic forcing. A repeat assessment using the SR1.5 trend-based definition (see Sect. 7.1.1) leads to results that are very similar to the single-year results reported in Table 6b, with 0.02 °C differences at most (Supplement, Sect. S7).

The attribution assessment in WGI AR6 concluded that, averaged for the 2010–2019 period, all observed warming was human-induced, with solar and volcanic drivers and internal climate variability estimated not to make a contribution. This conclusion remains the same for the 2013–2022 period. Generally, whatever methodology is used, the best estimate of the human-induced warming to date is (within small uncertainties) equal to the observed warming to date.

8 Remaining carbon budget

AR6 assessed the remaining carbon budget (RCB) in Chap. 5 of its WGI report (Canadell et al., 2021) for 1.5, 1.7 and 2 °C thresholds (see Table 7). They were also reported in its Summary for Policymakers (Table SPM.2, IPCC, 2021b). These are updated in this section using the same method with transparently described updates.

AR5 (IPCC, 2013) assessed that global surface temperature increase is close to linearly proportional to the total amount of cumulative CO_2 emissions (Collins et al., 2013). The most recent AR6 report reaffirmed this assessment (Canadell et al., 2021). This near-linear relationship implies that for keeping global warming below a specified temperature level, one can estimate the total amount of CO_2 that can ever be emitted. When expressed relative to a recent reference period, this is referred to as the remaining carbon budget (Rogelj et al., 2018).

The RCB is estimated by application of the WGI AR6 method described in Rogelj et al. (2019), which involves the combination of the assessment of five factors: (i) the most recent decade of human-induced warming, (ii) the transient climate response to cumulative emissions of CO_2 (TCRE), (iii) the zero emissions commitment (ZEC), (iv) the temperature contribution of non-CO_2 emissions and (v) an adjustment term for Earth system feedbacks that are otherwise not captured through the other factors. AR6 WGI reassessed all five terms (Canadell et al., 2021). The incorporation of factor (v) was further considered by Lamboll and Rogelj (2022).

Of these factors, only factor (i) (human-induced warming), where AR6 WGI used the decade-long period, 2010–2019, lends itself to a regular and systematic annual update. Historical CO_2 emissions from the middle of this period until the start of the RCB are required to have an as up-to-date RCB estimate as possible.

Other factors can be updated but depend on new evidence and insights being published rather than an additional year of observational data becoming available. Factor (iv) (temperature contribution of non-CO_2 emissions) depends both on the available mitigation scenario evidence and the assessment of non-CO_2 warming. Additional scenario evidence has become available through the publication of the scenario database supporting the AR6 WGIII report (Byers et al., 2022), which is taken into account in this update.

The RCB for 1.5, 1.7 and 2 °C warming levels is reassessed based on the most recent available data. Estimated RCBs are reported below. They are expressed both relative to 2020 to compare to AR6 and relative to the start of 2023 for estimates based on the 2013–2022 human-induced warming update. Note that between the start of 2020 and the end of 2022, about 122 $GtCO_2$ has been emitted (Sect. 2). Based on the variation in non-CO_2 emissions across the scenarios in AR6 WGIII scenario database, the estimated RCB values can be higher or lower by around 200 $GtCO_2$ depending on how deeply non-CO_2 emissions are reduced. The impact of non-CO_2 emissions on warming includes both the warming effects of other greenhouse gases such as methane and the cooling effects of aerosols such as sulfates. The impacts of these are assessed using a climate emulator (MAGICC; Meinshausen et al., 2011), which was updated to capture recent updates more accurately from the AR6 WGIII report but whose results were not captured in the AR6 WGI carbon budget estimates. This emulator update increased the estimate of the importance of aerosols, which are expected to decline with time in low emissions pathways (Rogelj et al., 2014), causing a net warming and decreasing the remaining carbon budget. The AR6 WGIII version of MAGICC is used here. If instead, the FaIR emulator were used, this would give reduced non-CO_2 warming and a larger carbon budget (Lamboll and Rogelj, 2022). For example, using non-CO_2 warming from the FaIR emulator to estimate the 1.5 °C remaining carbon budget results in 350 $GtCO_2$ for a 50 % likelihood with a 17 %–83 % range of 200–700 $GtCO_2$. The variation between the different estimates reflects the structural uncertainty in estimating future non-CO_2 warming contributions and highlights inherent limits to the precision with which remaining carbon budgets can be quantified. Such variation in remaining carbon budget estimates illustrates that most of the total carbon budget for limiting warming to 1.5 °C has already been emitted and emphasises the robust insight that the 1.5 °C compatible budget is very small in light of continuing high global CO_2 emissions.

Updated RCB estimates presented in Table 7 for 1.5, 1.7 and 2.0 °C of global warming are smaller than AR6, and geophysical and other uncertainties therefore have become larger in relative terms. This is a feature that will have to be kept in mind when communicating budgets. The estimates presented here differ from those presented in the annual Global Carbon Budget (GCB) publications (Friedlingstein et al., 2022a). The GCB updates have previously started from the AR6 WGI estimate and subtracted the latest estimates of historical CO_2 emissions. The RCB estimates presented here consider the same updates in historical CO_2 emissions from the GCB as well as the latest available quantification of human-induced warming to date and a reassessment of non-CO_2 warming contributions.

If the single-year human-induced warming until 2022 (Sect. 7) were used directly in the RCB calculation, this would lead to similar remaining carbon budgets estimates to those from the decadal average approach used here; the 50 % likelihood estimates would be unchanged although other likelihoods alter somewhat because the spread due to TCRE uncertainty starts 5 years later. However, we choose to only show the decadal calculation as this was assessed to be the best estimate for human-induced warming and the method adopted in AR6 WGI.

The RCB for limiting warming to 1.5 °C is becoming very small. It is important, however, to correctly interpret this information. RCB estimates consider projected reductions in non-CO_2 emissions that are aligned with a global transi-

Table 7. Updated estimates of the remaining carbon budget for 1.5, 1.7 and 2.0 °C, for five levels of likelihood, considering only uncertainty in TCRE.

Historical cumulative CO_2 emissions (1850–2019) AR6 WGI Table SPM.2	2390 (±240; *likely* (66 %–100 % probability) range)					
Remaining carbon budgets Case/update	Base year	Estimated remaining carbon budgets from the beginning of base year ($GtCO_2$)				
Likelihood of limiting global warming to temperature limit.		17 %	33 %	50 %	67 %	83 %
1.5 °C from AR6 WGI	2020	900	650	500	400	300
+ AR6 emulator update	2020	750	500	400	300	200
+ as above with AR6 scenario update	2020	750	500	400	300	200
+ as above with warming update (2013–2022) (best estimate)	**2023**	**500**	**300**	**250**	**150**	**100**
1.7 °C from AR6 WGI	2020	1450	1050	850	700	550
+ AR6 emulator update	2020	1250	900	700	600	450
+ as above with AR6 scenario update	2020	1300	950	750	600	500
+ as above with warming update (2013–2022) (best estimate)	**2023**	**1100**	**800**	**600**	**500**	**350**
2 °C from AR6 WGI	2020	2300	1700	1350	1150	900
+ AR6 emulator update	2020	2050	1500	1200	1000	800
+ as above with AR6 scenario update	2020	2200	1650	1300	1100	900
+ as above with warming update (2013–2022) (best estimate)	**2023**	**2000**	**1450**	**1150**	**950**	**800**

Estimates start from AR6 WGI estimates (first row for each warming level), updated with the latest scenario information from AR6 WGIII (from second row for each warming level), and an update of the anthropogenic historical warming, which is estimated for the 2013–2022 period (third row for each warming level). Estimates are expressed relative to either the start of the year 2020 or 2023. The probability includes only the uncertainty in how the Earth immediately responds to carbon, not long-term committed warming or uncertainty in other emissions. All values are rounded to the nearest 50 $GtCO_2$.

tion to net zero CO_2 emissions. These estimates assume median reductions in non-CO_2 emissions between 2020–2050 of CH_4 (50 %), N_2O (25 %) and SO_2 (77 %). If these non-CO_2 greenhouse gas emission reductions are not achieved, the RCB will be smaller (see Supplement, Sect. S8). Note that the 50 % RCB is expected to be exhausted a few years before the 1.5 °C global warming level is reached due to the way it factors future warming from non-CO_2 emissions into its estimate.

9 Examples of climate and weather extremes: maximum temperature over land

Climate and weather extremes are among the most visible human-induced climate changes. Within AR6 WGI, a full chapter was dedicated to the assessment of past and projected changes in extremes on continents (Seneviratne et al., 2021), and the chapter on ocean, cryosphere and sea level changes also provided assessments on changes in marine heatwaves (Fox-Kemper et al., 2021). Global indicators related to climate extremes include averaged changes in climate extremes, for example, the mean increase of annual minimum and maximum temperatures on land (AR6 WGI Chap. 11, Fig. 11.2, Seneviratne et al., 2021) or the area affected by certain types of extremes (AR6 WGI Chap. 11, Box 11.1, Fig. 1, Seneviratne et al., 2021; Sippel et al., 2015). In contrast to global surface temperature, extreme indicators are less established. They are therefore expected to be subject to improvements, reflecting advances in understanding and better data collection. Indeed, such efforts are planned within the World Climate Research Programme (WCRP) Grand Challenge on Weather and Climate Extremes, which will likely inform the next iteration of this study.

As part of this first update, we provide an upgraded version of the analysis in Fig. 11.2 from Seneviratne et al. (2021) (Fig. 6). Like the analysis of global mean temperature, the choice of datasets is based on a compromise on the length of the data record, the data availability, near-real-time updates and long-term support. As the indicator (in its current form) averages over all available land grid points, the spatial coverage should be high to obtain a meaningful average, which further limits the choice of datasets. The HadEX3 dataset (Dunn et al., 2020), which is used for Fig. 11.2 in Seneviratne et al. (2021), is static and does not cover years after 2018. We therefore additionally include the Berkeley Earth Surface Temperature dataset (building off Rohde et al., 2013) and the fifth-generation ECMWF atmospheric reanalysis of the global climate (ERA5; Hersbach et al., 2020). Berkeley Earth data currently enable an analysis of annual indices up

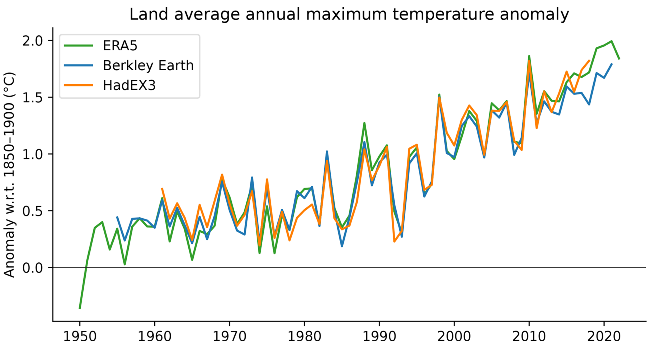

Figure 6. Time series of observed temperature anomalies for land average annual maximum temperature (TXx) for ERA5 (1950–2022), Berkeley Earth (1955–2021) and HadEX3 (1961–2018), with respect to 1850–1900. Note that the datasets have different spatial coverage and are not coverage-matched. All anomalies are calculated relative to 1961–1990, and an offset of 0.53 °C is added to obtain TXx values relative to 1850–1900. Note that while the HadEX3 numbers are the same as shown in Seneviratne et al. (2021) Fig. 11.2, these numbers were not specifically assessed.

to 2021, while ERA5 is updated daily with a latency of about 5 d (and the final release occurs after 2–3 months).

Our proposed climate indicator of changes in temperature extremes consists of land average annual maximum temperatures (TXx) (excluding Antarctica). For HadEX3, we select the years 1961–2018, to exclude years with insufficient data coverage, and require at least 90 % temporal completeness, thus applying the same criteria as for Fig. 11.2 (Seneviratne et al., 2021). Berkeley Earth provides daily maximum temperatures, and we require more than 99 % data availability for each individual year and grid, such that years with more than 4 missing days are removed. Based on this criterion, Berkeley Earth covers at least 95 % of the global land area from 1955 onwards. ERA5, on the other hand, has full spatio-temporal coverage by design, and hence the entire currently available period of 1950 to 2022 is used. The annual maximum temperature is then computed for each grid cell, and a global area-weighted average is calculated for all grid cells with at least 90 % temporal completeness in the respective available period (1955–2021 and 1961–2018 for Berkeley Earth and HadEX3, while ERA5 is again not affected by this criterion). We thus enforce high data availability to adequately calculate global land averaged TXx across all three datasets, but their coverage is not identical, which introduces minor deviations in the estimated global land averages. The resulting TXx time series are then computed as anomalies with respect to a baseline period of 1961–1990.

To express the TXx as anomalies with respect to 1850–1900, we add an offset to all three datasets. The offset is based on the Berkeley Earth data and is derived from the linear regression of land mean TXx to the annual mean global mean air temperature over the period 1955 to 2020. The offset is then calculated as the slope of the linear regression

Table 8. Anomalies of land average annual maximum temperature (TXx) for recent decades based on HadEX3 and ERA5.

Period	Anomaly w.r.t. 1961–1990 (°C)		Anomaly w.r.t. 1850–1900 (°C)
	HadEX3	ERA5	ERA5
2000–2009	0.72	0.69	1.23
2009–2018	1.01	1.02	1.55
2010–2019	–	1.11	1.64
2011–2020	–	1.12	1.65
2012–2021	–	1.18	1.71

times the global mean temperature difference between the reference periods 1850–1900 and 1961–1990 (see Supplement, Fig. S4).

Our climate has warmed rapidly in the last few decades, which also manifests in changes in the occurrence and intensity of climate and weather extremes. We visualise this with land average annual maximum temperatures (TXx) from three different datasets (ERA5, Berkeley Earth and HadEX3), expressed as anomalies with respect to the pre-industrial baseline period of 1850–1900 (Fig. 6). From about 1980 onwards, all employed datasets point to a strong TXx increase, which coincides with the transition from global dimming, associated with aerosol increases, to brightening, associated with decreases (Wild et al., 2005). Together with strongly increasing greenhouse gas emissions (Sect. 2), this explains why human-induced climate change has emerged at an even greater pace in the last 4 decades than previously. For example, land average annual maximum temperatures have warmed by more than 0.5 °C in the past 10 years (1.72 °C with respect to pre-industrial conditions) compared to the first decade of the millennium (1.22 °C; Table 8). Since the offset relative to our pre-industrial baseline period is calculated relative to 1961–1990, within the latter period, temperature anomalies align by construction but can diverge afterwards. In an extensive comparison of climate extreme indices across several reanalyses and observational products, Dunn et al. (2022) point to an overall strong correspondence between temperature extreme indices across reanalysis and observational products, with ERA5 exhibiting especially high correlations to HadEX3 among all regularly updated datasets. This suggests that both our choice of datasets and approach to calculate anomalies does not affect our conclusion – the intensity of heatwaves across all land areas has unequivocally increased since pre-industrial times.

The anomalies with respect to 1850–1900 are derived by adding an offset of 0.53 °C. Note that while the HadEX3 numbers are the same as shown in Seneviratne et al. (2021) Fig. 11.2, these numbers were not specifically assessed.

Table 9. Summary of headline results and methodological updates from the Indicators of Global Climate Change (IGCC) initiative.

Climate indicator	AR6 2021 assessment	This 2023 assessment	Explanation of changes	Methodological updates
Greenhouse gas emissions AR6 WGIII Chap. 2: Dhakal et al. (2022); see also Minx et al. (2021)	2010–2019 average: 56 ± 6 $GtCO_2e$*	2010–2019 average: 53 ± 5.6 $GtCO_2e$ 2012–2021 average: 54 ± 5.3 $GtCO_2e$	The change from AR6 is due to a systematic downward revision in CO_2-LULUCF and CH_4 estimates. Real-world emissions have slightly increased. Average emissions in the past decade grew at a slower rate than in the previous decade. Note that following convention, ODS F-gases are excluded from the total.	CO_2-LULUCF emissions revised down. PRIMAP-hist used in place of EDGAR for CH_4 and N_2O emissions and atmospheric measurements taken for F-gas emissions. These changes reduce estimates by around 3 $GtCO_2e$ (Sect. 2)
Greenhouse gas concentrations AR6 WGI Chap. 2: Gulev et al. (2021)	2019: CO_2, 410.1 [±0.36] ppm CH_4, 1866.3 [± 3.2] ppb N_2O, 332.1 [±0.7] ppb	2022: CO_2, 417.1 [±0.4] ppm CH_4, 1911.9 [±3.3] ppb N_2O, 335.9 [±0.4] ppb	Continued and increasing emissions	Updates based on NOAA data as AGAGE not yet available for 2022. To make an AR6-like product, N_2O scaled to approximate NOAA-AGAGE average (Sect. 3)
Effective radiative forcing change since 1750 AR6 WGI Chap. 7: Forster et al. (2021)	2019: 2.72 [1.96 to 3.48] $W m^{-2}$	2022: 2.91 [2.19 to 3.63] $W m^{-2}$	Overall substantial increase and high decadal rate of change, arising from increases in greenhouse gas concentrations and reductions in aerosol precursors	Minor update in aerosol precursor method for improved future estimates – had no impact at quoted accuracy level (Sect. 4)
Global mean surface temperature change above 1850–1900 AR6 WGI Chap. 2: Gulev et al. (2021)	2011–2020 average: 1.09 [0.95 to 1.20] °C	2013–2022 average: 1.15 [1.00–1.25] °C	An increase of 0.06 °C within 2 years, indicating a high decadal rate of change	Methods match AR6 (Sect. 5).
Earth's energy imbalance AR6 WGI Chap. 7: Forster et al. (2021)	2006–2018 average: 0.79 [0.52 to 1.06] $W m^{-2}$	2010–2022. average: 0.89 [0.63 to 1.15] $W m^{-2}$	Substantial increase in energy imbalance estimated based on increased rate of ocean heating	Ocean heat content time series extended from 2018 to 2022 using four of the five AR6 datasets. Other heat inventory terms updated following von Schuckmann et al. (2023). Ocean heat content uncertainty is used as a proxy for total uncertainty. Further details in Sect. 6.
Human-induced global warming since pre-industrial AR6 WGI Chap. 3: Eyring et al. (2021)	2010–2019 average: 1.07 [0.8 to 1.3] °C	2013–2022 average: 1.14 [0.9 to 1.4] °C	An increase of 0.07 °C within 3 years, indicating a high decadal rate of change	The three methods for the basis of the AR6 assessment are retained, but each has new input data (Sect. 7).
Remaining carbon budget for 50 % likelihood of limiting global warming to 1.5 °C AR6 WGI Chap. 5: Canadell et al. (2021)	From the start of 2020: 500 $GtCO_2$	From the start of 2023: about 250 $GtCO_2$ and uncertain	The 1.5 °C budget is becoming very small. The RCB can be exhausted before the 1.5 °C threshold is reached due to having to allow for future non-CO_2 warming.	Methods match AR6 (Sect. 8).
Land average maximum temperature change compared to pre-industrial. AR6 WGI Chap. 11: Seneviratne et al. (2021)	2009–2018 average: 1.55 °C	2013–2022 average: 1.74 °C	Rising at a substantially faster rate compared to global mean surface temperature	HadEX3 data used in AR6 replaced with reanalysis data employed in this report which are more updatable going forward. Adds 0.01 °C to estimate (Sect. 9).

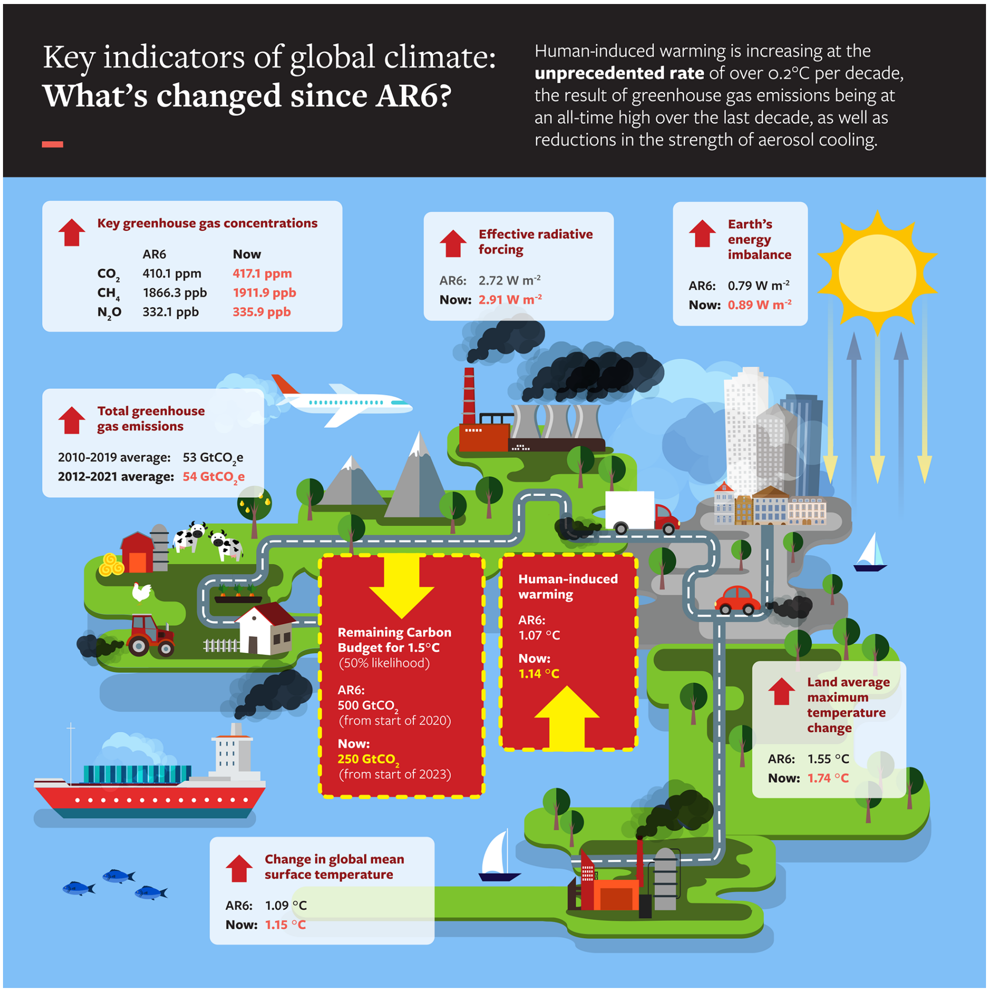

Figure 7. Infographic associated with headline results in Table 9. "AR6" refers to approximately 2019, and "Now" refers to 2022. The AR6 period total emissions are our re-evaluated assessment for 2010–2019. For details and uncertainties, see Table 9.

10 Dashboard data visualisations

The Climate Change Tracker (https://climatechangetracker.org/, last access: 2 June 2023), a platform hosting a range of publicly available climate data, aims to provide a range of audiences with a reliable, user-friendly means of tracking and understanding climate change and its progression.

Building on the existing platform, a bespoke "dashboard" places several of the updated IPCC-consistent indicators of climate change set out above in the public domain. This bespoke dashboard is primarily aimed at policymakers involved in UNFCCC negotiations, but the ultimate intention is to reach and inform a much wider audience.

The dashboard initially focuses on three key indicator sets: greenhouse gas emissions (Sect. 2), human-induced global warming (Sect. 7) and the remaining global carbon budget (Sect. 8), bringing together and presenting up-to-date information crucial to effective climate decision-making in a findable, accessible, traceable and reproducible way. In addition, the Climate Change Tracker provides standardised application programming interfaces (APIs), dashboards and charts to embed in third-party apps and websites. All data are traceable to the GitHub repository employed for this paper (Sect. 11).

In time, and with feedback from the user community, the initial set of indicators displayed by the dashboard may be expanded to include others alongside their rates of change.

11 Code and data availability

The carbon budget calculation is available from https://github.com/Rlamboll/AR6CarbonBudgetCalc (Lamboll and Rogelj, 2023). The code and data used to produce other indicators are available in repositories under https://github.com/ClimateIndicator (Smith et al., 2023b). All data are available from https://doi.org/10.5281/zenodo.8000192 (Smith et al., 2023a). Data are provided under the CC-BY 4.0 Licence.

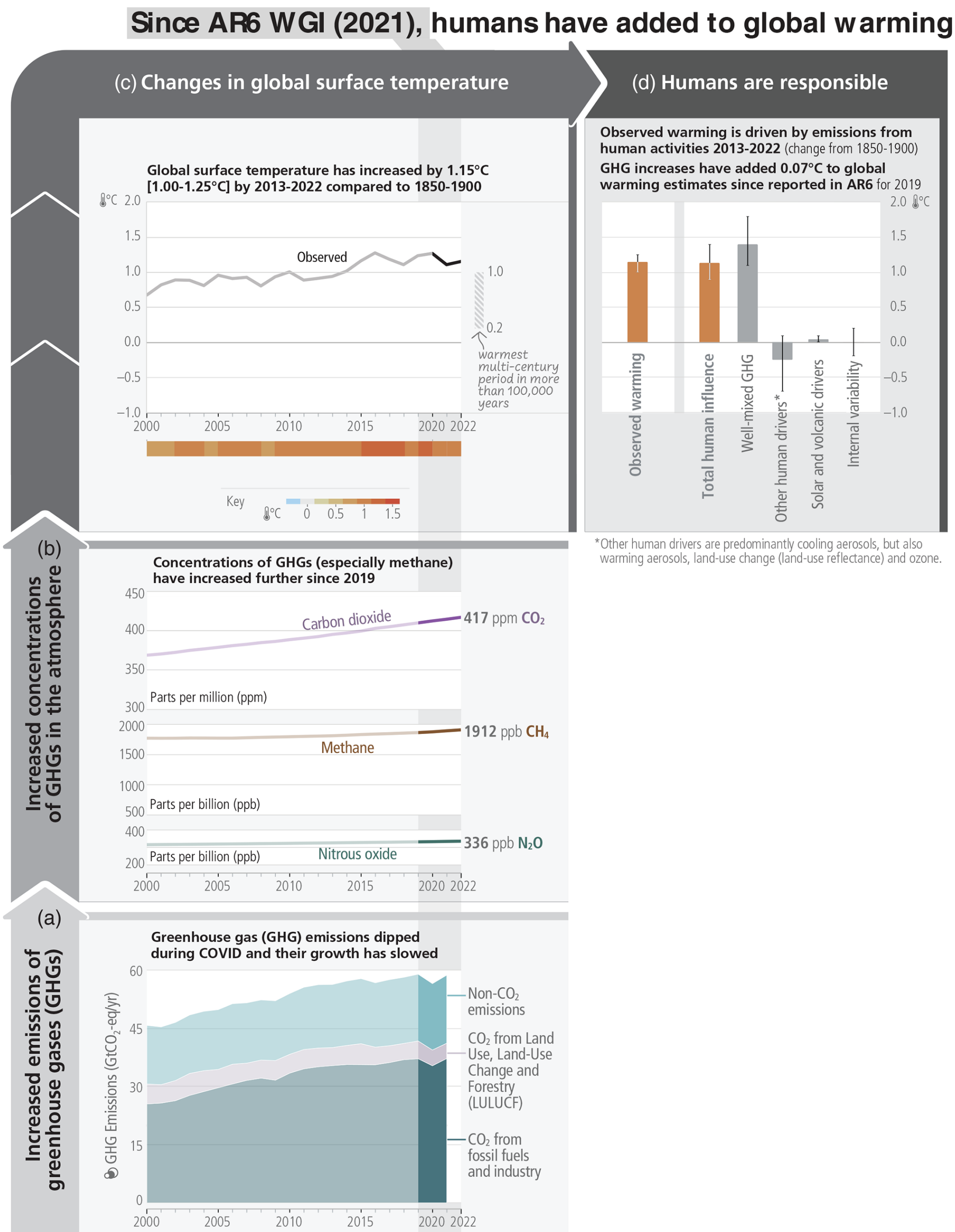

Figure 8. The causal chain from emissions to resulting warming of the climate system. Emissions of GHGs have increased rapidly over recent decades **(a)**. These emissions have led to increases in the atmospheric concentrations of several GHGs including the three major well-mixed GHGs **(b)**. The global surface temperature (shown as annual anomalies from an 1850–1900 baseline) has increased by around 1.15 °C since 1850–1900 **(c)**. The human-induced warming estimate over the last decade is a close match to the observed warming **(d)**. Whiskers show 5 % to 95 % ranges. Figure is modified from AR6 SYR with a zoomed-in view of the period 2000 to 2022 for the upper two panels (Fig. 2.1, Lee et al., 2023).

HadEX3 [3.0.4] data were obtained from https://catalogue.ceda.ac.uk/uuid/115d5e4ebf7148ec941423ec86fa9f26 (Dunn et al., 2023) on 5 April 2023 and are © British Crown Copyright, Met Office, 2022, provided under an Open Government Licence; http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2/ (last access: 2 June 2023).

12 Discussion and conclusions

The first year of the Global Climate Change (IGCC) initiative has built on the AR6 report cycle to provide a comprehensive update of the climate change indicators required to estimate the human-induced warming and the remaining carbon budget. Table 9 and Fig. 7 present a summary of the headline figures from each section compared to those given in the AR6 assessment. The main substantive dataset change since AR6 is that land-use CO_2 emissions have been revised down by around 2 $GtCO_2$ (Table 9). However, as CO_2 ERF and human-induced warming estimates depend on concentrations, not emissions, this does not affect most of the other findings. Note it does slightly increase the remaining carbon budget, but this is only by 5 $GtCO_2$, less than the 50 $GtCO_2$ rounding precision.

Figure 8 summarises contributions to warming, repeating Fig. 2.1 of the AR6 Synthesis Report (Lee et al., 2023). It highlights changes since the assessment period in AR6 WGI. Table 9 also summarises methodological updates.

It is hoped that this update can support the science community in its collection and provision of reliable and timely global climate data. In future years we are particularly interested in improving SLCF updating methods to get a more accurate estimate of short-term ERF changes. The work also highlights the importance of high-quality metadata to document changes in methodological approaches over time. In future years we hope to improve the robustness of the indicators presented here but also extend the breadth of indicators reported through coordinated research activities. For example, we could begin to make use of new satellite data inversion techniques to infer recent emissions. We are particularly interested in exploring how we might update indicators of regional climate extremes and their attribution, which are particularly relevant for supporting actions on adaptation and loss and damage.

Generally, scientists and scientific organisations such as the WMO and IPCC have an important role as "watchdogs" to critically inform evidence-based decision-making. This annual update traced to IPCC methods can provide a reliable, timely source of trustworthy information. As well as helping inform decisions, we can use the update to track changes in dataset homogeneity between their use in one IPCC report and the next. We can also provide information and testing to motivate updates in methods that future IPCC reports might choose to employ.

Figure 9 shows decadal trends for the attributed warming and ERF. The most recent trends were unprecedented at the time of AR6 and have increased further since then (red markers), showing that human activities are consistently causing global warming recently of more than 0.2 °C per decade. As nations and businesses forge climate policies and take meaningful action, the latest available evidence shows that global actions are not yet at the scale to manifest a substantive shift in the direction of global human influence on the Earth's energy imbalance and the resulting global warming. Indeed, our results point to the opposite: the evidence shows continued increase in cumulative CO_2 emissions, increased emissions of other GHGs and gains in air quality at the expense of the loss of the cooling effect from aerosols. Both AR6 WGI and WGIII reports highlighted the benefits of short-term reductions in methane emissions to counter the loss of aerosol cooling and further improve air quality – however, at the global scale, methane emissions are at their highest level and rising (see Table 1). Policymakers, civil society and the scientific community require monitoring data and analyses from rigorous, robust assessments available on a regular basis. These results illustrate how assessments such as ours provide a strong "reality check" based on science and real-world data.

This is a critical decade: human-induced global warming rates are at their highest historical level, and 1.5 °C global warming might be expected to be reached or exceeded within the next 10 years in the absence of cooling from major volcanic eruptions (Lee et al., 2021). Yet this is also the decade that global greenhouse gas emissions could be expected to peak and begin to substantially decline. The indicators of global climate change presented here show that the Earth's energy imbalance has increased to around 0.9 $W\,m^{-2}$, averaged over the last 12 years. This also has implications for the committed response of slow components in the climate system (glaciers, deep ocean, ice sheets) and committed long-term sea level rise, but this is not part of the update here. However, rapid and stringent GHG emission decreases could halve warming rates over the next 20 years (McKenna et al., 2021). Table 1 shows that global GHG emissions are at a long-term high, yet there are signs that their rate of increase

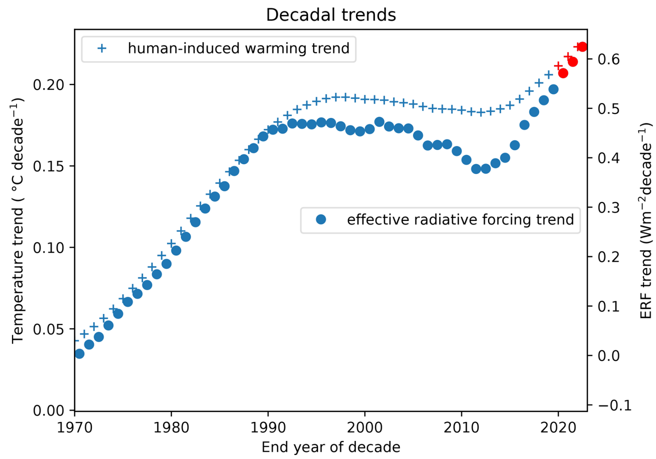

Figure 9. Decadal trends in human-induced warming on the left axis and anthropogenic effective radiative forcing (ERF) on the right axis. These are computed from the Global Warming Index human-induced warming estimate shown in the Supplement, Sect. S7 and Fig. 2b, respectively. The red points mark 3 additional years since the AR6 time series for these indicators ended in 2019.

has slowed. Depending on the societal choices made in this critical decade, a continued series of these annual updates could track a change in direction for the human influence on climate.

Supplement. The supplement related to this article is available online at: https://doi.org/10.5194/essd-15-2295-2023-supplement.

Author contributions. PMF, CJS, MA, PF, JR, MRC and AP developed the concept of an annual update in discussions with the wider IPCC community over many years. CJS led the work of the data repositories. ABo and JAB led the website development with visualisation support from DR, JMG and ABi. VMD, PZ, SS, JM, CFS, SIS, VN, AP, JYL, NG, FD, GP, BT, MSP, MRC, JR, PF, MA and PT provided important IPCC and UNFCCC framing. PMF coordinated the production of the manuscript with support from DR. WFL led Sect. 2 with contributions from CJS, JM, PF, GP, JG, JP and RA. CJS led Sects. 3 and 4 with contributions from BH, FD, SS, VN and XL. BT led Sect. 5 with contributions from PT, CM, CK, JK, RR, RV and LC. KvS and MDP led Sect. 6 with contributions from LC, MI, TB and RK. TW led Sect. 7 with contributions and calculations from AR, NG and MR. JR led Sect. 8 with contributions from RL and KZ. Section 9 was led by SIS and XC with calculations by MH and DS. All authors either edited or commented on the manuscript.

Competing interests. The contact author has declared that none of the authors has any competing interests.

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Financial support. This research has been supported by the Horizon 2020 Framework Programme, H2020 Excellent Science (grant nos. 820829 and 821003), the H2020 European Research Council (grant no. 951542) and the Natural Environment Research Council (grant no. NE/T009381/1). Matthew D. Palmer, Colin Morice and Rachel Killick were supported by the Met Office Hadley Centre Climate Programme funded by BEIS.

Review statement. This paper was edited by David Carlson and reviewed by Albertus J. (Han) Dolman, Martin Heimann, Matthew Jones, Greet Janssens-Maenhout, and one anonymous referee.

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explore, enjoy, and protect the planet.

April 11, 2019

Via email to Matthew Higdon at mshigdon@tva.gov

Matthew Higdon
NEPA Specialist
Tennessee Valley Authority
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Knoxville, TN 37902

Re: Comment Regarding Sugar Camp Coal Mine Expansion Viking District #2 Draft Supplemental Environmental Assessment, Franklin and Hamilton Counties, Illinois

Dear Mr. Higdon and other TVA officials,

The Illinois Chapter of the Sierra Club objects to the Draft Supplemental Environmental Assessment (SEA) for the Sugar Camp Coal Mine Expansion Viking District #2 in Franklin and Hamilton counties, Illinois. We request that the TVA not approve the proposal, based on the lack of complete information regarding adverse impacts of this project and the substantive lack of full consideration of clear harm that will result if TVA approves this project.

Expanded coal mining is proposed, damage to air quality and the climate is certain. Further, the fact that a room and pillar mine is proposed does not guarantee that there will not be damage to water quality and other elements of the human environment.

Further, while in this case the No Action alternative should be adopted, if the mine is to go forward in any form, more alternatives should be considered than the No Action alternative and doing exactly what the applicant wishes.

Our organization represents over 31,000 members in Illinois. Our members are affected by global climate change caused by the burning of fossil fuels and concerned and potentially affected by pollutant discharges into the Middle Fork Big Muddy River and creeks in Franklin County impacted by the Sugar Camp Mine, including an unnamed tributary to Middle Fork Big Muddy River, an unnamed tributary to Akin Creek and Akin Creek.[1] Further, our members are concerned with the growing levels of chloride and other water pollutants in the Middle Fork Big Muddy River and Big Muddy River, which is a Water of the State as part of the Mississippi River Basin. The Middle Fork Big Muddy River is listed on the draft 2016 303(d) list of impaired waters for reasons that may include pollutants from coal mining.

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[1] IEPA NPDES IL0078565 Sugar Camp Mine, Viking Coal, list of receiving waters; permit attached as Att. 2

We are concerned about the additional harm that this facility may cause to the human environment if this project is approved based on this inadequate SEA.

Objections:

1. The repeated history of violations and non-compliance on record for the Sugar Camp Mine clearly shows this mine has consistently failed to remove coal in an environmentally sound manner as evidenced by its repeated quarters in non-compliance with basic permit levels, including 125 state and federal violations from 2015 to 2018. The problematic history of this mine includes two formal enforcement actions in recent years, including mine construction of two deep underground injection wells before permitted to do so. This mine has a repeated history of contaminated water releases and coal slurry releases to area waterways, including adverse impacts off-site putting water resources of the state of Illinois at risk. This mine has a history of failure to maintain its waste containment structures, to the detriment of area creeks and discharges to the Middle Fork Big Muddy River and recorded instances of coal waste overflowing mine containment structures. [2]

The SEA should consider the environmental impacts of the water pollution being caused by the mine and that will be caused if this expansion is allowed. Given the fact that the applicant has been discharging chloride at high concentrations (higher even than its current permit allows), the SEA should also consider the evidence regarding chloride toxicity and other effects on the environmental. Much information regarding the environmental impacts of chloride pollution is contained in the record of IPCB 18-32.[3]

Further, particularly given the history of violations at this facility, the SEA should consider alternatives for monitoring and contract penalties to assuring future compliance with sound environmental practices and the law.

2. Additional pollution loading of the Big Muddy River must also be considered. The Williamson Energy Pond Creek No. 1 Mine, located near Johnston City, Williamson County, but also with shadow area in Franklin County, has proposed a 12.5-mile pipeline to pump contaminated mine water for direct discharge into the Big Muddy River. This proposal is for 2,700,000 gallons per day up to 3,500,000 gallons per day of high chloride and sulfate contaminated water. The cumulative impacts of mine discharges to the Big Muddy River and its tributaries must be fully reviewed before any new permits allowing mine contaminated water to these Waters of the State are approved.

3. Room and pillar mining can subside, causing burdensome costs to the public and governmental entities. No consideration is given in the SEA to the propensity for eventual subsidence of room and

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[2] EPA ECHO database https://echo.epa.gov/detailed-facility-report?fid=110037943795 and see download from April 11, 2019 attached as Att. 1

[3] https://pcb.illinois.gov/Cases/GetCaseDetailsById?caseId=15588

pillar mining or the fact the mining company often avoids all responsibility for the environmental and financial damage done by subsidence due to the extended time it can take for such subsidence to manifest itself. Examples of societal damages and public costs from room and pillar mine subsidence include $26 million for replacement of the Benld School, Macoupin County, Illinois.[4] Because mine tunnels are known to be prone to collapse at some future point in time, the re-located school had added costs of pumping tens of thousands of tons of concrete slurry into old coal mine room and pillar works hundreds of feet below the location for a new school. Coal mine subsidence insurance is mandatory in Franklin County, where this Sugar Camp Mine expansion is located, as well as other near-by counties. Thirty four counties in Illinois require mine subsidence insurance because of the known risks and existing and potential mine subsidence. As the brochure states, most experts agree that mines will eventually experience some degree of collapse, but currently there is no way to know when or exactly where mine subsidence will occur.[5] Subsidence can cause costly drainage and erosion problems for fields as well as significant damages to buildings.

The SEA should consider eventual subsidence and potential societal harm and public and private costs that will be incurred. While hopefully the required insurance can be used to compensate for some of the costs of subsidence, the insurance will not cover much damage to the environment that subsidence will cause. The SEA should also consider the applicant's specific plans to determine whether the risk of subsidence has been minimized. Alternatives, including mining less coal than the applicant proposes to create more support, should be considered as well as alternatives for bonding or other requirements that will assure that the environment and the public will not bear the cost of any eventual need for groundwater remediation or other work needed including mitigation for all water pollution and other environmental damage. See, Union Neighbors United v. Jewell, 831 F.3d 564 (D.C. Cir. 2016).

3. Demand on area water resources have not been considered. The Sugar Camp Mine obtains water from Rend Lake. Concerns for demands on Rend Lake Water and impacts from extended drought have not been taken into consideration. A contract signed in 2007 with Adena Resources LLC for direct withdrawal of water from Rend Lake to supply Sugar Camp and Pond Creek mines, states that the daily withdrawal quota will initially be set at 6 million gallons per day. That amount is likely to be higher now. Rend Lake provides public water for all or part of seven counties in Southern Illinois.[6] A water main break in 2018 put 60 communities at risk due to lack of water and resulted in school and business closures and extended boil orders for the water users. In 2007 drought conditions caused a significant drop in Rend Lake water levels and restrictions on lake use.[7] The Sugar Camp Mine can use up to 4.3 millions gallons per day of Rend Lake water. No consideration is given to the additional water use the proposed SEP will require.

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[4] https://www.stltoday.com/news/local/illinois/illinois-district-replacing-elementary-school-ruined-by-collapsing-mine/article_ef5a27fa-df51-5c36-b52c-eaf53b1b905a.html

[5] "Should I Purchase Mine Subsidence Insurance," Illinois Mine Subsidence Insurance Fund, 2008, attached as Att. 3

[6] https://thesouthern.com/news/local/southern-illinois-faces-water-shortage-as-rend-lake-conservancy-district/article_dc9a3ceb-99fb-5732-aeb7-e88b683889a8.html

[7] https://williamsoncountytourism.blogspot.com/2007/10/drought-hits-rend-lake-water-levels.html

4. Based on the unjustified and unjustifiable assumption of the SEA that a room and pillar mine will never affect groundwater or surface water, the SEA proposes no specific mitigation. TVA, however, should take a hard look at the likelihood of such impacts and consider steps needed for mitigation of them. While not required under NEPA to consider a "worst case scenario," TVA is certainly required to consider the potential for environmental effects that have actually occurred such as mine subsidence. See, AquAlliance v. U.S. Bureau of Reclamation, 287 F.Supp. 3d 969, 1030-31 (E.D. Cal. 2018)

5. Global climate change with rising overall planetary temperatures, increased ocean warming and acidification, rapid melting of polar ice caps, rising sea levels, and clear evidence of more severe weather events must be taken into consideration as part of the SEP review. Blanket approvals of coal mine permits can no longer be considered to foster the social and economic well-being of residents, of the TVA or the nation. The true costs of coal are paid by the public and all levels of government. Coal mining privatizes the profits and has shifted the costs of air and water pollution, land damages, and public health harm to the citizens of the U.S. for decades. The public is paying the costs of coal via taxes and other governmental payments through emergency relief for severe storm impacts, flooding, public infrastructure damages, farm and crop damages, major forest fires, and a wide-range of other disasters. The public has paid the costs of coal air pollution via increased cases of asthma and health problems caused by the burning of coal and added air pollution and involuntary personal health pollution impacts. Groundwater at nearly all coal-fired power plants in Illinois has been polluted by coal ash ponds and is not potable, creating liabilities for future generations and future public health risks and costs from the lack of adequate containment and management of coal combustion waste residues, which continues. Calculations have been made that the annual cost to the public from pollution impacts and other damages from coal are from over one third to a half trillion dollars annually.[8]

6. The TVA is aiding and abetting the abuse of coal rights contracts signed many decades ago. Property owners who sold their coal rights to the Tennessee Valley Authority were dealing with a governmental agency, for whom coal would be used for the provision of energy for the public under the TVA. Many of these coal rights allow advantages for surface property takings which have been used by existing coal companies to pressure local land owners. Since the TVA has allowed for-profit coal companies to obtain extensive coal rights with these old coal contracts, some of which contain extraordinary surface rights provisions from an entirely different era and circumstances, the tables are turned on the public. For-profit coal companies get the advantages of very low-priced coal contracts that were originally sold to and owned by a governmental entity. Local property owners bear the psychological, physical, and emotional harm of living with concerns for what will happen to their property or they are driven to the point of selling out to the coal companies. The for-profit coal companies make the additional profit from the TVA leases. The Sugar Camp Mine is thought to have 7.2 billion tons of TVA coal leases. This current permit is not needed to allow this company to continue.

The current existing TVA SEP assessment is arbitrary and capricious, completely ignoring and failing to take into any adequate consideration the full impacts of this mining permit expansion. The TVA fails to fully review key areas with which the mine impacts are a clear and present danger. The TVA should not approve the mining and removal of coal as proposed by Sugar Camp based on the proposed Mining Plan

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[8] https://www.motherjones.com/environment/2015/08/coals-cost-climate-change/

for Sugar Camp Mine No. 1 because it will add adverse impacts to all categories under TVA jurisdiction for review.

Sincerely,

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Tom Benner, IDNR Office of Mines and Minerals to tom.benner@illinois.gov

Attachments:

1- ECHO report
2- Sugar Camp Mine NPDES permit
3- Illinois Mine Subsidence Insurance Fund brochure

Attachment 1: Download from ECHO April 11, 2019

Compliance Summary Data

Statute	Source ID	Current SNC/HPV	Current As Of	Qtrs with NC (of 12)	Data Last Refreshed
CWA	IL0078565	No	12/31/2018	4	04/05/2019

Three-Year Compliance History by Quarter

Download Data

Statute	Program/Pollutant/Violation Type			QTR 1	QTR 2	QTR 3	QTR 4	QTR 5	QTR 6	QTR 7	QTR 8	QTR 9	QTR 10	QTR 11	QTR 12	QTR 13+
CWA (Source ID: IL0078565)				01/01-03/31/16	04/01-06/30/16	07/01-09/30/16	10/01-12/31/16	01/01-03/31/17	04/01-06/30/17	07/01-09/30/17	10/01-12/31/17	01/01-03/31/18	04/01-06/30/18	07/01-09/30/18	10/01-12/31/18	01/01-04/05/19
	Facility-Level Status			No Violation Identified	No Violation Identified	Violation Identified	No Violation Identified	Violation Identified	No Violation Identified	No Violation Identified	No Violation Identified	Violation Identified	No Violation Identified	Violation Identified	Unknown	Undetermined
	Quarterly Noncompliance Report History			Resolved		Other Violation	Resolved	Reportable Noncompliance	Resolved			Other Violation		Other Violation	Undetermined	
	Pollutant	Disch Point	Freq													
CWA	Chloride [as Cl]	001	N Mth									30%				
CWA	Chloride [as Cl]	003	N Mth			266%						1080%		520%		
CWA	pH	003	Neither			LIMIT VIOLATION										
CWA	Iron, total	008	N Mt									45%				

Statute	Program/Pollutant/Violation Type			QTR 1	QTR 2	QTR 3	QTR 4	QTR 5	QTR 6	QTR 7	QTR 8	QTR 9	QTR 10	QTR 11	QTR 12	QTR 13+
	[as Fe]		h													
CWA	Manganese, total [as Mn]	008	N Mth			333%										
CWA	Solids, total suspended	008	N Mth									90%				
CWA	Chloride [as Cl]	013	N Mth				260 %									
	Late or Missing Discharge Monitoring Report (DMR) Measurements															
	Counts of Missing DMR Measurements													13		

Informal Enforcement Actions (5 Years)

Statute	System	Source ID	Type of Action	Lead Agency	Date
CWA	ICP	IL0078565	Letter of Violation/ Warning Letter	State	10/23/2014

Formal Enforcement Actions (5 Years)

Statute	System	Law/Section	Source ID	Action Type	Case No.	Lead Agency	Case Name	Issued/Filed Date	Settlements/Actions	Settlement/Action Date	Federal Penalty	State/Local Penalty	SEP Cost	Comp Action Cost
CWA	ICP	OTHER	NPDES/IL0078565	Administrative - Formal	IL-0078565-1	State	CCAM-2014-02002	03/24/2015	1	03/24/2015				

https://www.wpsdlocal6.com/news/company-faces-nearly-1-2-million-in-federal-penalties-for-failing-to-evacuate-miners-after/article_a298cf8e-ee98-11ec-a829-d7850af25825.html

Company faces nearly $1.2 million in federal penalties for failing to evacuate miners after fire broke out in southern Illinois coal mine

Leanne Fuller
Jun 17, 2022

FRANKLIN COUNTY, IL — The U.S. Department of Labor's Mine Safety and Health Administration is proposing nearly $1.2 million in penalties against the operator of a Macedonia, Illinois, coal mine where employees continued to work after a fire broke out along an underground longwall section of the mine.

MSHA says mine operator M-Class Mining LLC continued operations at the coal mine in Macedonia without evacuating miners after the fire broke out on Aug. 13, 2021, and didn't notify MSHA about the fire.

The government agency says it learned about the fire via an anonymous complaint on Aug. 14. MSHA ordered the company to withdraw all miners and initiate an accident investigation. The agency says that investigation found that the company continued coal production and didn't take follow the approved Mine Emergency Evacuation and Firefighting Program to evacuate the miners immediately.

MSHA says the company was required by law to notify officials about the fire within 15 minutes after it started. The agency says M-Class Mining not only failed to meet that requirement, but also failed to fully comply with federal orders to evacuate miners from the mine.

“M-Class Mining LLC deliberately jeopardized the lives of the very miners it was responsible for protecting, and violated numerous important safety and health standards in the process,” Assistant Secretary for Mine Safety and Health Chris Williamson said in a statement released Friday. “The fact that this operator continued business as usual while miners underground had no idea there was an ongoing fire hazard more than justifies the civil penalties that we propose.”

M-Class Mining now faces 14 citations, including 10 stemming from what the Labor Department calls its "reckless disregard for the miners' safety and health." Two of the proposed citations are flagrant, which means they are subject to the highest penalty under law. MSHA says those two citations stem from the operator's failure to evacuate the mine when the fire was discovered and the fact that it allowed miners to work underground without being tracked.

The government agency says it has assessed $1,165,396 in proposed penalties against M-Class Mining. The company has 30 days to pay the fines or contest the citations to the Federal Mine Safety and Health Review Commission.

The fire and actions operators took after it broke out are also the subject of two lawsuits filed last year. Sierra Club Illinois and the Champaign-based Prairie Rivers Network **announced in November** that they would be suing over the use of toxic chemical foam in an unsuccessful attempt to douse the fire. The groups said 46,000 gallons of fire extinguishing foam was dumped into the underground mine, including at least 660 gallons of concentrated PFAS-based foam.

PFAS is short for perfluoroalkyl and polyfluoroalkyl substances. The term refers to a group of manmade chemicals that don't break down in the environment or the human body. According to the Environmental Protection Agency, PFAS can accumulate over time, and there's evidence that exposure to them can cause negative health effects, such as cancer, liver damage, fertility issues and other medical conditions.

In January, the **Illinois Attorney General's Office** announced that the state is also suing over the use of PFAS at the mine. The AG's office says the fire extinguishing foam caused water pollution, jeopardizing public safety and violating state statutes.

Summary for Policymakers

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This Summary for Policymakers should be cited as:

IPCC, 2018: Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-24. https://doi.org/10.1017/9781009157940.001.

SPM

Introduction

This Report responds to the invitation for IPCC '... to provide a Special Report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways' contained in the Decision of the 21st Conference of Parties of the United Nations Framework Convention on Climate Change to adopt the Paris Agreement.[1]

The IPCC accepted the invitation in April 2016, deciding to prepare this Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

This Summary for Policymakers (SPM) presents the key findings of the Special Report, based on the assessment of the available scientific, technical and socio-economic literature[2] relevant to global warming of 1.5°C and for the comparison between global warming of 1.5°C and 2°C above pre-industrial levels. The level of confidence associated with each key finding is reported using the IPCC calibrated language.[3] The underlying scientific basis of each key finding is indicated by references provided to chapter elements. In the SPM, knowledge gaps are identified associated with the underlying chapters of the Report.

A. Understanding Global Warming of 1.5°C[4]

A.1 Human activities are estimated to have caused approximately 1.0°C of global warming[5] above pre-industrial levels, with a *likely* range of 0.8°C to 1.2°C. Global warming is *likely* to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. (*high confidence*) (Figure SPM.1) {1.2}

A.1.1 Reflecting the long-term warming trend since pre-industrial times, observed global mean surface temperature (GMST) for the decade 2006–2015 was 0.87°C (*likely* between 0.75°C and 0.99°C)[6] higher than the average over the 1850–1900 period (*very high confidence*). Estimated anthropogenic global warming matches the level of observed warming to within ±20% (*likely range*). Estimated anthropogenic global warming is currently increasing at 0.2°C (*likely* between 0.1°C and 0.3°C) per decade due to past and ongoing emissions (*high confidence*). {1.2.1, Table 1.1, 1.2.4}

A.1.2 Warming greater than the global annual average is being experienced in many land regions and seasons, including two to three times higher in the Arctic. Warming is generally higher over land than over the ocean. (*high confidence*) {1.2.1, 1.2.2, Figure 1.1, Figure 1.3, 3.3.1, 3.3.2}

A.1.3 Trends in intensity and frequency of some climate and weather extremes have been detected over time spans during which about 0.5°C of global warming occurred (*medium confidence*). This assessment is based on several lines of evidence, including attribution studies for changes in extremes since 1950. {3.3.1, 3.3.2, 3.3.3}

1 Decision 1/CP.21, paragraph 21.

2 The assessment covers literature accepted for publication by 15 May 2018.

3 Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, more unlikely than likely 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, for example, *very likely*. This is consistent with AR5.

4 See also Box SPM.1: Core Concepts Central to this Special Report.

5 Present level of global warming is defined as the average of a 30-year period centred on 2017 assuming the recent rate of warming continues.

6 This range spans the four available peer-reviewed estimates of the observed GMST change and also accounts for additional uncertainty due to possible short-term natural variability. {1.2.1, Table 1.1}

A.2 Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and will continue to cause further long-term changes in the climate system, such as sea level rise, with associated impacts (*high confidence*), but these emissions alone are *unlikely* to cause global warming of 1.5°C (*medium confidence*). (Figure SPM.1) {1.2, 3.3, Figure 1.5}

A.2.1 Anthropogenic emissions (including greenhouse gases, aerosols and their precursors) up to the present are *unlikely* to cause further warming of more than 0.5°C over the next two to three decades (*high confidence*) or on a century time scale (*medium confidence*). {1.2.4, Figure 1.5}

A.2.2 Reaching and sustaining net zero global anthropogenic CO_2 emissions and declining net non-CO_2 radiative forcing would halt anthropogenic global warming on multi-decadal time scales (*high confidence*). The maximum temperature reached is then determined by cumulative net global anthropogenic CO_2 emissions up to the time of net zero CO_2 emissions (*high confidence*) and the level of non-CO_2 radiative forcing in the decades prior to the time that maximum temperatures are reached (*medium confidence*). On longer time scales, sustained net negative global anthropogenic CO_2 emissions and/or further reductions in non-CO_2 radiative forcing may still be required to prevent further warming due to Earth system feedbacks and to reverse ocean acidification (*medium confidence*) and will be required to minimize sea level rise (*high confidence*). {Cross-Chapter Box 2 in Chapter 1, 1.2.3, 1.2.4, Figure 1.4, 2.2.1, 2.2.2, 3.4.4.8, 3.4.5.1, 3.6.3.2}

A.3 Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C (*high confidence*). These risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options (*high confidence*). (Figure SPM.2) {1.3, 3.3, 3.4, 5.6}

A.3.1 Impacts on natural and human systems from global warming have already been observed (*high confidence*). Many land and ocean ecosystems and some of the services they provide have already changed due to global warming (*high confidence*). (Figure SPM.2) {1.4, 3.4, 3.5}

A.3.2 Future climate-related risks depend on the rate, peak and duration of warming. In the aggregate, they are larger if global warming exceeds 1.5°C before returning to that level by 2100 than if global warming gradually stabilizes at 1.5°C, especially if the peak temperature is high (e.g., about 2°C) (*high confidence*). Some impacts may be long-lasting or irreversible, such as the loss of some ecosystems (*high confidence*). {3.2, 3.4.4, 3.6.3, Cross-Chapter Box 8 in Chapter 3}

A.3.3 Adaptation and mitigation are already occurring (*high confidence*). Future climate-related risks would be reduced by the upscaling and acceleration of far-reaching, multilevel and cross-sectoral climate mitigation and by both incremental and transformational adaptation (*high confidence*). {1.2, 1.3, Table 3.5, 4.2.2, Cross-Chapter Box 9 in Chapter 4, Box 4.2, Box 4.3, Box 4.6, 4.3.1, 4.3.2, 4.3.3, 4.3.4, 4.3.5, 4.4.1, 4.4.4, 4.4.5, 4.5.3}

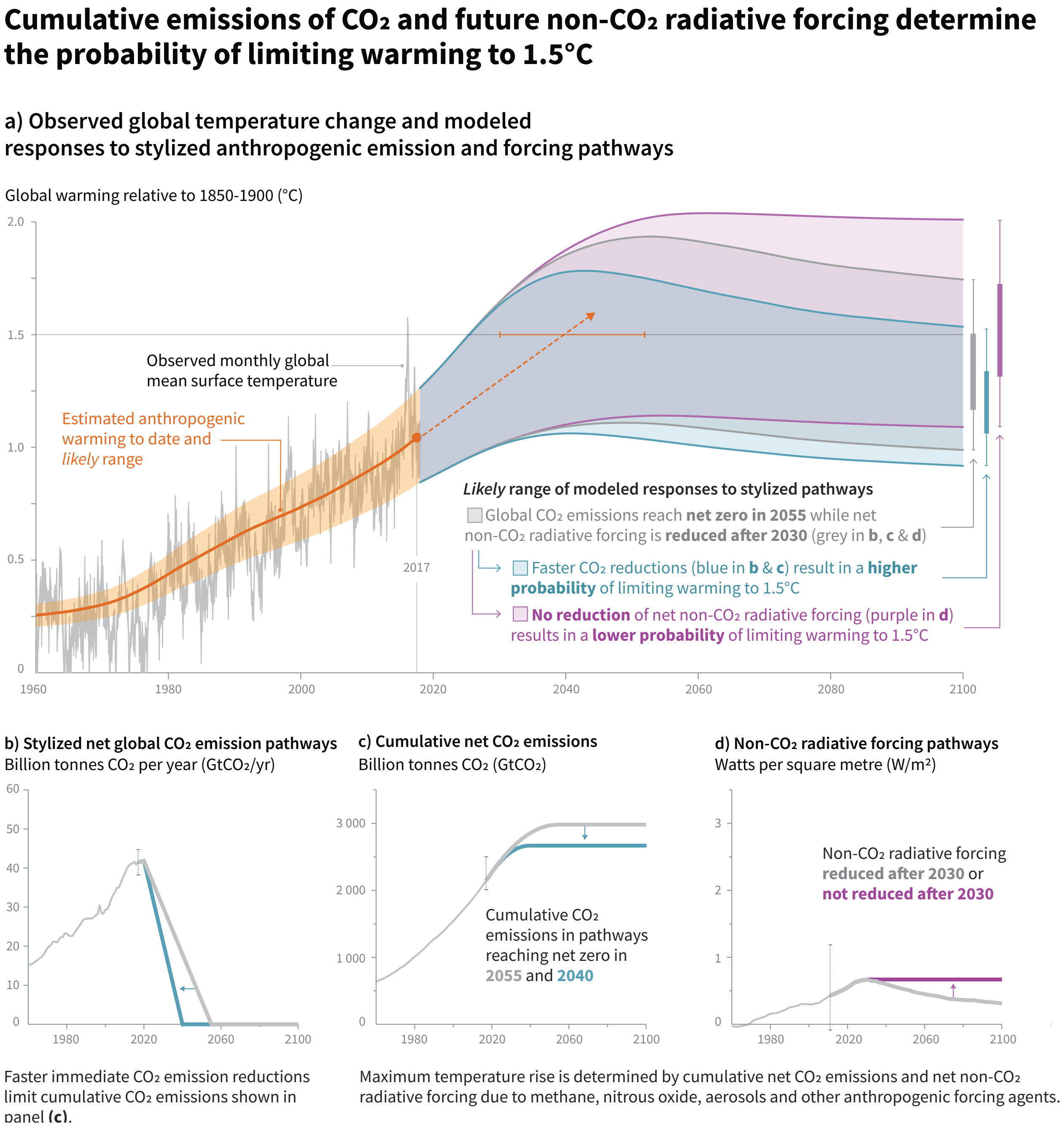

Figure SPM.1 | Panel a: Observed monthly global mean surface temperature (GMST, grey line up to 2017, from the HadCRUT4, GISTEMP, Cowtan–Way, and NOAA datasets) change and estimated anthropogenic global warming (solid orange line up to 2017, with orange shading indicating assessed *likely* range). Orange dashed arrow and horizontal orange error bar show respectively the central estimate and *likely* range of the time at which 1.5°C is reached if the current rate of warming continues. The grey plume on the right of panel a shows the *likely* range of warming responses, computed with a simple climate model, to a stylized pathway (hypothetical future) in which net CO_2 emissions (grey line in panels b and c) decline in a straight line from 2020 to reach net zero in 2055 and net non-CO_2 radiative forcing (grey line in panel d) increases to 2030 and then declines. The blue plume in panel a) shows the response to faster CO_2 emissions reductions (blue line in panel b), reaching net zero in 2040, reducing cumulative CO_2 emissions (panel c). The purple plume shows the response to net CO_2 emissions declining to zero in 2055, with net non-CO_2 forcing remaining constant after 2030. The vertical error bars on right of panel a) show the *likely* ranges (thin lines) and central terciles (33rd – 66th percentiles, thick lines) of the estimated distribution of warming in 2100 under these three stylized pathways. Vertical dotted error bars in panels b, c and d show the *likely* range of historical annual and cumulative global net CO_2 emissions in 2017 (data from the Global Carbon Project) and of net non-CO_2 radiative forcing in 2011 from AR5, respectively. Vertical axes in panels c and d are scaled to represent approximately equal effects on GMST. {1.2.1, 1.2.3, 1.2.4, 2.3, Figure 1.2 and Chapter 1 Supplementary Material, Cross-Chapter Box 2 in Chapter 1}

B. Projected Climate Change, Potential Impacts and Associated Risks

B.1 Climate models project robust[7] differences in regional climate characteristics between present-day and global warming of 1.5°C,[8] and between 1.5°C and 2°C.[8] These differences include increases in: mean temperature in most land and ocean regions (*high confidence*), hot extremes in most inhabited regions (*high confidence*), heavy precipitation in several regions (*medium confidence*), and the probability of drought and precipitation deficits in some regions (*medium confidence*). {3.3}

B.1.1 Evidence from attributed changes in some climate and weather extremes for a global warming of about 0.5°C supports the assessment that an additional 0.5°C of warming compared to present is associated with further detectable changes in these extremes (*medium confidence*). Several regional changes in climate are assessed to occur with global warming up to 1.5°C compared to pre-industrial levels, including warming of extreme temperatures in many regions (*high confidence*), increases in frequency, intensity, and/or amount of heavy precipitation in several regions (*high confidence*), and an increase in intensity or frequency of droughts in some regions (*medium confidence*). {3.2, 3.3.1, 3.3.2, 3.3.3, 3.3.4, Table 3.2}

B.1.2 Temperature extremes on land are projected to warm more than GMST (*high confidence*): extreme hot days in mid-latitudes warm by up to about 3°C at global warming of 1.5°C and about 4°C at 2°C, and extreme cold nights in high latitudes warm by up to about 4.5°C at 1.5°C and about 6°C at 2°C (*high confidence*). The number of hot days is projected to increase in most land regions, with highest increases in the tropics (*high confidence*). {3.3.1, 3.3.2, Cross-Chapter Box 8 in Chapter 3}

B.1.3 Risks from droughts and precipitation deficits are projected to be higher at 2°C compared to 1.5°C of global warming in some regions (*medium confidence*). Risks from heavy precipitation events are projected to be higher at 2°C compared to 1.5°C of global warming in several northern hemisphere high-latitude and/or high-elevation regions, eastern Asia and eastern North America (*medium confidence)*. Heavy precipitation associated with tropical cyclones is projected to be higher at 2°C compared to 1.5°C global warming (*medium confidence*). There is generally *low confidence* in projected changes in heavy precipitation at 2°C compared to 1.5°C in other regions. Heavy precipitation when aggregated at global scale is projected to be higher at 2°C than at 1.5°C of global warming (*medium confidence*). As a consequence of heavy precipitation, the fraction of the global land area affected by flood hazards is projected to be larger at 2°C compared to 1.5°C of global warming (*medium confidence*). {3.3.1, 3.3.3, 3.3.4, 3.3.5, 3.3.6}

B.2 By 2100, global mean sea level rise is projected to be around 0.1 metre lower with global warming of 1.5°C compared to 2°C (*medium confidence*). Sea level will continue to rise well beyond 2100 (*high confidence*), and the magnitude and rate of this rise depend on future emission pathways. A slower rate of sea level rise enables greater opportunities for adaptation in the human and ecological systems of small islands, low-lying coastal areas and deltas (*medium confidence*). {3.3, 3.4, 3.6}

B.2.1 Model-based projections of global mean sea level rise (relative to 1986–2005) suggest an indicative range of 0.26 to 0.77 m by 2100 for 1.5°C of global warming, 0.1 m (0.04–0.16 m) less than for a global warming of 2°C (*medium confidence*). A reduction of 0.1 m in global sea level rise implies that up to 10 million fewer people would be exposed to related risks, based on population in the year 2010 and assuming no adaptation (*medium confidence*). {3.4.4, 3.4.5, 4.3.2}

B.2.2 Sea level rise will continue beyond 2100 even if global warming is limited to 1.5°C in the 21st century (*high confidence*). Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could result in multi-metre rise in sea level over hundreds to thousands of years. These instabilities could be triggered at around 1.5°C to 2°C of global warming (*medium confidence*). (Figure SPM.2) {3.3.9, 3.4.5, 3.5.2, 3.6.3, Box 3.3}

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7 Robust is here used to mean that at least two thirds of climate models show the same sign of changes at the grid point scale, and that differences in large regions are statistically significant.

8 Projected changes in impacts between different levels of global warming are determined with respect to changes in global mean surface air temperature.

B.2.3 Increasing warming amplifies the exposure of small islands, low-lying coastal areas and deltas to the risks associated with sea level rise for many human and ecological systems, including increased saltwater intrusion, flooding and damage to infrastructure (*high confidence*). Risks associated with sea level rise are higher at 2°C compared to 1.5°C. The slower rate of sea level rise at global warming of 1.5°C reduces these risks, enabling greater opportunities for adaptation including managing and restoring natural coastal ecosystems and infrastructure reinforcement (*medium confidence*). (Figure SPM.2) {3.4.5, Box 3.5}

B.3 On land, impacts on biodiversity and ecosystems, including species loss and extinction, are projected to be lower at 1.5°C of global warming compared to 2°C. Limiting global warming to 1.5°C compared to 2°C is projected to lower the impacts on terrestrial, freshwater and coastal ecosystems and to retain more of their services to humans (*high confidence*). (Figure SPM.2) {3.4, 3.5, Box 3.4, Box 4.2, Cross-Chapter Box 8 in Chapter 3}

B.3.1 Of 105,000 species studied,[9] 6% of insects, 8% of plants and 4% of vertebrates are projected to lose over half of their climatically determined geographic range for global warming of 1.5°C, compared with 18% of insects, 16% of plants and 8% of vertebrates for global warming of 2°C (*medium confidence*). Impacts associated with other biodiversity-related risks such as forest fires and the spread of invasive species are lower at 1.5°C compared to 2°C of global warming (*high confidence*). {3.4.3, 3.5.2}

B.3.2 Approximately 4% (interquartile range 2–7%) of the global terrestrial land area is projected to undergo a transformation of ecosystems from one type to another at 1°C of global warming, compared with 13% (interquartile range 8–20%) at 2°C (*medium confidence*). This indicates that the area at risk is projected to be approximately 50% lower at 1.5°C compared to 2°C (*medium confidence*). {3.4.3.1, 3.4.3.5}

B.3.3 High-latitude tundra and boreal forests are particularly at risk of climate change-induced degradation and loss, with woody shrubs already encroaching into the tundra (*high confidence*) and this will proceed with further warming. Limiting global warming to 1.5°C rather than 2°C is projected to prevent the thawing over centuries of a permafrost area in the range of 1.5 to 2.5 million km^2 (*medium confidence*). {3.3.2, 3.4.3, 3.5.5}

B.4 Limiting global warming to 1.5°C compared to 2°C is projected to reduce increases in ocean temperature as well as associated increases in ocean acidity and decreases in ocean oxygen levels (*high confidence*). Consequently, limiting global warming to 1.5°C is projected to reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans, as illustrated by recent changes to Arctic sea ice and warm-water coral reef ecosystems (*high confidence*). {3.3, 3.4, 3.5, Box 3.4, Box 3.5}

B.4.1 There is *high confidence* that the probability of a sea ice-free Arctic Ocean during summer is substantially lower at global warming of 1.5°C when compared to 2°C. With 1.5°C of global warming, one sea ice-free Arctic summer is projected per century. This likelihood is increased to at least one per decade with 2°C global warming. Effects of a temperature overshoot are reversible for Arctic sea ice cover on decadal time scales (*high confidence*). {3.3.8, 3.4.4.7}

B.4.2 Global warming of 1.5°C is projected to shift the ranges of many marine species to higher latitudes as well as increase the amount of damage to many ecosystems. It is also expected to drive the loss of coastal resources and reduce the productivity of fisheries and aquaculture (especially at low latitudes). The risks of climate-induced impacts are projected to be higher at 2°C than those at global warming of 1.5°C (*high confidence*). Coral reefs, for example, are projected to decline by a further 70–90% at 1.5°C (*high confidence*) with larger losses (>99%) at 2°C (*very high confidence*). The risk of irreversible loss of many marine and coastal ecosystems increases with global warming, especially at 2°C or more (*high confidence*). {3.4.4, Box 3.4}

9 Consistent with earlier studies, illustrative numbers were adopted from one recent meta-study.

B.4.3 The level of ocean acidification due to increasing CO_2 concentrations associated with global warming of 1.5°C is projected to amplify the adverse effects of warming, and even further at 2°C, impacting the growth, development, calcification, survival, and thus abundance of a broad range of species, for example, from algae to fish (*high confidence*). {3.3.10, 3.4.4}

B.4.4 Impacts of climate change in the ocean are increasing risks to fisheries and aquaculture via impacts on the physiology, survivorship, habitat, reproduction, disease incidence, and risk of invasive species (*medium confidence*) but are projected to be less at 1.5°C of global warming than at 2°C. One global fishery model, for example, projected a decrease in global annual catch for marine fisheries of about 1.5 million tonnes for 1.5°C of global warming compared to a loss of more than 3 million tonnes for 2°C of global warming (*medium confidence*). {3.4.4, Box 3.4}

B.5 Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5°C and increase further with 2°C. (Figure SPM.2) {3.4, 3.5, 5.2, Box 3.2, Box 3.3, Box 3.5, Box 3.6, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5, 5.2}

B.5.1 Populations at disproportionately higher risk of adverse consequences with global warming of 1.5°C and beyond include disadvantaged and vulnerable populations, some indigenous peoples, and local communities dependent on agricultural or coastal livelihoods (*high confidence*). Regions at disproportionately higher risk include Arctic ecosystems, dryland regions, small island developing states, and Least Developed Countries (*high confidence*). Poverty and disadvantage are expected to increase in some populations as global warming increases; limiting global warming to 1.5°C, compared with 2°C, could reduce the number of people both exposed to climate-related risks and susceptible to poverty by up to several hundred million by 2050 (*medium confidence*). {3.4.10, 3.4.11, Box 3.5, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5, 4.2.2.2, 5.2.1, 5.2.2, 5.2.3, 5.6.3}

B.5.2 Any increase in global warming is projected to affect human health, with primarily negative consequences (*high confidence*). Lower risks are projected at 1.5°C than at 2°C for heat-related morbidity and mortality (*very high confidence*) and for ozone-related mortality if emissions needed for ozone formation remain high (*high confidence*). Urban heat islands often amplify the impacts of heatwaves in cities (*high confidence*). Risks from some vector-borne diseases, such as malaria and dengue fever, are projected to increase with warming from 1.5°C to 2°C, including potential shifts in their geographic range (*high confidence*). {3.4.7, 3.4.8, 3.5.5.8}

B.5.3 Limiting warming to 1.5°C compared with 2°C is projected to result in smaller net reductions in yields of maize, rice, wheat, and potentially other cereal crops, particularly in sub-Saharan Africa, Southeast Asia, and Central and South America, and in the CO_2-dependent nutritional quality of rice and wheat (*high confidence*). Reductions in projected food availability are larger at 2°C than at 1.5°C of global warming in the Sahel, southern Africa, the Mediterranean, central Europe, and the Amazon (*medium confidence*). Livestock are projected to be adversely affected with rising temperatures, depending on the extent of changes in feed quality, spread of diseases, and water resource availability (*high confidence*). {3.4.6, 3.5.4, 3.5.5, Box 3.1, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4}

B.5.4 Depending on future socio-economic conditions, limiting global warming to 1.5°C compared to 2°C may reduce the proportion of the world population exposed to a climate change-induced increase in water stress by up to 50%, although there is considerable variability between regions (*medium confidence*). Many small island developing states could experience lower water stress as a result of projected changes in aridity when global warming is limited to 1.5°C, as compared to 2°C (*medium confidence*). {3.3.5, 3.4.2, 3.4.8, 3.5.5, Box 3.2, Box 3.5, Cross-Chapter Box 9 in Chapter 4}

B.5.5 Risks to global aggregated economic growth due to climate change impacts are projected to be lower at 1.5°C than at 2°C by the end of this century[10] (*medium confidence*). This excludes the costs of mitigation, adaptation investments and the benefits of adaptation. Countries in the tropics and Southern Hemisphere subtropics are projected to experience the largest impacts on economic growth due to climate change should global warming increase from 1.5°C to 2°C (*medium confidence*). {3.5.2, 3.5.3}

10 Here, impacts on economic growth refer to changes in gross domestic product (GDP). Many impacts, such as loss of human lives, cultural heritage and ecosystem services, are difficult to value and monetize.

B.5.6 Exposure to multiple and compound climate-related risks increases between 1.5°C and 2°C of global warming, with greater proportions of people both so exposed and susceptible to poverty in Africa and Asia (*high confidence*). For global warming from 1.5°C to 2°C, risks across energy, food, and water sectors could overlap spatially and temporally, creating new and exacerbating current hazards, exposures, and vulnerabilities that could affect increasing numbers of people and regions (*medium confidence*). {Box 3.5, 3.3.1, 3.4.5.3, 3.4.5.6, 3.4.11, 3.5.4.9}

B.5.7 There are multiple lines of evidence that since AR5 the assessed levels of risk increased for four of the five Reasons for Concern (RFCs) for global warming to 2°C (*high confidence*). The risk transitions by degrees of global warming are now: from high to very high risk between 1.5°C and 2°C for RFC1 (Unique and threatened systems) (*high confidence*); from moderate to high risk between 1°C and 1.5°C for RFC2 (Extreme weather events) (*medium confidence*); from moderate to high risk between 1.5°C and 2°C for RFC3 (Distribution of impacts) (*high confidence*); from moderate to high risk between 1.5°C and 2.5°C for RFC4 (Global aggregate impacts) (*medium confidence*); and from moderate to high risk between 1°C and 2.5°C for RFC5 (Large-scale singular events) (*medium confidence*). (Figure SPM.2) {3.4.13; 3.5, 3.5.2}

B.6 Most adaptation needs will be lower for global warming of 1.5°C compared to 2°C (*high confidence*). There are a wide range of adaptation options that can reduce the risks of climate change (*high confidence*). There are limits to adaptation and adaptive capacity for some human and natural systems at global warming of 1.5°C, with associated losses (*medium confidence*). The number and availability of adaptation options vary by sector (*medium confidence*). {Table 3.5, 4.3, 4.5, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5}

B.6.1 A wide range of adaptation options are available to reduce the risks to natural and managed ecosystems (e.g., ecosystem-based adaptation, ecosystem restoration and avoided degradation and deforestation, biodiversity management, sustainable aquaculture, and local knowledge and indigenous knowledge), the risks of sea level rise (e.g., coastal defence and hardening), and the risks to health, livelihoods, food, water, and economic growth, especially in rural landscapes (e.g., efficient irrigation, social safety nets, disaster risk management, risk spreading and sharing, and community-based adaptation) and urban areas (e.g., green infrastructure, sustainable land use and planning, and sustainable water management) (*medium confidence*). {4.3.1, 4.3.2, 4.3.3, 4.3.5, 4.5.3, 4.5.4, 5.3.2, Box 4.2, Box 4.3, Box 4.6, Cross-Chapter Box 9 in Chapter 4}.

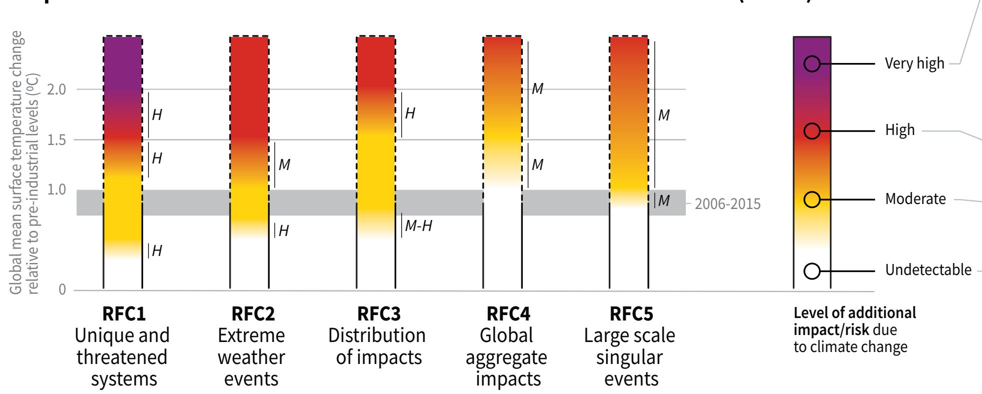
B.6.2 Adaptation is expected to be more challenging for ecosystems, food and health systems at 2°C of global warming than for 1.5°C (*medium confidence*). Some vulnerable regions, including small islands and Least Developed Countries, are projected to experience high multiple interrelated climate risks even at global warming of 1.5°C (*high confidence*). {3.3.1, 3.4.5, Box 3.5, Table 3.5, Cross-Chapter Box 9 in Chapter 4, 5.6, Cross-Chapter Box 12 in Chapter 5, Box 5.3}

B.6.3 Limits to adaptive capacity exist at 1.5°C of global warming, become more pronounced at higher levels of warming and vary by sector, with site-specific implications for vulnerable regions, ecosystems and human health (*medium confidence*). {Cross-Chapter Box 12 in Chapter 5, Box 3.5, Table 3.5}

How the level of global warming affects impacts and/or risks associated with the Reasons for Concern (RFCs) and selected natural, managed and human systems

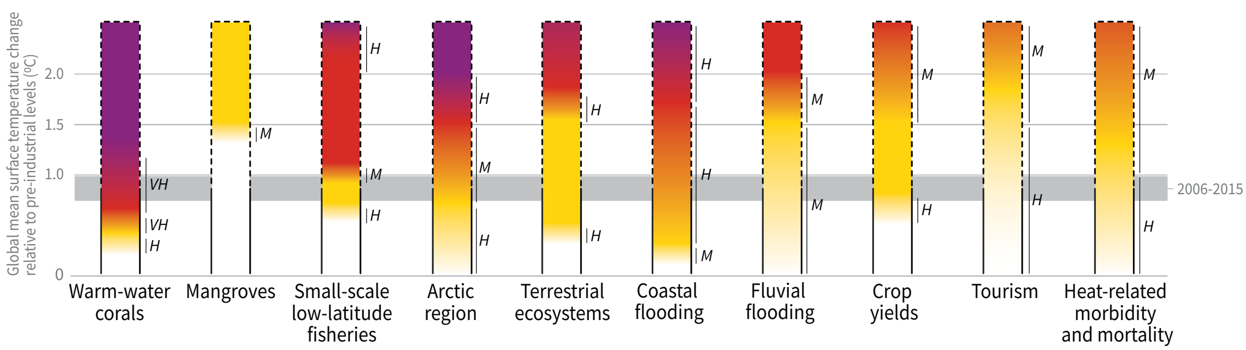
Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

Impacts and risks associated with the Reasons for Concern (RFCs)



Purple indicates very high risks of severe impacts/risks and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.
Red indicates severe and widespread impacts/risks.
Yellow indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.
White indicates that no impacts are detectable and attributable to climate change.

Impacts and risks for selected natural, managed and human systems



Confidence level for transition: *L*=Low, *M*=Medium, *H*=High and *VH*=Very high

Figure SPM.2 | Five integrative reasons for concern (RFCs) provide a framework for summarizing key impacts and risks across sectors and regions, and were introduced in the IPCC Third Assessment Report. RFCs illustrate the implications of global warming for people, economies and ecosystems. Impacts and/or risks for each RFC are based on assessment of the new literature that has appeared. As in AR5, this literature was used to make expert judgments to assess the levels of global warming at which levels of impact and/or risk are undetectable, moderate, high or very high. The selection of impacts and risks to natural, managed and human systems in the lower panel is illustrative and is not intended to be fully comprehensive. {3.4, 3.5, 3.5.2.1, 3.5.2.2, 3.5.2.3, 3.5.2.4, 3.5.2.5, 5.4.1, 5.5.3, 5.6.1, Box 3.4}
RFC1 Unique and threatened systems: ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its indigenous people, mountain glaciers and biodiversity hotspots.
RFC2 Extreme weather events: risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events such as heat waves, heavy rain, drought and associated wildfires, and coastal flooding.
RFC3 Distribution of impacts: risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability.
RFC4 Global aggregate impacts: global monetary damage, global-scale degradation and loss of ecosystems and biodiversity.
RFC5 Large-scale singular events: are relatively large, abrupt and sometimes irreversible changes in systems that are caused by global warming. Examples include disintegration of the Greenland and Antarctic ice sheets.

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C. Emission Pathways and System Transitions Consistent with 1.5°C Global Warming

C.1 In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO_2 emissions decline by about 45% from 2010 levels by 2030 (40–60% interquartile range), reaching net zero around 2050 (2045–2055 interquartile range). For limiting global warming to below 2°C[11] CO_2 emissions are projected to decline by about 25% by 2030 in most pathways (10–30% interquartile range) and reach net zero around 2070 (2065–2080 interquartile range). Non-CO_2 emissions in pathways that limit global warming to 1.5°C show deep reductions that are similar to those in pathways limiting warming to 2°C. (*high confidence*) (Figure SPM.3a) {2.1, 2.3, Table 2.4}

C.1.1 CO_2 emissions reductions that limit global warming to 1.5°C with no or limited overshoot can involve different portfolios of mitigation measures, striking different balances between lowering energy and resource intensity, rate of decarbonization, and the reliance on carbon dioxide removal. Different portfolios face different implementation challenges and potential synergies and trade-offs with sustainable development. (*high confidence*) (Figure SPM.3b) {2.3.2, 2.3.4, 2.4, 2.5.3}

C.1.2 Modelled pathways that limit global warming to 1.5°C with no or limited overshoot involve deep reductions in emissions of methane and black carbon (35% or more of both by 2050 relative to 2010). These pathways also reduce most of the cooling aerosols, which partially offsets mitigation effects for two to three decades. Non-CO_2 emissions[12] can be reduced as a result of broad mitigation measures in the energy sector. In addition, targeted non-CO_2 mitigation measures can reduce nitrous oxide and methane from agriculture, methane from the waste sector, some sources of black carbon, and hydrofluorocarbons. High bioenergy demand can increase emissions of nitrous oxide in some 1.5°C pathways, highlighting the importance of appropriate management approaches. Improved air quality resulting from projected reductions in many non-CO_2 emissions provide direct and immediate population health benefits in all 1.5°C model pathways. (*high confidence*) (Figure SPM.3a) {2.2.1, 2.3.3, 2.4.4, 2.5.3, 4.3.6, 5.4.2}

C.1.3 Limiting global warming requires limiting the total cumulative global anthropogenic emissions of CO_2 since the pre-industrial period, that is, staying within a total carbon budget (*high confidence*).[13] By the end of 2017, anthropogenic CO_2 emissions since the pre-industrial period are estimated to have reduced the total carbon budget for 1.5°C by approximately 2200 ± 320 $GtCO_2$ (*medium confidence*). The associated remaining budget is being depleted by current emissions of 42 ± 3 $GtCO_2$ per year (*high confidence*). The choice of the measure of global temperature affects the estimated remaining carbon budget. Using global mean surface air temperature, as in AR5, gives an estimate of the remaining carbon budget of 580 $GtCO_2$ for a 50% probability of limiting warming to 1.5°C, and 420 $GtCO_2$ for a 66% probability (*medium confidence*).[14] Alternatively, using GMST gives estimates of 770 and 570 $GtCO_2$, for 50% and 66% probabilities,[15] respectively (*medium confidence*). Uncertainties in the size of these estimated remaining carbon budgets are substantial and depend on several factors. Uncertainties in the climate response to CO_2 and non-CO_2 emissions contribute ±400 $GtCO_2$ and the level of historic warming contributes ±250 $GtCO_2$ (*medium confidence*). Potential additional carbon release from future permafrost thawing and methane release from wetlands would reduce budgets by up to 100 $GtCO_2$ over the course of this century and more thereafter (*medium confidence*). In addition, the level of non-CO_2 mitigation in the future could alter the remaining carbon budget by 250 $GtCO_2$ in either direction (*medium confidence*). {1.2.4, 2.2.2, 2.6.1, Table 2.2, Chapter 2 Supplementary Material}

C.1.4 Solar radiation modification (SRM) measures are not included in any of the available assessed pathways. Although some SRM measures may be theoretically effective in reducing an overshoot, they face large uncertainties and knowledge gaps

11 References to pathways limiting global warming to 2°C are based on a 66% probability of staying below 2°C.

12 Non-CO_2 emissions included in this Report are all anthropogenic emissions other than CO_2 that result in radiative forcing. These include short-lived climate forcers, such as methane, some fluorinated gases, ozone precursors, aerosols or aerosol precursors, such as black carbon and sulphur dioxide, respectively, as well as long-lived greenhouse gases, such as nitrous oxide or some fluorinated gases. The radiative forcing associated with non-CO_2 emissions and changes in surface albedo is referred to as non-CO_2 radiative forcing. {2.2.1}

13 There is a clear scientific basis for a total carbon budget consistent with limiting global warming to 1.5°C. However, neither this total carbon budget nor the fraction of this budget taken up by past emissions were assessed in this Report.

14 Irrespective of the measure of global temperature used, updated understanding and further advances in methods have led to an increase in the estimated remaining carbon budget of about 300 $GtCO_2$ compared to AR5. (*medium confidence*) {2.2.2}

15 These estimates use observed GMST to 2006–2015 and estimate future temperature changes using near surface air temperatures.

as well as substantial risks and institutional and social constraints to deployment related to governance, ethics, and impacts on sustainable development. They also do not mitigate ocean acidification. (*medium confidence*) {4.3.8, Cross-Chapter Box 10 in Chapter 4}

Global emissions pathway characteristics

General characteristics of the evolution of anthropogenic net emissions of CO_2, and total emissions of methane, black carbon, and nitrous oxide in model pathways that limit global warming to 1.5°C with no or limited overshoot. Net emissions are defined as anthropogenic emissions reduced by anthropogenic removals. Reductions in net emissions can be achieved through different portfolios of mitigation measures illustrated in Figure SPM.3b.

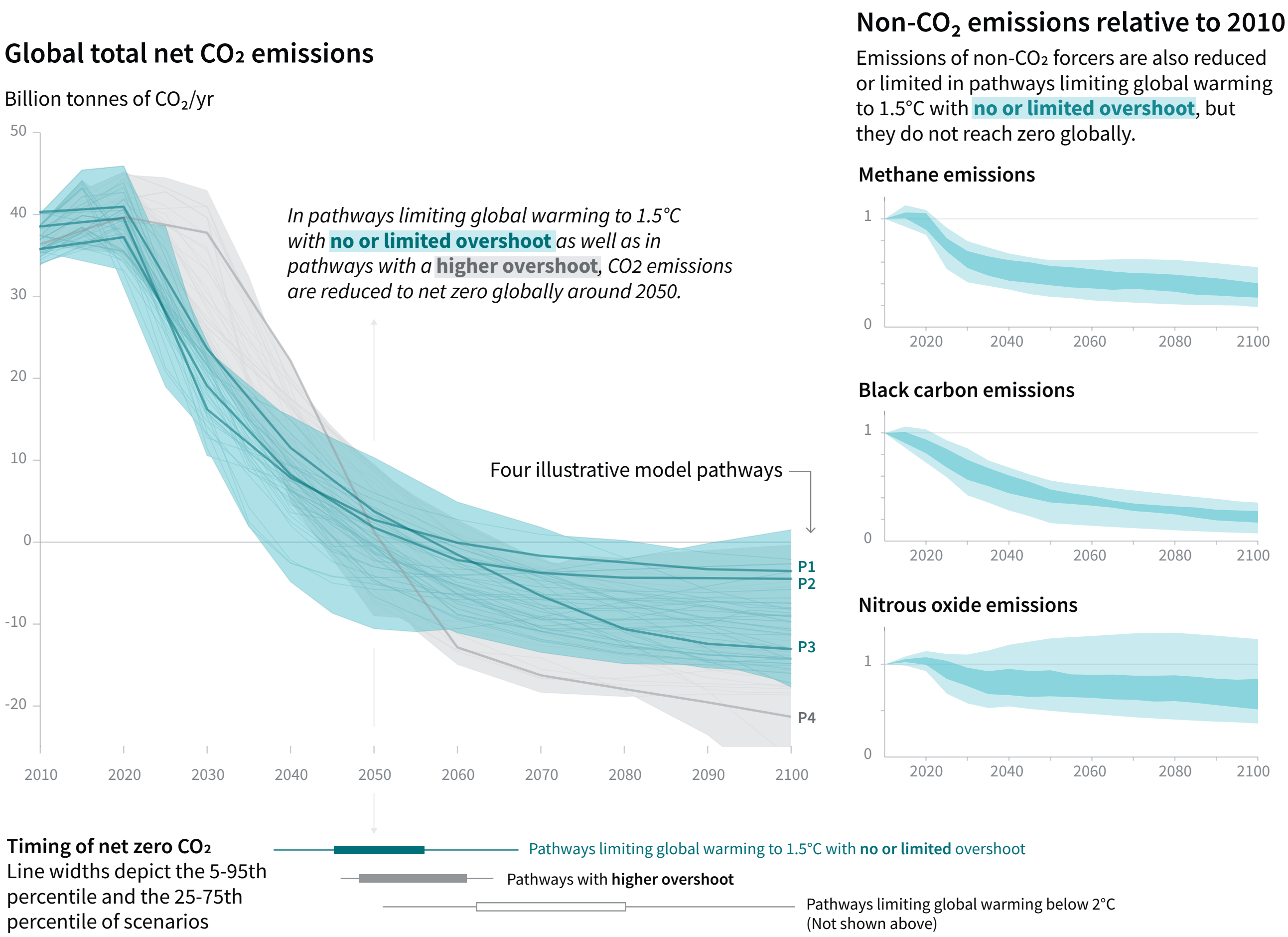
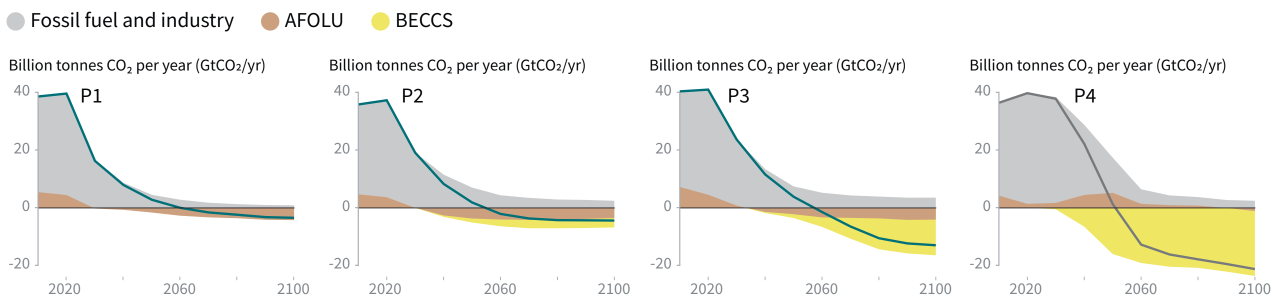


Figure SPM.3a | Global emissions pathway characteristics. The main panel shows global net anthropogenic CO_2 emissions in pathways limiting global warming to 1.5°C with no or limited (less than 0.1°C) overshoot and pathways with higher overshoot. The shaded area shows the full range for pathways analysed in this Report. The panels on the right show non-CO_2 emissions ranges for three compounds with large historical forcing and a substantial portion of emissions coming from sources distinct from those central to CO_2 mitigation. Shaded areas in these panels show the 5–95% (light shading) and interquartile (dark shading) ranges of pathways limiting global warming to 1.5°C with no or limited overshoot. Box and whiskers at the bottom of the figure show the timing of pathways reaching global net zero CO_2 emission levels, and a comparison with pathways limiting global warming to 2°C with at least 66% probability. Four illustrative model pathways are highlighted in the main panel and are labelled P1, P2, P3 and P4, corresponding to the LED, S1, S2, and S5 pathways assessed in Chapter 2. Descriptions and characteristics of these pathways are available in Figure SPM.3b. {2.1, 2.2, 2.3, Figure 2.5, Figure 2.10, Figure 2.11}

Characteristics of four illustrative model pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limits global warming to 1.5°C with no or limited overshoot. All pathways use Carbon Dioxide Removal (CDR), but the amount varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for emissions and several other pathway characteristics.

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Global indicators	P1	P2	P3	P4	**Interquartile range**
Pathway classification	No or limited overshoot	No or limited overshoot	No or limited overshoot	Higher overshoot	No or limited overshoot
CO_2 emission change in 2030 (% rel to 2010)	-58	-47	-41	4	(-58,-40)
└ in 2050 (% rel to 2010)	-93	-95	-91	-97	(-107,-94)
Kyoto-GHG emissions in 2030 (% rel to 2010)*	-50	-49	-35	-2	(-51,-39)
└ in 2050 (% rel to 2010)	-82	-89	-78	-80	(-93,-81)
*Final energy demand** in 2030 (% rel to 2010)*	-15	-5	17	39	(-12,7)
└ in 2050 (% rel to 2010)	-32	2	21	44	(-11,22)
Renewable share in electricity in 2030 (%)	60	58	48	25	(47,65)
└ in 2050 (%)	77	81	63	70	(69,86)
Primary energy from coal in 2030 (% rel to 2010)	-78	-61	-75	-59	(-78, -59)
└ in 2050 (% rel to 2010)	-97	-77	-73	-97	(-95, -74)
from oil in 2030 (% rel to 2010)	-37	-13	-3	86	(-34,3)
└ in 2050 (% rel to 2010)	-87	-50	-81	-32	(-78,-31)
from gas in 2030 (% rel to 2010)	-25	-20	33	37	(-26,21)
└ in 2050 (% rel to 2010)	-74	-53	21	-48	(-56,6)
from nuclear in 2030 (% rel to 2010)	59	83	98	106	(44,102)
└ in 2050 (% rel to 2010)	150	98	501	468	(91,190)
from biomass in 2030 (% rel to 2010)	-11	0	36	-1	(29,80)
└ in 2050 (% rel to 2010)	-16	49	121	418	(123,261)
from non-biomass renewables in 2030 (% rel to 2010)	430	470	315	110	(245,436)
└ in 2050 (% rel to 2010)	833	1327	878	1137	(576,1299)
Cumulative CCS until 2100 ($GtCO_2$)	0	348	687	1218	(550,1017)
└ of which BECCS ($GtCO_2$)	0	151	414	1191	(364,662)
Land area of bioenergy crops in 2050 (million km²)	0.2	0.9	2.8	7.2	(1.5,3.2)
Agricultural CH_4 emissions in 2030 (% rel to 2010)	-24	-48	1	14	(-30,-11)
in 2050 (% rel to 2010)	-33	-69	-23	2	(-47,-24)
Agricultural N_2O emissions in 2030 (% rel to 2010)	5	-26	15	3	(-21,3)
in 2050 (% rel to 2010)	6	-26	0	39	(-26,1)

NOTE: Indicators have been selected to show global trends identified by the Chapter 2 assessment. National and sectoral characteristics can differ substantially from the global trends shown above.

** Kyoto-gas emissions are based on IPCC Second Assessment Report GWP-100*
*** Changes in energy demand are associated with improvements in energy efficiency and behaviour change*

Figure SPM.3b | Characteristics of four illustrative model pathways in relation to global warming of 1.5°C introduced in Figure SPM.3a. These pathways were selected to show a range of potential mitigation approaches and vary widely in their projected energy and land use, as well as their assumptions about future socio-economic developments, including economic and population growth, equity and sustainability. A breakdown of the global net anthropogenic CO_2 emissions into the contributions in terms of CO_2 emissions from fossil fuel and industry; agriculture, forestry and other land use (AFOLU); and bioenergy with carbon capture and storage (BECCS) is shown. AFOLU estimates reported here are not necessarily comparable with countries' estimates. Further characteristics for each of these pathways are listed below each pathway. These pathways illustrate relative global differences in mitigation strategies, but do not represent central estimates, national strategies, and do not indicate requirements. For comparison, the right-most column shows the interquartile ranges across pathways with no or limited overshoot of 1.5°C. Pathways P1, P2, P3 and P4 correspond to the LED, S1, S2 and S5 pathways assessed in Chapter 2 (Figure SPM.3a). {2.2.1, 2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.4.1, 2.4.2, 2.4.4, 2.5.3, Figure 2.5, Figure 2.6, Figure 2.9, Figure 2.10, Figure 2.11, Figure 2.14, Figure 2.15, Figure 2.16, Figure 2.17, Figure 2.24, Figure 2.25, Table 2.4, Table 2.6, Table 2.7, Table 2.9, Table 4.1}

C.2 Pathways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems (*high confidence*). These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed, and imply deep emissions reductions in all sectors, a wide portfolio of mitigation options and a significant upscaling of investments in those options (*medium confidence*). {2.3, 2.4, 2.5, 4.2, 4.3, 4.4, 4.5}

C.2.1 Pathways that limit global warming to 1.5°C with no or limited overshoot show system changes that are more rapid and pronounced over the next two decades than in 2°C pathways (*high confidence*). The rates of system changes associated with limiting global warming to 1.5°C with no or limited overshoot have occurred in the past within specific sectors, technologies and spatial contexts, but there is no documented historic precedent for their scale (*medium confidence*). {2.3.3, 2.3.4, 2.4, 2.5, 4.2.1, 4.2.2, Cross-Chapter Box 11 in Chapter 4}

C.2.2 In energy systems, modelled global pathways (considered in the literature) limiting global warming to 1.5°C with no or limited overshoot (for more details see Figure SPM.3b) generally meet energy service demand with lower energy use, including through enhanced energy efficiency, and show faster electrification of energy end use compared to 2°C (*high confidence*). In 1.5°C pathways with no or limited overshoot, low-emission energy sources are projected to have a higher share, compared with 2°C pathways, particularly before 2050 (*high confidence*). In 1.5°C pathways with no or limited overshoot, renewables are projected to supply 70–85% (interquartile range) of electricity in 2050 (*high confidence*). In electricity generation, shares of nuclear and fossil fuels with carbon dioxide capture and storage (CCS) are modelled to increase in most 1.5°C pathways with no or limited overshoot. In modelled 1.5°C pathways with limited or no overshoot, the use of CCS would allow the electricity generation share of gas to be approximately 8% (3–11% interquartile range) of global electricity in 2050, while the use of coal shows a steep reduction in all pathways and would be reduced to close to 0% (0–2% interquartile range) of electricity (*high confidence*). While acknowledging the challenges, and differences between the options and national circumstances, political, economic, social and technical feasibility of solar energy, wind energy and electricity storage technologies have substantially improved over the past few years (*high confidence*). These improvements signal a potential system transition in electricity generation. (Figure SPM.3b) {2.4.1, 2.4.2, Figure 2.1, Table 2.6, Table 2.7, Cross-Chapter Box 6 in Chapter 3, 4.2.1, 4.3.1, 4.3.3, 4.5.2}

C.2.3 CO_2 emissions from industry in pathways limiting global warming to 1.5°C with no or limited overshoot are projected to be about 65–90% (interquartile range) lower in 2050 relative to 2010, as compared to 50–80% for global warming of 2°C (*medium confidence*). Such reductions can be achieved through combinations of new and existing technologies and practices, including electrification, hydrogen, sustainable bio-based feedstocks, product substitution, and carbon capture, utilization and storage (CCUS). These options are technically proven at various scales but their large-scale deployment may be limited by economic, financial, human capacity and institutional constraints in specific contexts, and specific characteristics of large-scale industrial installations. In industry, emissions reductions by energy and process efficiency by themselves are insufficient for limiting warming to 1.5°C with no or limited overshoot (*high confidence*). {2.4.3, 4.2.1, Table 4.1, Table 4.3, 4.3.3, 4.3.4, 4.5.2}

C.2.4 The urban and infrastructure system transition consistent with limiting global warming to 1.5°C with no or limited overshoot would imply, for example, changes in land and urban planning practices, as well as deeper emissions reductions in transport and buildings compared to pathways that limit global warming below 2°C (*medium confidence*). Technical measures and practices enabling deep emissions reductions include various energy efficiency options. In pathways limiting global warming to 1.5°C with no or limited overshoot, the electricity share of energy demand in buildings would be about 55–75% in 2050 compared to 50–70% in 2050 for 2°C global warming (*medium confidence*). In the transport sector, the share of low-emission final energy would rise from less than 5% in 2020 to about 35–65% in 2050 compared to 25–45% for 2°C of global warming (*medium confidence*). Economic, institutional and socio-cultural barriers may inhibit these urban and infrastructure system transitions, depending on national, regional and local circumstances, capabilities and the availability of capital (*high confidence*). {2.3.4, 2.4.3, 4.2.1, Table 4.1, 4.3.3, 4.5.2}

C.2.5 Transitions in global and regional land use are found in all pathways limiting global warming to 1.5°C with no or limited overshoot, but their scale depends on the pursued mitigation portfolio. Model pathways that limit global warming to 1.5°C with no or limited overshoot project a 4 million km^2 reduction to a 2.5 million km^2 increase of non-pasture agricultural land for food and feed crops and a 0.5–11 million km^2 reduction of pasture land, to be converted into a 0–6 million km^2 increase of agricultural land for energy crops and a 2 million km^2 reduction to 9.5 million km^2 increase in forests by 2050 relative to 2010 (*medium confidence*).[16] Land-use transitions of similar magnitude can be observed in modelled 2°C pathways (*medium confidence*). Such large transitions pose profound challenges for sustainable management of the various demands on land for human settlements, food, livestock feed, fibre, bioenergy, carbon storage, biodiversity and other ecosystem services (*high confidence*). Mitigation options limiting the demand for land include sustainable intensification of land-use practices, ecosystem restoration and changes towards less resource-intensive diets (*high confidence*). The implementation of land-based mitigation options would require overcoming socio-economic, institutional, technological, financing and environmental barriers that differ across regions (*high confidence*). {2.4.4, Figure 2.24, 4.3.2, 4.3.7, 4.5.2, Cross-Chapter Box 7 in Chapter 3}

C.2.6 Additional annual average energy-related investments for the period 2016 to 2050 in pathways limiting warming to 1.5°C compared to pathways without new climate policies beyond those in place today are estimated to be around 830 billion USD2010 (range of 150 billion to 1700 billion USD2010 across six models[17]). This compares to total annual average energy supply investments in 1.5°C pathways of 1460 to 3510 billion USD2010 and total annual average energy demand investments of 640 to 910 billion USD2010 for the period 2016 to 2050. Total energy-related investments increase by about 12% (range of 3% to 24%) in 1.5°C pathways relative to 2°C pathways. Annual investments in low-carbon energy technologies and energy efficiency are upscaled by roughly a factor of six (range of factor of 4 to 10) by 2050 compared to 2015 (*medium confidence*). {2.5.2, Box 4.8, Figure 2.27}

C.2.7 Modelled pathways limiting global warming to 1.5°C with no or limited overshoot project a wide range of global average discounted marginal abatement costs over the 21st century. They are roughly 3-4 times higher than in pathways limiting global warming to below 2°C (*high confidence*). The economic literature distinguishes marginal abatement costs from total mitigation costs in the economy. The literature on total mitigation costs of 1.5°C mitigation pathways is limited and was not assessed in this Report. Knowledge gaps remain in the integrated assessment of the economy-wide costs and benefits of mitigation in line with pathways limiting warming to 1.5°C. {2.5.2; 2.6; Figure 2.26}

16 The projected land-use changes presented are not deployed to their upper limits simultaneously in a single pathway.

17 Including two pathways limiting warming to 1.5°C with no or limited overshoot and four pathways with higher overshoot.

C.3 All pathways that limit global warming to 1.5°C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100–1000 $GtCO_2$ over the 21st century. CDR would be used to compensate for residual emissions and, in most cases, achieve net negative emissions to return global warming to 1.5°C following a peak (*high confidence*). CDR deployment of several hundreds of $GtCO_2$ is subject to multiple feasibility and sustainability constraints (*high confidence*). Significant near-term emissions reductions and measures to lower energy and land demand can limit CDR deployment to a few hundred $GtCO_2$ without reliance on bioenergy with carbon capture and storage (BECCS) (*high confidence*). {2.3, 2.4, 3.6.2, 4.3, 5.4}

C.3.1 Existing and potential CDR measures include afforestation and reforestation, land restoration and soil carbon sequestration, BECCS, direct air carbon capture and storage (DACCS), enhanced weathering and ocean alkalinization. These differ widely in terms of maturity, potentials, costs, risks, co-benefits and trade-offs (*high confidence*). To date, only a few published pathways include CDR measures other than afforestation and BECCS. {2.3.4, 3.6.2, 4.3.2, 4.3.7}

C.3.2 In pathways limiting global warming to 1.5°C with limited or no overshoot, BECCS deployment is projected to range from 0–1, 0–8, and 0–16 $GtCO_2$ yr^{-1} in 2030, 2050, and 2100, respectively, while agriculture, forestry and land-use (AFOLU) related CDR measures are projected to remove 0–5, 1–11, and 1–5 $GtCO_2$ yr^{-1} in these years (*medium confidence*). The upper end of these deployment ranges by mid-century exceeds the BECCS potential of up to 5 $GtCO_2$ yr^{-1} and afforestation potential of up to 3.6 $GtCO_2$ yr^{-1} assessed based on recent literature (*medium confidence*). Some pathways avoid BECCS deployment completely through demand-side measures and greater reliance on AFOLU-related CDR measures (*medium confidence*). The use of bioenergy can be as high or even higher when BECCS is excluded compared to when it is included due to its potential for replacing fossil fuels across sectors (*high confidence*). (Figure SPM.3b) {2.3.3, 2.3.4, 2.4.2, 3.6.2, 4.3.1, 4.2.3, 4.3.2, 4.3.7, 4.4.3, Table 2.4}

C.3.3 Pathways that overshoot 1.5°C of global warming rely on CDR exceeding residual CO_2 emissions later in the century to return to below 1.5°C by 2100, with larger overshoots requiring greater amounts of CDR (Figure SPM.3b) (*high confidence*). Limitations on the speed, scale, and societal acceptability of CDR deployment hence determine the ability to return global warming to below 1.5°C following an overshoot. Carbon cycle and climate system understanding is still limited about the effectiveness of net negative emissions to reduce temperatures after they peak (*high confidence*). {2.2, 2.3.4, 2.3.5, 2.6, 4.3.7, 4.5.2, Table 4.11}

C.3.4 Most current and potential CDR measures could have significant impacts on land, energy, water or nutrients if deployed at large scale (*high confidence*). Afforestation and bioenergy may compete with other land uses and may have significant impacts on agricultural and food systems, biodiversity, and other ecosystem functions and services (*high confidence*). Effective governance is needed to limit such trade-offs and ensure permanence of carbon removal in terrestrial, geological and ocean reservoirs (*high confidence*). Feasibility and sustainability of CDR use could be enhanced by a portfolio of options deployed at substantial, but lesser scales, rather than a single option at very large scale (*high confidence*). (Figure SPM.3b) {2.3.4, 2.4.4, 2.5.3, 2.6, 3.6.2, 4.3.2, 4.3.7, 4.5.2, 5.4.1, 5.4.2; Cross-Chapter Boxes 7 and 8 in Chapter 3, Table 4.11, Table 5.3, Figure 5.3}

C.3.5 Some AFOLU-related CDR measures such as restoration of natural ecosystems and soil carbon sequestration could provide co-benefits such as improved biodiversity, soil quality, and local food security. If deployed at large scale, they would require governance systems enabling sustainable land management to conserve and protect land carbon stocks and other ecosystem functions and services (*medium confidence*). (Figure SPM.4) {2.3.3, 2.3.4, 2.4.2, 2.4.4, 3.6.2, 5.4.1, Cross-Chapter Boxes 3 in Chapter 1 and 7 in Chapter 3, 4.3.2, 4.3.7, 4.4.1, 4.5.2, Table 2.4}

SPM

D. Strengthening the Global Response in the Context of Sustainable Development and Efforts to Eradicate Poverty

D.1 Estimates of the global emissions outcome of current nationally stated mitigation ambitions as submitted under the Paris Agreement would lead to global greenhouse gas emissions[18] in 2030 of 52–58 $GtCO_2eq\ yr^{-1}$ (*medium confidence*). Pathways reflecting these ambitions would not limit global warming to 1.5°C, even if supplemented by very challenging increases in the scale and ambition of emissions reductions after 2030 (*high confidence*). Avoiding overshoot and reliance on future large-scale deployment of carbon dioxide removal (CDR) can only be achieved if global CO_2 emissions start to decline well before 2030 (*high confidence*). {1.2, 2.3, 3.3, 3.4, 4.2, 4.4, Cross-Chapter Box 11 in Chapter 4}

D.1.1 Pathways that limit global warming to 1.5°C with no or limited overshoot show clear emission reductions by 2030 (*high confidence*). All but one show a decline in global greenhouse gas emissions to below 35 $GtCO_2eq\ yr^{-1}$ in 2030, and half of available pathways fall within the 25–30 $GtCO_2eq\ yr^{-1}$ range (interquartile range), a 40–50% reduction from 2010 levels (*high confidence*). Pathways reflecting current nationally stated mitigation ambition until 2030 are broadly consistent with cost-effective pathways that result in a global warming of about 3°C by 2100, with warming continuing afterwards (*medium confidence*). {2.3.3, 2.3.5, Cross-Chapter Box 11 in Chapter 4, 5.5.3.2}

D.1.2 Overshoot trajectories result in higher impacts and associated challenges compared to pathways that limit global warming to 1.5°C with no or limited overshoot (*high confidence*). Reversing warming after an overshoot of 0.2°C or larger during this century would require upscaling and deployment of CDR at rates and volumes that might not be achievable given considerable implementation challenges (*medium confidence*). {1.3.3, 2.3.4, 2.3.5, 2.5.1, 3.3, 4.3.7, Cross-Chapter Box 8 in Chapter 3, Cross-Chapter Box 11 in Chapter 4}

D.1.3 The lower the emissions in 2030, the lower the challenge in limiting global warming to 1.5°C after 2030 with no or limited overshoot (*high confidence*). The challenges from delayed actions to reduce greenhouse gas emissions include the risk of cost escalation, lock-in in carbon-emitting infrastructure, stranded assets, and reduced flexibility in future response options in the medium to long term (*high confidence*). These may increase uneven distributional impacts between countries at different stages of development (*medium confidence*). {2.3.5, 4.4.5, 5.4.2}

D.2 The avoided climate change impacts on sustainable development, eradication of poverty and reducing inequalities would be greater if global warming were limited to 1.5°C rather than 2°C, if mitigation and adaptation synergies are maximized while trade-offs are minimized (*high confidence*). {1.1, 1.4, 2.5, 3.3, 3.4, 5.2, Table 5.1}

D.2.1 Climate change impacts and responses are closely linked to sustainable development which balances social well-being, economic prosperity and environmental protection. The United Nations Sustainable Development Goals (SDGs), adopted in 2015, provide an established framework for assessing the links between global warming of 1.5°C or 2°C and development goals that include poverty eradication, reducing inequalities, and climate action. (*high confidence*) {Cross-Chapter Box 4 in Chapter 1, 1.4, 5.1}

D.2.2 The consideration of ethics and equity can help address the uneven distribution of adverse impacts associated with 1.5°C and higher levels of global warming, as well as those from mitigation and adaptation, particularly for poor and disadvantaged populations, in all societies (*high confidence*). {1.1.1, 1.1.2, 1.4.3, 2.5.3, 3.4.10, 5.1, 5.2, 5.3. 5.4, Cross-Chapter Box 4 in Chapter 1, Cross-Chapter Boxes 6 and 8 in Chapter 3, and Cross-Chapter Box 12 in Chapter 5}

D.2.3 Mitigation and adaptation consistent with limiting global warming to 1.5°C are underpinned by enabling conditions, assessed in this Report across the geophysical, environmental-ecological, technological, economic, socio-cultural and institutional

18 GHG emissions have been aggregated with 100-year GWP values as introduced in the IPCC Second Assessment Report.

dimensions of feasibility. Strengthened multilevel governance, institutional capacity, policy instruments, technological innovation and transfer and mobilization of finance, and changes in human behaviour and lifestyles are enabling conditions that enhance the feasibility of mitigation and adaptation options for 1.5°C-consistent systems transitions. (*high confidence*) {1.4, Cross-Chapter Box 3 in Chapter 1, 2.5.1, 4.4, 4.5, 5.6}

D.3 Adaptation options specific to national contexts, if carefully selected together with enabling conditions, will have benefits for sustainable development and poverty reduction with global warming of 1.5°C, although trade-offs are possible (*high confidence*). {1.4, 4.3, 4.5}

D.3.1 Adaptation options that reduce the vulnerability of human and natural systems have many synergies with sustainable development, if well managed, such as ensuring food and water security, reducing disaster risks, improving health conditions, maintaining ecosystem services and reducing poverty and inequality (*high confidence*). Increasing investment in physical and social infrastructure is a key enabling condition to enhance the resilience and the adaptive capacities of societies. These benefits can occur in most regions with adaptation to 1.5°C of global warming (*high confidence*). {1.4.3, 4.2.2, 4.3.1, 4.3.2, 4.3.3, 4.3.5, 4.4.1, 4.4.3, 4.5.3, 5.3.1, 5.3.2}

D.3.2 Adaptation to 1.5°C global warming can also result in trade-offs or maladaptations with adverse impacts for sustainable development. For example, if poorly designed or implemented, adaptation projects in a range of sectors can increase greenhouse gas emissions and water use, increase gender and social inequality, undermine health conditions, and encroach on natural ecosystems (*high confidence*). These trade-offs can be reduced by adaptations that include attention to poverty and sustainable development (*high confidence*). {4.3.2, 4.3.3, 4.5.4, 5.3.2; Cross-Chapter Boxes 6 and 7 in Chapter 3}

D.3.3 A mix of adaptation and mitigation options to limit global warming to 1.5°C, implemented in a participatory and integrated manner, can enable rapid, systemic transitions in urban and rural areas (*high confidence*). These are most effective when aligned with economic and sustainable development, and when local and regional governments and decision makers are supported by national governments (*medium confidence*). {4.3.2, 4.3.3, 4.4.1, 4.4.2}

D.3.4 Adaptation options that also mitigate emissions can provide synergies and cost savings in most sectors and system transitions, such as when land management reduces emissions and disaster risk, or when low-carbon buildings are also designed for efficient cooling. Trade-offs between mitigation and adaptation, when limiting global warming to 1.5°C, such as when bioenergy crops, reforestation or afforestation encroach on land needed for agricultural adaptation, can undermine food security, livelihoods, ecosystem functions and services and other aspects of sustainable development. (*high confidence*) {3.4.3, 4.3.2, 4.3.4, 4.4.1, 4.5.2, 4.5.3, 4.5.4}

D.4 Mitigation options consistent with 1.5°C pathways are associated with multiple synergies and trade-offs across the Sustainable Development Goals (SDGs). While the total number of possible synergies exceeds the number of trade-offs, their net effect will depend on the pace and magnitude of changes, the composition of the mitigation portfolio and the management of the transition. (*high confidence*) (Figure SPM.4) {2.5, 4.5, 5.4}

D.4.1 1.5°C pathways have robust synergies particularly for the SDGs 3 (health), 7 (clean energy), 11 (cities and communities), 12 (responsible consumption and production) and 14 (oceans) (*very high confidence*). Some 1.5°C pathways show potential trade-offs with mitigation for SDGs 1 (poverty), 2 (hunger), 6 (water) and 7 (energy access), if not managed carefully (*high confidence*). (Figure SPM.4) {5.4.2; Figure 5.4, Cross-Chapter Boxes 7 and 8 in Chapter 3}

D.4.2 1.5°C pathways that include low energy demand (e.g., see P1 in Figure SPM.3a and SPM.3b), low material consumption, and low GHG-intensive food consumption have the most pronounced synergies and the lowest number of trade-offs with respect to sustainable development and the SDGs (*high confidence*). Such pathways would reduce dependence on CDR. In modelled pathways, sustainable development, eradicating poverty and reducing inequality can support limiting warming to 1.5°C (*high confidence*). (Figure SPM.3b, Figure SPM.4) {2.4.3, 2.5.1, 2.5.3, Figure 2.4, Figure 2.28, 5.4.1, 5.4.2, Figure 5.4}

Indicative linkages between mitigation options and sustainable development using SDGs (The linkages do not show costs and benefits)

Mitigation options deployed in each sector can be associated with potential positive effects (synergies) or negative effects (trade-offs) with the Sustainable Development Goals (SDGs). The degree to which this potential is realized will depend on the selected portfolio of mitigation options, mitigation policy design, and local circumstances and context. Particularly in the energy-demand sector, the potential for synergies is larger than for trade-offs. The bars group individually assessed options by level of confidence and take into account the relative strength of the assessed mitigation-SDG connections.

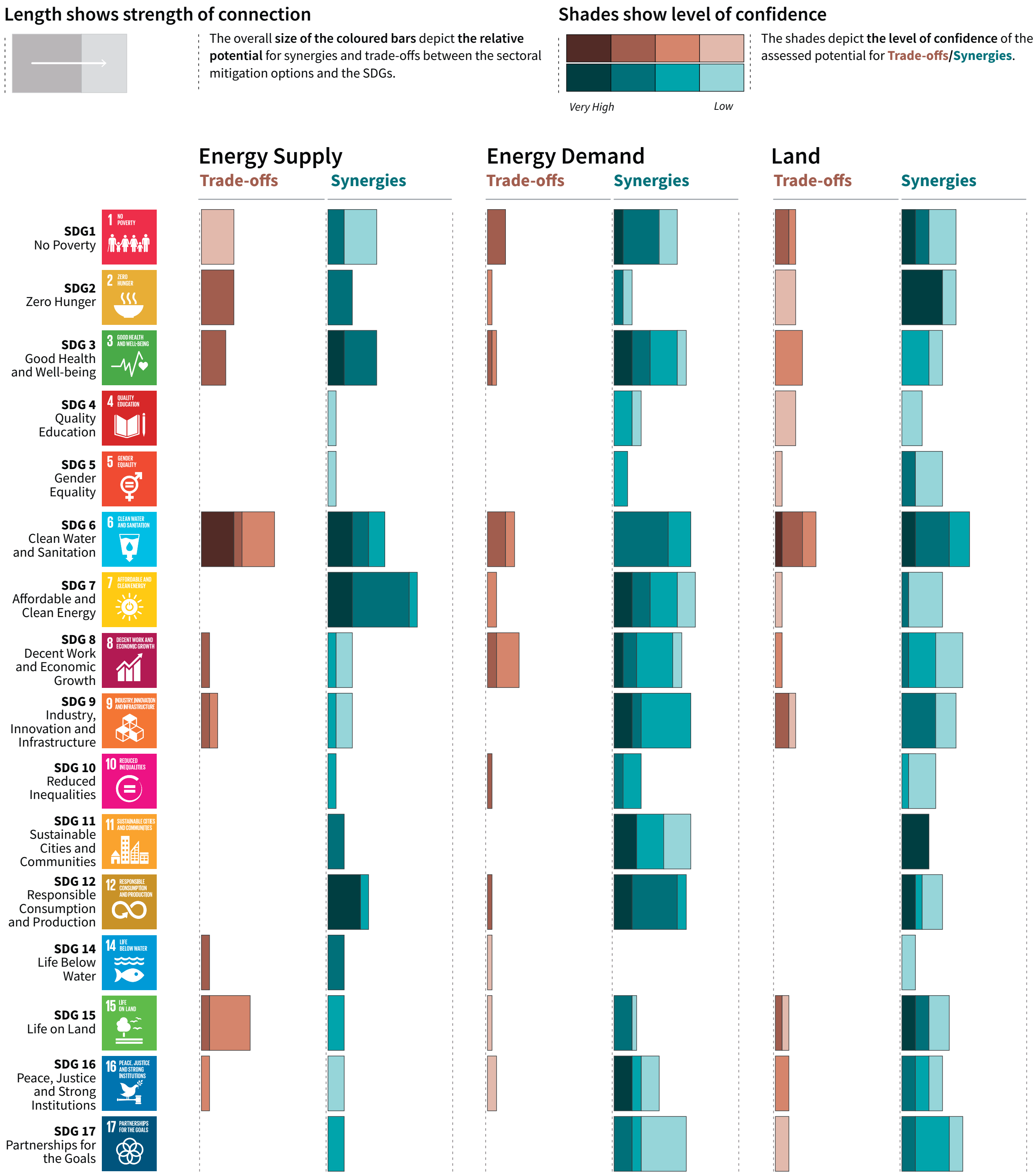


Figure SPM.4 | Potential synergies and trade-offs between the sectoral portfolio of climate change mitigation options and the Sustainable Development Goals (SDGs). The SDGs serve as an analytical framework for the assessment of the different sustainable development dimensions, which extend beyond the time frame of the 2030 SDG targets. The assessment is based on literature on mitigation options that are considered relevant for 1.5°C. The assessed strength of the SDG interactions is based on the qualitative and quantitative assessment of individual mitigation options listed in Table 5.2. For each mitigation option, the strength of the SDG-connection as well as the associated confidence of the underlying literature (shades of green and red) was assessed. The strength of positive connections (synergies) and negative connections (trade-offs) across all individual options within a sector (see Table 5.2) are aggregated into sectoral potentials for the whole mitigation portfolio. The (white) areas outside the bars, which indicate no interactions, have *low confidence* due to the uncertainty and limited number of studies exploring indirect effects. The strength of the connection considers only the effect of mitigation and does not include benefits of avoided impacts. SDG 13 (climate action) is not listed because mitigation is being considered in terms of interactions with SDGs and not vice versa. The bars denote the strength of the connection, and do not consider the strength of the impact on the SDGs. The energy demand sector comprises behavioural responses, fuel switching and efficiency options in the transport, industry and building sector as well as carbon capture options in the industry sector. Options assessed in the energy supply sector comprise biomass and non-biomass renewables, nuclear, carbon capture and storage (CCS) with bioenergy, and CCS with fossil fuels. Options in the land sector comprise agricultural and forest options, sustainable diets and reduced food waste, soil sequestration, livestock and manure management, reduced deforestation, afforestation and reforestation, and responsible sourcing. In addition to this figure, options in the ocean sector are discussed in the underlying report. {5.4, Table 5.2, Figure 5.2}

Information about the net impacts of mitigation on sustainable development in 1.5°C pathways is available only for a limited number of SDGs and mitigation options. Only a limited number of studies have assessed the benefits of avoided climate change impacts of 1.5°C pathways for the SDGs, and the co-effects of adaptation for mitigation and the SDGs. The assessment of the indicative mitigation potentials in Figure SPM.4 is a step further from AR5 towards a more comprehensive and integrated assessment in the future.

D.4.3 1.5°C and 2°C modelled pathways often rely on the deployment of large-scale land-related measures like afforestation and bioenergy supply, which, if poorly managed, can compete with food production and hence raise food security concerns (*high confidence*). The impacts of carbon dioxide removal (CDR) options on SDGs depend on the type of options and the scale of deployment (*high confidence*). If poorly implemented, CDR options such as BECCS and AFOLU options would lead to trade-offs. Context-relevant design and implementation requires considering people's needs, biodiversity, and other sustainable development dimensions (*very high confidence*). (Figure SPM.4) {5.4.1.3, Cross-Chapter Box 7 in Chapter 3}

D.4.4 Mitigation consistent with 1.5°C pathways creates risks for sustainable development in regions with high dependency on fossil fuels for revenue and employment generation (*high confidence*). Policies that promote diversification of the economy and the energy sector can address the associated challenges (*high confidence*). {5.4.1.2, Box 5.2}

D.4.5 Redistributive policies across sectors and populations that shield the poor and vulnerable can resolve trade-offs for a range of SDGs, particularly hunger, poverty and energy access. Investment needs for such complementary policies are only a small fraction of the overall mitigation investments in 1.5°C pathways. (*high confidence*) {2.4.3, 5.4.2, Figure 5.5}

D.5 Limiting the risks from global warming of 1.5°C in the context of sustainable development and poverty eradication implies system transitions that can be enabled by an increase of adaptation and mitigation investments, policy instruments, the acceleration of technological innovation and behaviour changes (*high confidence*). {2.3, 2.4, 2.5, 3.2, 4.2, 4.4, 4.5, 5.2, 5.5, 5.6}

D.5.1 Directing finance towards investment in infrastructure for mitigation and adaptation could provide additional resources. This could involve the mobilization of private funds by institutional investors, asset managers and development or investment banks, as well as the provision of public funds. Government policies that lower the risk of low-emission and adaptation investments can facilitate the mobilization of private funds and enhance the effectiveness of other public policies. Studies indicate a number of challenges, including access to finance and mobilization of funds. (*high confidence*) {2.5.1, 2.5.2, 4.4.5}

D.5.2 Adaptation finance consistent with global warming of 1.5°C is difficult to quantify and compare with 2°C. Knowledge gaps include insufficient data to calculate specific climate resilience-enhancing investments from the provision of currently underinvested basic infrastructure. Estimates of the costs of adaptation might be lower at global warming of 1.5°C than for 2°C. Adaptation needs have typically been supported by public sector sources such as national and subnational government budgets, and in developing countries together with support from development assistance, multilateral development banks, and United Nations Framework Convention on Climate Change channels (*medium confidence*). More recently there is a growing understanding of the scale and increase in non-governmental organizations and private funding in some regions (*medium confidence*). Barriers include the scale of adaptation financing, limited capacity and access to adaptation finance (*medium confidence*). {4.4.5, 4.6}

D.5.3 Global model pathways limiting global warming to 1.5°C are projected to involve the annual average investment needs in the energy system of around 2.4 trillion USD2010 between 2016 and 2035, representing about 2.5% of the world GDP (*medium confidence*). {4.4.5, Box 4.8}

D.5.4 Policy tools can help mobilize incremental resources, including through shifting global investments and savings and through market and non-market based instruments as well as accompanying measures to secure the equity of the transition, acknowledging the challenges related with implementation, including those of energy costs, depreciation of assets and impacts on international competition, and utilizing the opportunities to maximize co-benefits (*high confidence*). {1.3.3, 2.3.4, 2.3.5, 2.5.1, 2.5.2, Cross-Chapter Box 8 in Chapter 3, Cross-Chapter Box 11 in Chapter 4, 4.4.5, 5.5.2}

D.5.5 The systems transitions consistent with adapting to and limiting global warming to 1.5°C include the widespread adoption of new and possibly disruptive technologies and practices and enhanced climate-driven innovation. These imply enhanced technological innovation capabilities, including in industry and finance. Both national innovation policies and international cooperation can contribute to the development, commercialization and widespread adoption of mitigation and adaptation technologies. Innovation policies may be more effective when they combine public support for research and development with policy mixes that provide incentives for technology diffusion. (*high confidence*) {4.4.4, 4.4.5}.

D.5.6 Education, information, and community approaches, including those that are informed by indigenous knowledge and local knowledge, can accelerate the wide-scale behaviour changes consistent with adapting to and limiting global warming to 1.5°C. These approaches are more effective when combined with other policies and tailored to the motivations, capabilities and resources of specific actors and contexts (*high confidence*). Public acceptability can enable or inhibit the implementation of policies and measures to limit global warming to 1.5°C and to adapt to the consequences. Public acceptability depends on the individual's evaluation of expected policy consequences, the perceived fairness of the distribution of these consequences, and perceived fairness of decision procedures (*high confidence*). {1.1, 1.5, 4.3.5, 4.4.1, 4.4.3, Box 4.3, 5.5.3, 5.6.5}

D.6 Sustainable development supports, and often enables, the fundamental societal and systems transitions and transformations that help limit global warming to 1.5°C. Such changes facilitate the pursuit of climate-resilient development pathways that achieve ambitious mitigation and adaptation in conjunction with poverty eradication and efforts to reduce inequalities (*high confidence*). {Box 1.1, 1.4.3, Figure 5.1, 5.5.3, Box 5.3}

D.6.1 Social justice and equity are core aspects of climate-resilient development pathways that aim to limit global warming to 1.5°C as they address challenges and inevitable trade-offs, widen opportunities, and ensure that options, visions, and values are deliberated, between and within countries and communities, without making the poor and disadvantaged worse off (*high confidence*). {5.5.2, 5.5.3, Box 5.3, Figure 5.1, Figure 5.6, Cross-Chapter Boxes 12 and 13 in Chapter 5}

D.6.2 The potential for climate-resilient development pathways differs between and within regions and nations, due to different development contexts and systemic vulnerabilities (*very high confidence*). Efforts along such pathways to date have been limited (*medium confidence*) and enhanced efforts would involve strengthened and timely action from all countries and non-state actors (*high confidence*). {5.5.1, 5.5.3, Figure 5.1}

D.6.3 Pathways that are consistent with sustainable development show fewer mitigation and adaptation challenges and are associated with lower mitigation costs. The large majority of modelling studies could not construct pathways characterized by lack of international cooperation, inequality and poverty that were able to limit global warming to 1.5°C. (*high confidence*) {2.3.1, 2.5.1, 2.5.3, 5.5.2}

D.7 Strengthening the capacities for climate action of national and sub-national authorities, civil society, the private sector, indigenous peoples and local communities can support the implementation of ambitious actions implied by limiting global warming to 1.5°C (*high confidence*). International cooperation can provide an enabling environment for this to be achieved in all countries and for all people, in the context of sustainable development. International cooperation is a critical enabler for developing countries and vulnerable regions (*high confidence*). {1.4, 2.3, 2.5, 4.2, 4.4, 4.5, 5.3, 5.4, 5.5, 5.6, 5, Box 4.1, Box 4.2, Box 4.7, Box 5.3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 13 in Chapter 5}

D.7.1 Partnerships involving non-state public and private actors, institutional investors, the banking system, civil society and scientific institutions would facilitate actions and responses consistent with limiting global warming to 1.5°C (*very high confidence*). {1.4, 4.4.1, 4.2.2, 4.4.3, 4.4.5, 4.5.3, 5.4.1, 5.6.2, Box 5.3}.

D.7.2 Cooperation on strengthened accountable multilevel governance that includes non-state actors such as industry, civil society and scientific institutions, coordinated sectoral and cross-sectoral policies at various governance levels, gender-sensitive policies, finance including innovative financing, and cooperation on technology development and transfer can ensure participation, transparency, capacity building and learning among different players (*high confidence*). {2.5.1, 2.5.2, 4.2.2, 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5, 4.5.3, Cross-Chapter Box 9 in Chapter 4, 5.3.1, 5.5.3, Cross-Chapter Box 13 in Chapter 5, 5.6.1, 5.6.3}

D.7.3 International cooperation is a critical enabler for developing countries and vulnerable regions to strengthen their action for the implementation of 1.5°C-consistent climate responses, including through enhancing access to finance and technology and enhancing domestic capacities, taking into account national and local circumstances and needs (*high confidence*). {2.3.1, 2.5.1, 4.4.1, 4.4.2, 4.4.4, 4.4.5, 5.4.1 5.5.3, 5.6.1, Box 4.1, Box 4.2, Box 4.7}.

D.7.4 Collective efforts at all levels, in ways that reflect different circumstances and capabilities, in the pursuit of limiting global warming to 1.5°C, taking into account equity as well as effectiveness, can facilitate strengthening the global response to climate change, achieving sustainable development and eradicating poverty (*high confidence*). {1.4.2, 2.3.1, 2.5.1, 2.5.2, 2.5.3, 4.2.2, 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5, 4.5.3, 5.3.1, 5.4.1, 5.5.3, 5.6.1, 5.6.2, 5.6.3}

Box SPM.1: Core Concepts Central to this Special Report

Global mean surface temperature (GMST): Estimated global average of near-surface air temperatures over land and sea ice, and sea surface temperatures over ice-free ocean regions, with changes normally expressed as departures from a value over a specified reference period. When estimating changes in GMST, near-surface air temperature over both land and oceans are also used.[19] {1.2.1.1}

Pre-industrial: The multi-century period prior to the onset of large-scale industrial activity around 1750. The reference period 1850–1900 is used to approximate pre-industrial GMST. {1.2.1.2}

Global warming: The estimated increase in GMST averaged over a 30-year period, or the 30-year period centred on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue. {1.2.1}

Net zero CO_2 emissions: Net zero carbon dioxide (CO_2) emissions are achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period.

Carbon dioxide removal (CDR): Anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities.

Total carbon budget: Estimated cumulative net global anthropogenic CO_2 emissions from the pre-industrial period to the time that anthropogenic CO_2 emissions reach net zero that would result, at some probability, in limiting global warming to a given level, accounting for the impact of other anthropogenic emissions. {2.2.2}

Remaining carbon budget: Estimated cumulative net global anthropogenic CO_2 emissions from a given start date to the time that anthropogenic CO_2 emissions reach net zero that would result, at some probability, in limiting global warming to a given level, accounting for the impact of other anthropogenic emissions. {2.2.2}

Temperature overshoot: The temporary exceedance of a specified level of global warming.

Emission pathways: In this Summary for Policymakers, the modelled trajectories of global anthropogenic emissions over the 21st century are termed emission pathways. Emission pathways are classified by their temperature trajectory over the 21st century: pathways giving at least 50% probability based on current knowledge of limiting global warming to below 1.5°C are classified as 'no overshoot'; those limiting warming to below 1.6°C and returning to 1.5°C by 2100 are classified as '1.5°C limited-overshoot'; while those exceeding 1.6°C but still returning to 1.5°C by 2100 are classified as 'higher-overshoot'.

Impacts: Effects of climate change on human and natural systems. Impacts can have beneficial or adverse outcomes for livelihoods, health and well-being, ecosystems and species, services, infrastructure, and economic, social and cultural assets.

Risk: The potential for adverse consequences from a climate-related hazard for human and natural systems, resulting from the interactions between the hazard and the vulnerability and exposure of the affected system. Risk integrates the likelihood of exposure to a hazard and the magnitude of its impact. Risk also can describe the potential for adverse consequences of adaptation or mitigation responses to climate change.

Climate-resilient development pathways (CRDPs): Trajectories that strengthen sustainable development at multiple scales and efforts to eradicate poverty through equitable societal and systems transitions and transformations while reducing the threat of climate change through ambitious mitigation, adaptation and climate resilience.

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19 Past IPCC reports, reflecting the literature, have used a variety of approximately equivalent metrics of GMST change.

JANUARY 2019

DRILLING TOWARDS DISASTER:

WHY U.S. OIL AND GAS EXPANSION IS INCOMPATIBLE WITH CLIMATE LIMITS

OIL CHANGE INTERNATIONAL

Published in collaboration with

Amazon Watch · Bold Alliance · Center for Biological Diversity · Earthworks · Food & Water Watch · Friends of the Earth · Greenpeace · Hip Hop Caucus · Indigenous Environmental Network (Keep It In The Ground) · Labor Network for Sustainability · Oil Change United States · Our Revolution · People's Action · Rainforest Action Network · Sierra Club · Working Families Party · 350

This report was written and researched by Kelly Trout and Lorne Stockman. It was edited by Susan Rubinstein. Design adjustments by Matt Maiorana. All are with Oil Change International.

This publication is part of an Oil Change International series of national and sub-national reports based on our global analysis, *The Sky's Limit: Why the Paris Climate Goals Require a Managed Decline of Fossil Fuel Production*, released in September 2016.

The authors are grateful for feedback from the following reviewers:

Stephen Kretzmann, Hannah McKinnon, Greg Muttitt, and David Turnbull of Oil Change International; Leah Donahey and Kelsie Rudolph of the Alaska Wilderness League; Taylor McKinnon, Michael Saul, Kassie Siegel, and Shaye Wolf of the Center for Biological Diversity; Scott Edwards and Hugh MacMillan of Food and Water Watch; Nicole Ghio of Friends of the Earth US; Janet Redman of Greenpeace USA; Jeremy Brecher of the Labor Network for Sustainability; Alison Kirsch and Patrick McCully of Rainforest Action Network; Cara Bottorff, Pedro Cruz, and Kelly Martin of the Sierra Club; Peter Erickson of the Stockholm Environment Institute.

Design: paul@hellopaul.com
Cover Image: John Ciccarelli, Bureau of Land Management

January 2019

Published by Oil Change International (www.priceofoil.org), in collaboration with:

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CONTENTS

ABBREVIATIONS USED IN THIS REPORT

°C	Degrees Celsius
Bbl	Barrel
Bp/d	Barrels per day
BECCS	Bioenergy with carbon capture and storage
BOE	Barrels of oil equivalent
CCS	Carbon capture and storage
Cf/d	Cubic feet per day
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
EIA	U.S. Energy Information Administration
EJ	Exajoule
EPA	U.S. Environmental Protection Agency
GDP	Gross domestic product
Gt	Billion metric tons / Gigatons
ITUC	International Trade Union Confederation
IPCC	Intergovernmental Panel on Climate Change
IEA	International Energy Agency
LNG	Liquefied natural gas
MBOE	Million barrels of oil equivalent
Mt	Million metric tons
NGLs	Natural gas liquids
SR15	IPCC Special Report on 1.5°C of Global Warming

PREFACE

World governments, including the United States, committed in 2015 in the Paris Agreement to pursue efforts to limit global average temperature rise to 1.5 degrees Celsius above pre-industrial levels and, at a maximum, to keep warming well below 2 degrees Celsius (°C).[1] This report is part of *The Sky's Limit* series by Oil Change International examining why governments must stop the expansion of fossil fuel production and manage its decline – in tandem with addressing fossil fuel consumption – to fulfill this commitment.

The global *Sky's Limit* report, released in 2016, found that the world's existing oil and gas fields and coal mines contain more than enough carbon to push the world beyond the Paris Agreement's temperature limits.[2] This finding indicates that exploring for and developing new fossil fuel reserves is incompatible with the Paris goals. In fact, some already-operating fields and mines will need to be phased out ahead of schedule.

Since the global *Sky's Limit* report in 2016, new scientific evidence has added urgency to this call for a managed decline of fossil fuel production. The latest report from the Intergovernmental Panel on Climate Change warns that reaching 2°C of warming would significantly increase the odds of severe, potentially irreversible impacts to human and natural systems, compared to limiting warming to 1.5°C.[3] The difference could be the wipeout or resilience of whole communities and ecosystems. The report underscores that a 1.5°C path is possible but will require "rapid and far-reaching" transitions and "deep emissions reductions in all sectors" so that carbon pollution nears zero by 2050.[4]

Unfortunately, existing climate measures aren't cutting it – literally. Current national policy pledges under the Paris Agreement would put the world on course for 2.4 to 3.8°C of warming,[5] a catastrophic outcome.

This glaring gap in ambition has been driven in part by a systemic policy omission. Over the past three decades, climate policies have primarily focused on addressing emissions where they exit the smokestack or tailpipe. Meanwhile, they have largely left the source of those emissions – the oil, gas, and coal extracted by fossil fuel companies – to the vagaries of the market.

Basic economics tells us that the consumption of any product is shaped by both supply and demand. It follows that reducing supply and demand together, or 'cutting with both arms of the scissors,'[a] is the most efficient and effective way to reduce a harmful output. Putting limits on fossil fuel extraction – or 'keeping it in the ground' – is a core yet underutilized lever for accelerating climate action.

Curbing the supply of fossil fuels does not mean turning off the taps overnight. Rather, it means stopping new projects that would lock in new pollution for the coming decades. It means managing an orderly and equitable wind-down of existing fossil fuel infrastructure and extraction projects within climate limits. It makes it possible to plan for a just transition for workers and communities.

If the world is to succeed in meeting the Paris goals, this type of comprehensive and clear-eyed approach is urgently needed everywhere, and particularly in the United States – one of the world's top producers and users of fossil fuels.

a In his seminal 1890 work, *Principles of Economics*, Alfred Marshall remarked, "We might as reasonably dispute whether it is the upper or the under blade of a pair of scissors that cuts a piece of paper, as whether value is governed by utility [demand] or cost of production [supply]." Marshall's writing inspired the title of the 2018 article in *Climatic Change* by Fergus Green and Richard Denniss, "Cutting with both arms of the scissors: The economic and political case for restrictive supply-side climate policies."

IF YOU'RE IN A HOLE, STOP DIGGING.

Oil fields near Midland, Texas. European Space Agency / NASA.

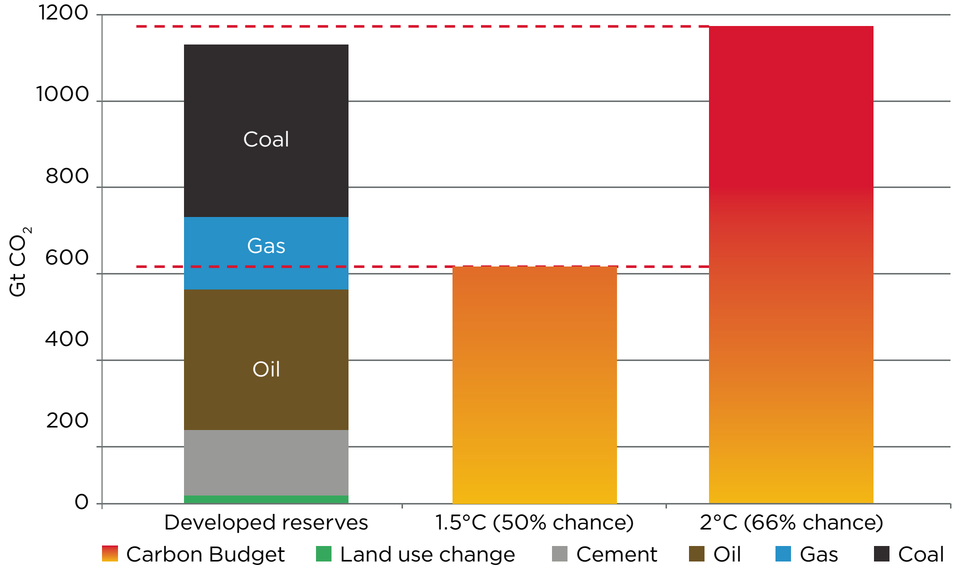
EXECUTIVE SUMMARY

Previous analysis has shown that existing oil and gas fields and coal mines already contain enough carbon to push the world beyond the goals of the Paris Agreement – to limit temperature rise to 1.5 degrees Celsius (°C) above pre-industrial levels or, at maximum, *well below* 2°C (Figure ES-1).[6] To limit catastrophic climate change, governments must manage the decline of the fossil fuel industry, and do so over the next few decades.[b]

The United States should be moving first and fastest in this direction. The United States is the world's largest oil and gas producer and third-largest coal producer.[7] It also has the resources and technology at hand to rapidly phase out extraction while investing in a just transition that guarantees a 'Green New Deal' for affected workers and communities currently living on the front lines of the fossil fuel industry and its pollution.[c]

Instead, the U.S. oil and gas industry is gearing up to unleash the largest burst of new carbon emissions in the world between now and 2050. **At precisely the time in which the world must begin rapidly decarbonizing to avoid runaway climate disaster, the United States is moving further and faster than any other country to expand oil and gas extraction.**

Figure ES-1: CO_2 Emissions from Developed Fossil Fuel Reserves, Compared to Carbon Budgets (as of Jan. 2018) within Range of the Paris Goals



Sources: Oil Change International analysis[21] based on data from Rystad Energy, International Energy Agency (IEA), World Energy Council, and IPCC

b In the 2016 global *Sky's Limit* report and in this U.S. analysis we take a precautionary approach to carbon capture and storage (CCS) and negative emissions technologies – assessing how the energy system will need to change without large-scale reliance on them. CCS has yet to be successfully deployed at scale despite major efforts. Meanwhile, scientists have identified significant social and ecological risks and governance challenges associated with large-scale use of carbon-dioxide removal technologies.

c At its core, a just transition means ensuring that nobody is left behind in the shift from fossil fuels to a clean energy economy. This process must include active government support and social protection, including wage insurance, health benefits, and pensions, for workers who lose their jobs when an oilfield or coal mine ceases operation. It must also include deep investment in new economic opportunities for affected communities. At the U.S. federal level, energy is increasingly coalescing around the concept of a Green New Deal – mobilizing mass public investment to decarbonize the U.S. economy while guaranteeing good-paying jobs in the transformation – to drive a just transition.

We offer this analysis as a warning and as a guide to U.S. elected officials and policymakers at all levels of government who remain committed to the Paris Agreement goals. If the United States is to start helping, rather than severely hindering, the world's chances at averting climate disaster, U.S. politicians at all levels must start flexing an underutilized muscle: their ability to say 'no' to the fossil fuel industry, and to steer it towards an equitable and orderly phase-out.

KEY FINDINGS

Oil & Gas: Unprecedented, Reckless Expansion

- **Between now and 2030, the United States is on track to account for 60 percent of world growth in oil and gas production, expanding extraction at least four times more than any other country.** This is the time period over which climate scientists say global carbon dioxide (CO_2) emissions should be roughly halved to stay in line with the 1.5°C target in the Paris Agreement.[8]

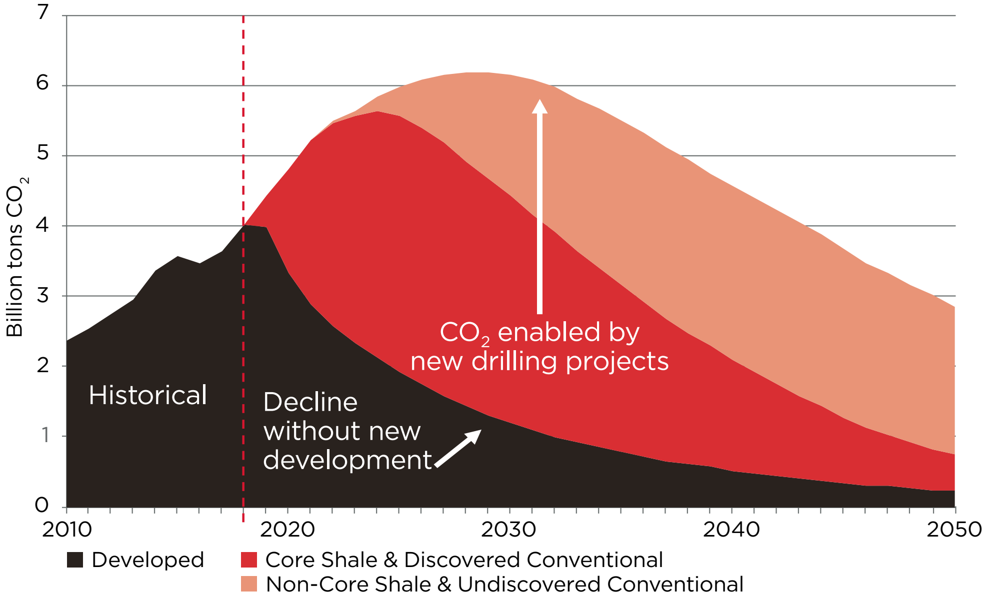
- **Between 2018 and 2050, the United States is set to unleash the world's largest burst of CO_2 emissions from new oil and gas development (Figure ES-2).** U.S. drilling into new oil and gas reserves – primarily shale – could unlock 120 billion metric tons[d] of CO_2 emissions, **which is equivalent to the lifetime CO_2 emissions of nearly 1,000 coal-fired power plants.**[e]

- **Methane leakage could increase the total climate pollution enabled by U.S. oil and gas expansion by 10 to 24 percent between 2018 and 2050,** adding 16 to 39 billion metric tons of CO_2-equivalent emissions to the 120 billion total given above.[f]

- **If not curtailed, U.S. oil and gas expansion will impede the rest of the world's ability to manage a climate-safe, equitable decline of oil and gas production.** We find that, under an illustrative 1.5°C pathway for oil and gas taken from the Intergovernmental Panel on Climate Change (IPCC), U.S. production would exhaust nearly 50 percent of the world's total allowance for oil and gas by 2030 and exhaust more than 90 percent by 2050.[g]

Oil rig operating in Williston, North Dakota. Lindsey Gira. (CC BY 2.0)

Figure ES-2: Projected Annual CO_2 Emissions of U.S.-Produced Oil and Gas, 2010-2050, by Current Stage of Development



Source: Oil Change International calculation using data from Rystad UCube (October 2018) and IPCC

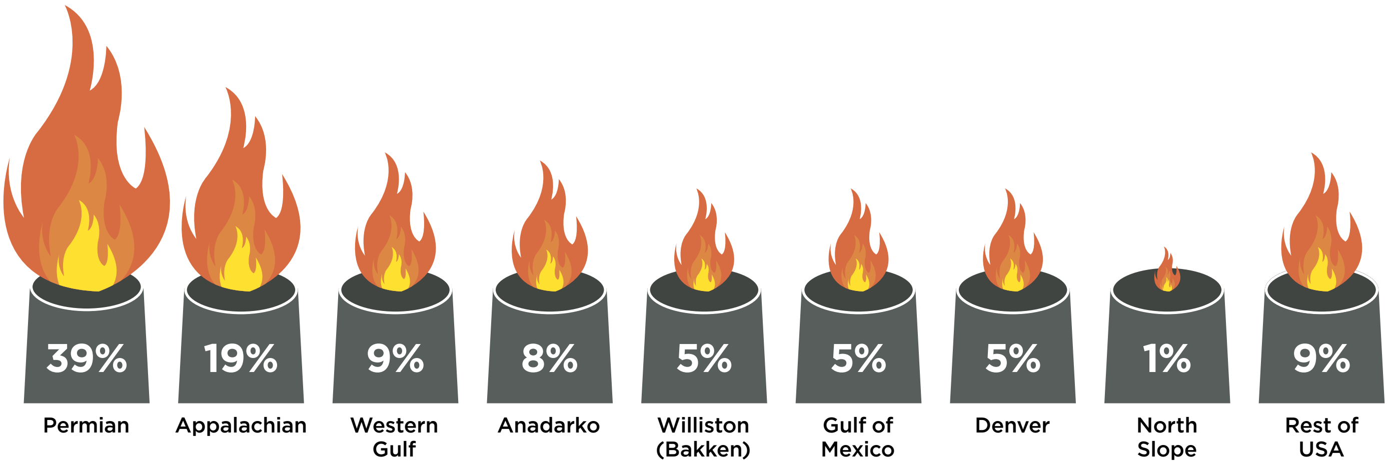
d All references to tons in this report refer to metric tons.

e CO_2 totals account for the emissions caused globally by burning oil and gas produced in the United States. The coal plant comparison is derived from Environmental Protection Agency (EPA) data (Sept. 2017 version) on the annual CO_2 emissions of an average U.S. coal plant and factors in a 30-year plant lifetime.

f This estimate is based on assuming an average methane leakage rate of 2.3 percent of U.S. gas production. The given range relates to using a 100-year or 20-year factor for the global warming potential of methane when converting to its CO_2 equivalent.

g As discussed in Section II, we compare the U.S. oil and gas production trajectory to the global trajectory for oil and gas demand in the P1 or low-energy-demand illustrative pathway featured in the IPCC 1.5°C Special Report. This is the archetypal pathway that does not rely on CCS.

Figure ES-3: Sources of CO_2 Emissions from New Oil and Gas Development, by Key U.S. Basins, 2018-2050



Source: Oil Change International calculation using data from Rystad Energy (October 2018) and IPCC

Expansion Hot Spots: The Permian and Appalachian Basins

The oil and gas industry is targeting two basins as the epicenters of its production expansion between now and 2050: the Permian Basin in Texas and New Mexico for oil and the Appalachian Basin spanning Pennsylvania, West Virginia, and Ohio for gas.

- **Nearly 60 percent of the 120 billion tons of CO_2 emissions unlocked by new U.S. oil and gas drilling from 2018 to 2050 is set to come from the Permian and Appalachian Basins (Figure ES-3).**

- The CO_2 pollution enabled by oil and gas production in the Permian Basin from 2018 through 2050 could exhaust **close to 10 percent of the entire world's carbon budget for staying within 1.5°C of warming.**[h] By its projected peak year of production, 2029, the Permian Basin could see nearly as much oil extraction as Saudi Arabia does today.[i]

Coal: Existing Mines Have Too Much Already

While U.S. coal mining is already in decline, this decline is not being managed in a way that is fast enough for the climate or fair for workers.

- If U.S. coal production is phased out over a timeframe consistent with equitably meeting the Paris goals, **at least 70 percent of U.S. coal reserves in already-producing mines would stay in the ground.**[j]

- The focus of U.S. policy towards the coal industry should be on accelerating its phase-out by 2030 or sooner while ensuring a just transition for workers and mining communities.

h We compare the emissions associated with Permian oil and gas production from 2018 to 2050 to the carbon budget for a 50 percent (one-in-two) chance of limiting warming to 1.5°C (580 Gt CO_2), as estimated in the IPCC 1.5°C Special Report.

i Oil production figures include crude oil, natural gas liquids (NGLs), and condensate, with NGLs being a significant portion of Permian production.

j The 70 percent figure is consistent with a phase-out of U.S. mining by 2030. Analyses based on both economic efficiency and equity indicate that wealthier countries like the United States should phase out coal by 2030 to align with the Paris goals.

RECOMMENDATIONS

The extreme scale of U.S. oil and gas expansion is not an accident; neither is the slowing decline of coal production. They result from ongoing policy decisions to lease federal and state lands and waters for extraction, to approve permits for new wells, mines, pipelines, and other infrastructure, to excuse air and water pollution, and to maintain billions of dollars in subsidies.

A different path is possible – if U.S. policymakers muster the political will to pursue it. Every decision around a new fossil fuel lease, permit, subsidy, or setback is an opportunity for U.S. politicians to stop fossil fuel expansion and champion a just transition to an economy powered by clean energy. This transformation will be challenging, but it is manageable. It is also the only way towards an economically secure, livable future. While all mining, including oil and gas extraction, accounted for only 1.4 percent of U.S. gross domestic product (GDP) in 2017,[9] the latest National Climate Assessment warns that worsening climate disruption driven by fossil fuel pollution could destroy up to 10 percent of U.S. GDP by the end of this century from damaged infrastructure, lost work hours, pollution-induced deaths, and more.[10]

Now is the time to chart a U.S. fossil fuel phase-out that aligns with climate limits, takes care of workers and communities on its front lines, and builds a more healthy and just economy for all in the process.

Climate leadership in the United States must include a commitment to:

- **Ban new leases, licenses, or permits** that enable new fossil fuel exploration or production, or new infrastructure such as pipelines, export terminals, or refineries – and reject existing proposals in the meantime. This would include ending new leasing of federal or state lands and waters for fossil fuel extraction.
- **Plan for the phase-out of existing fossil fuel projects in a way that prioritizes environmental justice.** This entails winding down existing fossil fuel projects first and fastest in places where they disproportionately harm vulnerable communities and pose the greatest risks to human health.
- **End subsidies** and other public finance for the fossil fuel industry.
- **Champion a Green New Deal that ensures a rapid and just transition to 100 percent renewable energy,** guaranteeing a good-paying job for every worker impacted by the phase-out of fossil fuels and investing in communities entwined in the fossil fuel economy now.
- **Reject the influence of fossil fuel industry money.**

MOVEMENT IN THE RIGHT DIRECTION

U.S. officials who embrace this comprehensive approach will be standing with communities across the United States who are already leading the way, fighting massive new gas pipelines on the East Coast, the Keystone XL, Line 3, and Dakota Access pipelines in the Midwest, new offshore oil leases and gas export terminals on the Gulf Coast, and refinery expansions and coal terminals on the West Coast.

These leaders will build on supply-side climate policies initiated towards the end of the previous administration. While the Obama administration oversaw a marked uptick in oil and gas production, the administration took steps in 2016 to pause federal coal leasing and put large areas of Arctic waters off limits for drilling, recognizing that, “[I]t would take decades to fully develop the production infrastructure necessary for any large-scale oil and gas leasing production in the region – at a time when we need to continue to move decisively away from fossil fuels.”[11]

They will also join a growing list of institutions and jurisdictions acting globally and locally to limit and wind down the fossil fuel industry. The World Bank announced in 2017 that it will cease financing oil and gas extraction.[12] New Zealand recently passed a ban on new offshore licenses,[13] joining France,[14] Costa Rica,[15] and Belize[16] in limiting new drilling. Portland, Oregon, has enacted a ban on all new fossil fuel infrastructure,[17] the states of New York[18] and Maryland[19] have banned fracking, and in California’s most heavily drilled county, the Arvin City Council recently voted unanimously to place the first-ever limits on new oil wells, joining six other California counties in restricting oil development.[20]

One of the most powerful – and most underutilized – climate policy levers is also the simplest: stop digging for more fossil fuels.

Hundreds march in Minneapolis to protest Energy Transfer Partners’ dangerous pipeline projects. Matt Maiorana, Oil Change International.

I. THE GLOBAL CARBON BUDGET AND WHY SUPPLY MATTERS

The Paris Agreement, now officially in force and ratified by more than 170 nations, sets the goal of striving to limit global temperature rise to 1.5 degrees Celsius (°C) above pre-industrial levels and keeping it well below 2°C.[22,23] In 2018, the Intergovernmental Panel on Climate Change (IPCC) released a powerful report showing the critical importance of the 1.5°C threshold.[24] Limiting warming to this level – the higher-ambition end of the Paris goals – would significantly reduce the risks of severe and widespread damage to human communities and ecosystems (see Box 1).

While the Trump administration has withdrawn its support for the Paris Agreement, the United States is still a party to the agreement. In defiance of President Trump's attempted pull-out, a significant number of U.S. governors, mayors, and other local officials, as well as members of Congress, have pledged their continued commitment to meeting the Paris goals.[25] The recent string of deadly weather disasters in the United States – fueled by the effects of reaching 1°C of global warming to date[26] – underscore the urgency of action.

In this report, we examine why U.S. elected officials and policymakers who have committed to lead on climate, and pledged to be "still in" on Paris, must act to stop the expansion of U.S. fossil fuel production.

In this section, we review the scientific, economic, and political imperatives for tackling fossil fuel supply. In the following sections, we bring this lens to the U.S. context, examining the current trajectory of U.S. fossil fuel production (Section II), hot zones for oil and gas expansion (Section III), the urgent need for U.S. leadership towards an equitable fossil fuel phase-out (Section IV), and how U.S. politicians can and must lead (Section V).

Box 1: The Growing Case for 1.5°C as an Absolute Limit

The Paris Agreement calls for, "Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change."[27] The 1.5°C target exists within the Paris Agreement because many of the world's most climate-vulnerable nations demanded it, asserting this level of ambition as essential to their survival.[28]

Throughout this report, we emphasize climate scenarios consistent with limiting warming to 1.5°C given the latest scientific evidence on how the risks of catastrophic climate change ratchet up significantly beyond this threshold. For example, the IPCC's 2018 special report finds that limiting global warming to 1.5°C, compared with 2°C, could:[29]

- "[R]educe the number of people both exposed to climate-related risks and susceptible to poverty by up to several hundred million by 2050;"
- Result in "up to 10 million fewer people" exposed to sea level rise and related risks, while "enabling greater opportunities for adaptation;"
- "[R]educe the proportion of the world population exposed to a climate change-induced increase in water stress by up to 50%;"
- Lessen the odds of "multiple and compound climate-related ... risks across energy, food, and water sectors" that "could overlap spatially and temporally;" and
- Lower the risks of "species loss and extinction," "forest fires and the spread of invasive species," and the "irreversible loss of many marine and coastal ecosystems."

These findings suggest we can significantly lessen the loss of human lives, whole communities, and ecosystems if governments interpret the upper limit of the Paris Agreement – of keeping warming "well below" 2°C – to mean limiting it to 1.5°C.

ENOUGH ALREADY: THE SCIENCE BEHIND 'KEEP IT IN THE GROUND'

Climate science shows us that *cumulative* carbon dioxide (CO_2) emissions over time are the primary determinant of how much global warming will occur. Based on evolving study of this relationship, and factoring in the effects of other greenhouse gas emissions like methane (see Box 2), scientists are able to estimate the cumulative CO_2 emissions that relate to a given temperature limit. These cumulative totals – called a 'carbon budget' – indicate a set limit to how much fossil fuel can be extracted and burned to meet global climate goals.

Several studies have shown that the vast majority of known fossil fuel reserves must stay in the ground to keep global warming below 2°C.[30] In 2016, Oil Change International produced the first analysis comparing carbon budget limits to the subset of fossil fuel reserves in already-operating or under-construction fields and mines globally.[31] We focused on these 'developed reserves' because they represent the oil, gas, and coal that fossil fuel companies have already invested in extracting: the necessary wells have been (or are being) drilled, the pits dug, and the related infrastructure constructed.

Figure 1 updates our 2016 analysis to reflect more recent carbon budget estimates from the IPCC's 2018 report on 1.5°C of global warming.[k,32] The 2°C budget shown here reflects a two-in-three chance of limiting warming to that level, the highest-probability available from the IPCC. It should not be interpreted as a 'target.' Rather, 2°C represents an absolute limit to stay as far below as possible.

The results show that the oil, gas, and coal in existing fields and mines would push the world far beyond 1.5°C while exhausting a 2°C budget as well. These conclusions account for optimistic estimates of future land use and cement manufacture emissions, which are the largest sources of non-energy emissions and more difficult to reduce than energy-sector emissions.[34]

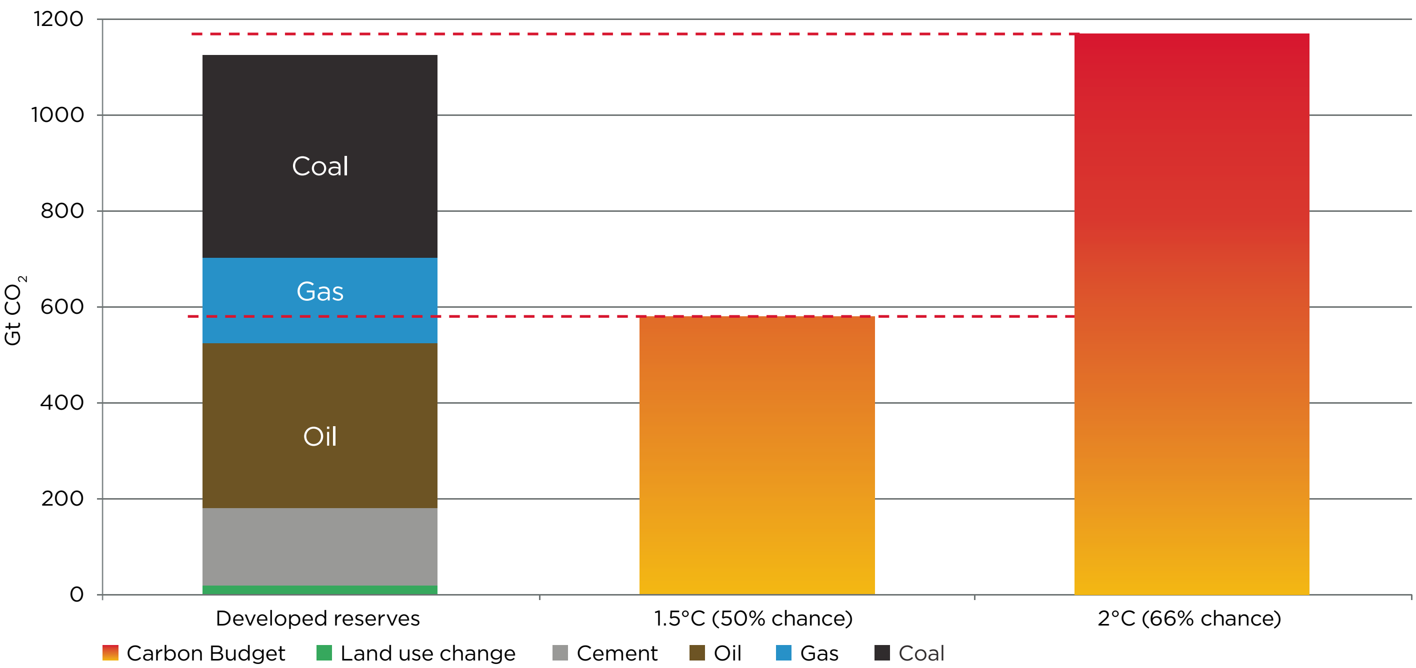
These findings indicate that there is no room for new fossil fuel development. Meeting the Paris goals will require that governments proactively manage the decline of fossil fuel production. In practice, this means:

- **Governments should cease issuing licenses, leases, and permits for new fossil fuel projects** in order to stop pushing the developed reserves bar in Figure 1 even higher.
- Stopping new projects alone will not be enough to keep warming well below 2°C. **Governments must also phase out a significant number of existing projects** ahead of schedule.

Negative Emissions Are Not an Escape Hatch

A precautionary approach towards carbon capture and storage (CCS) and so-called 'negative emissions technologies' underpins these conclusions. In theory, the world could continue developing new fossil fuel reserves if paired with technologies to remove some or all of the associated carbon emissions from the atmosphere. The world could temporarily exceed carbon budgets and then use carbon dioxide removal technologies to suck excess carbon out of the atmosphere in later decades, in hopes that temperatures would eventually return to target levels. Oil companies frequently point to such scenarios to justify continued investment in fossil fuels.[35]

Figure 1: CO_2 Emissions from Developed Fossil Fuel Reserves, Compared to Carbon Budgets (as of Jan. 2018) within Range of the Paris Goals



Sources: Oil Change International analysis[33] based on data from Rystad Energy, International Energy Agency (IEA), World Energy Council, and IPCC

k The original *Sky's Limit* report used carbon budgets from the IPCC's 5th Assessment Report, which was the scientific basis for the Paris Agreement. Evolving carbon budget methodologies have since led to updated, somewhat larger estimates in the IPCC Special Report on 1.5°C (SR15). However, the authors caution that, "Uncertainties in the size of these estimated remaining carbon budgets are substantial and depend on several factors." For example, "Potential additional carbon release from future permafrost thawing and methane release from wetlands would reduce budgets by up to 100 Gt CO_2 over the course of this century and more thereafter" (IPCC, "Summary for Policymakers," p. 14). Given what the new IPCC report tells us about uncertainties in the budgets, a precautionary approach would entail aiming as low as possible below the thresholds shown in Figure 1.

However, CCS itself has yet to be proven commercially viable.[36] Reliance on negative emissions technologies, whether bioenergy with carbon capture and storage (BECCS) or the mass planting of forests, would come with significant social and ecological risks and governance challenges. Scientists Kevin Anderson and Glen Peters write in regard to bioenergy production and CCS that "both face major and perhaps insurmountable obstacles."[37]

BECCS exists to date primarily in theoretical models and may be infeasible to deploy at the scale that would be required to enable new fossil fuel development. One study estimated that it would require a CO_2 pipeline system about seven times the size of today's global fossil gas infrastructure to handle the removal of about 10 billion tons of CO_2 from the atmosphere per year using BECCS.[38] The IPCC special report notes that emissions pathways relying on both large-scale afforestation and BECCS could require "up to the magnitude of the current global cropland area" and "would pose significant food supply, environmental and governance challenges."[39] How such systems would be regulated to ensure they actually absorb more CO_2 than they create is a major uncertainty.[l]

Even if the world invests in a new industrial and/or forest-planting system of this scale, scientists are not certain that it will work out. The IPCC special report cautions that, "Carbon cycle and climate system understanding is still limited about the effectiveness of net negative emissions to reduce temperatures after they peak," and adds that, "reliance on such technology is a major risk in the ability to limit warming to 1.5°C."[40]

Betting on large-scale deployment of negative emissions technologies would be a gamble of the highest stakes.[41] If carbon budgets are exceeded, and these technologies do not work, then humanity's chance at stabilizing the climate would be gone. **Managing the decline of fossil fuels within carbon budget limits while scaling up clean alternatives offers the surest path to a livable climate.**

Box 2: Carbon Budgets, Methane, and Other Greenhouse Gases

While there are multiple greenhouse gases that affect the climate, carbon budgets apply only to the most abundant, carbon dioxide, because of the way it accumulates in the atmosphere over many decades. The budgets concept cannot be used in the same way to account for other greenhouse gases that persist in the atmosphere for shorter periods because their warming effect is different. However, when calculating the size of carbon budgets, scientists factor in emissions projections for other greenhouse gases. For this reason, we only count CO_2 when making carbon budget comparisons in this report.

However, if real-world emissions of other climate pollutants are higher than assumed in the carbon budgets, then the available carbon budget may be smaller. Methane, or CH_4, is the most abundant of these other short-lived pollutants and the most relevant to this analysis.

Methane is the main component of fossil gas. Its warming effect is 87 times greater than CO_2 over a 20-year period and 36 times greater over a 100-year period (see endnote 84). While there are non-fossil fuel sources of methane, methane is often vented into the atmosphere without combustion during the process of extracting oil, gas, and coal and operating pipelines. A peer reviewed study published in June 2018 in the journal *Science* finds that average methane leakage in the U.S. oil and gas sector is 2.3 percent of gas production. This is 60 percent higher than estimates from the U.S. Environmental Protection Agency (EPA), but could still be a low estimate.[42] Recent research from NASA suggests that 68 percent of the rise in atmospheric methane between 2006 and 2014 came from oil and gas production.[43]

With U.S. oil and gas production growing far faster, and to a far higher level, than was thought possible just a few years ago, the risk of methane emissions increasing beyond the level assumed in IPCC scenarios is significant.[m] Initiatives to reduce methane leakage in oil and gas production are helpful but may not lead to a reduction of methane emissions if production continues to expand. If reductions in methane are not achieved to the degree assumed in carbon budgets, CO_2 budgets for fossil fuel combustion may be lower than assumed.

WHY SUPPLY MATTERS: LOCK-IN, LEAKAGE, AND JUST TRANSITION

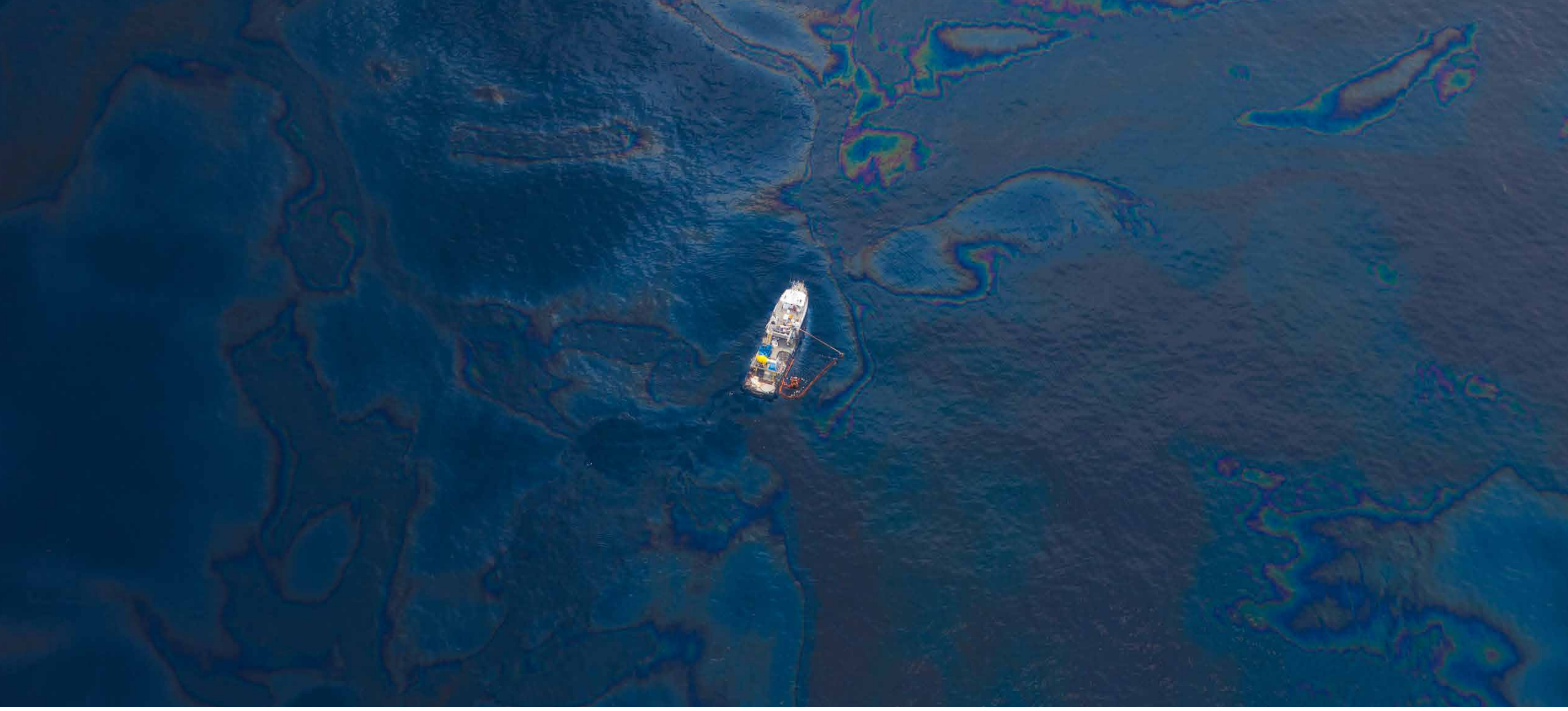
While science indicates a hard limit to how much fossil fuel can be extracted and burned, lessons from economics and politics reinforce that limiting fossil fuel supply is a key lever of climate action.

In other policy arenas, restrictions on the supply of harmful substances – such as tobacco and asbestos – have been widely employed as part of comprehensive strategies to reduce their damaging effects. Climate policy, however, has traditionally focused on measures to slow demand for fossil fuels while leaving their production to the vagaries of the market.[44] Where governments have intervened on the production side, it has most often been to subsidize rather than to constrain it.[n]

This is beginning to change. The World Bank announced in 2017 that it will phase out finance for oil and gas extraction, recognizing such finance as inconsistent with climate goals.[45] In 2016, the Obama administration initiated a moratorium on federal coal leasing, in part to reassess its climate implications.[46] A growing number of

l For example, bioenergy grown on the wrong soils, or replacing existing biomass, or using the wrong inputs (such as fertilizer and machinery) can emit more CO_2 than it absorbs, and CO_2 injected in the wrong geological structure may not be safe over the long term.

m The Summary for Policymakers of the IPCC SR15 states that, "Modelled pathways that limit global warming to 1.5°C with no or limited overshoot involve deep reductions in emissions of methane and black carbon (35% or more of both by 2050 relative to 2010)." IPCC, "Summary for Policymakers," In: *Global warming of 1.5°C*, p. 14.



A ship floats amongst a sea of spilled oil in the Gulf of Mexico after the BP Deepwater Horizon disaster. Kris Krüg. (CC BY-SA 2.0)

governments, including Costa Rica, France, New Zealand, Belize, and Denmark, have implemented full or partial bans on new oil and gas licensing.[47] Similar measures are currently under consideration in Spain and Ireland.[48]

For the reasons we outline below, this type of comprehensive approach will be necessary if the world is to close the dangerous gap between current action and what is required to meet the Paris goals. **Continued investment in fossil fuel extraction leads to higher emissions through the 'lock-in' of infrastructure, perverse political and legal incentives, and lower fossil fuel prices.** On the other hand, planning for the phase-out of fossil fuel assets strengthens demand-side action and makes it possible to plan for a just transition to clean energy that protects workers and communities currently entwined in the fossil fuel economy.

Prevent Further Infrastructure Lock-In

Investment in new fossil fuel extraction and infrastructure projects represents a commitment to future emissions due to the dynamics of carbon lock-in.[49] Once a company has sunk capital into a project – a pipeline, an offshore drilling rig, or a shale play – it has a financial commitment to that project for as long as it takes to turn a profit, which can be several decades for capital-intensive projects. The company will seek to recoup its investment, or at least limit its losses, as long as the prevailing market conditions cover marginal operating costs. The more capital-intensive the project, the deeper the lock-in effect.[50]

Once polluting infrastructure is built, it can crowd out cleaner alternatives even as they become cost-competitive or cheaper. For example, along the U.S. East Coast, the glut of gas supply driven by fracking in Appalachia has led energy companies to seek new customers for it. This has led to a massive buildout of new infrastructure, including pipelines, power plants, and export terminals. The power plants will be more expensive to operate than wind and solar farms,[51] yet utility customers are getting locked into long-term contracts to pay for this infrastructure by corporations taking advantage of a compliant regulatory environment.[52] In this way, supply can manufacture demand.

Governments also face higher legal hurdles to shut down polluting infrastructure after it is built, compared to rejecting its permitting in the first place. Such action may get tied up in lawsuits as fossil fuel companies seek to protect their investments, further delaying regulatory action to reduce pollution.[53]

Lessen the Grip of the Fossil Fuel Lobby

There is a political dimension to lock-in too. Governments tend to act more strongly to protect existing industries than to stimulate future ones due to their lobbying power as well as the valid fears tied up in disrupting existing jobs to build a new economy.

When politicians allow continued fossil fuel expansion, they reinforce the industry's incumbent power, which runs particularly deep in the United States. Over the past five decades, fossil fuel companies have pumped billions of dollars into federal and state lobbying and elections to sow doubt about climate science, block and weaken climate-related regulations, and distort markets in favor of fossil fuels (see Box 3). In return, oil, gas, and coal companies receive around $20 billion worth of federal and state subsidies each year.[54] When their investments face economic headwinds, the first response of the industry is often to lobby for more subsidies and bailouts.

By rejecting new infrastructure and extraction projects, politicians send a powerful signal that the fossil fuel era is ending, creating political space for stronger action to reduce demand and spur clean energy.

n For example, research led by the Stockholm Environment Institute has shown that up to half of new, yet-to-be developed U.S. oil production could be subsidy-dependent over the next several decades (see endnote 155).

Box 3: Fossil Fuel Influence Blocks Needed Action

Winding down the fossil fuel industry will require breaking the fossil fuel industry's pervasive hold over climate and energy policy and U.S. democracy.

In 1965 – more than 50 years ago – the head of the American Petroleum Institute (API) warned that, "[T]here is still time to save the world's peoples from the catastrophic consequence of pollution, but time is running out," adding that, "[Carbon] dioxide is being added to the Earth's atmosphere by the burning of coal, oil, and natural gas at such a rate that by the year 2000" the result could be "marked changes in climate beyond local or even national efforts."[55]

Wealthy fossil fuel companies like Exxon and Shell,[56] and lobby groups like API, went on to spend decades distorting and denying this science in order to block meaningful climate solutions and continue profiting from fossil fuel extraction. They continue to do so:

- From 2009 to 2010, the last period in which Congress debated major climate legislation, proposals included major concessions to fossil fuel companies – including gutting the EPA's authority to regulate climate pollution.[57] Fossil fuel interests, led by Exxon, ConocoPhillips, and Chevron, spent over half a billion dollars to weaken and defeat climate action.[58]
- The U.S. Congress and the Obama administration caved to oil and gas industry lobbying in 2015 when they lifted the four-decade-long ban on crude oil exports in exchange for temporary extensions of some renewable energy tax breaks. The lifting of the ban enabled the current drilling spree in Texas.[59]
- In the 2018 midterm elections, oil and gas companies spent huge sums to defeat state-level ballot measures. The industry spent $41 million to defeat a measure in Colorado that would have extended the setback zone between oil and gas wells and homes, schools, and other vulnerable areas to 2,500 feet.[60] Oil companies spent $8 million in a single California county, San Luis Obispo, to defeat a ban on fracking and new oil wells.[61] In Washington State, primarily out-of-state oil companies spent more than $31 million to defeat a carbon tax and just transition plan.[62]

A growing group of U.S. politicians is rejecting fossil fuel industry influence, recognizing it to be politically toxic. More than 1,300 federal, state, and local candidates and elected officials pledged to refuse all contributions from oil, gas, and coal companies during the 2018 election cycle.[63] If adequate climate solutions are to take hold, the ranks of U.S. politicians actively opposing and resisting fossil fuel influence must continue to grow.

Make Climate Policy Less 'Leaky'

In a global market, supply and demand interact to affect fossil fuel prices and, ultimately, consumption levels. Reducing fossil fuel supply or demand in one place will make fossil fuels more lucrative to produce or cheaper to use elsewhere, respectively. This effect is called carbon 'leakage,' and every climate policy comes with some degree of it.[64] For every barrel of oil either left in the ground or kept out of a car tank, global emissions go down, but the net benefit is not one-to-one. For example, a recent study by the Stockholm Environment Institute found that global oil consumption would drop by 0.2 to 0.6 barrels for each barrel of oil that California keeps in the ground.[65] Reducing demand and supply simultaneously – for example, by pairing fuel efficiency standards with cuts in oil production – makes climate policy less 'leaky' and ultimately more effective by balancing out undesired price effects. In other words, 'cutting with both arms of the scissors' maximizes emissions reductions.[66]

Make Way for a Just Transition

By allowing continued expansion of the fossil fuel economy, governments not only enable new pollution, they also entangle more workers and communities in an industry that has no viable future on a livable planet. The first step in taking care of workers and communities that will be affected by the phase-out of the fossil fuel industry is to acknowledge that this transition must occur. Only then can governments begin to plan for it.

At its core, a just transition means ensuring that nobody is left behind in the shift from fossil fuels to a clean energy economy. The International Trade Union Confederation (ITUC), which fought for inclusion of just transition in the preamble to the Paris Agreement, defines a just transition as "an economy-wide process that produces the plans, policies and investments that lead to a future where all jobs are green and decent, emissions are at net zero, poverty is eradicated, and communities are thriving and resilient."[67] As we discuss in Section IV, this process must include active government support and social protection, including wage insurance, health benefits, and guaranteed pensions, for workers who lose their jobs when an oilfield or coal mine ceases operation. It must also include deep investment in new economic opportunities for affected communities. In a political context, investing in just transition policies helps to reduce fear and resistance to the significant and rapid economic shifts that will be required to stay within agreed climate limits.

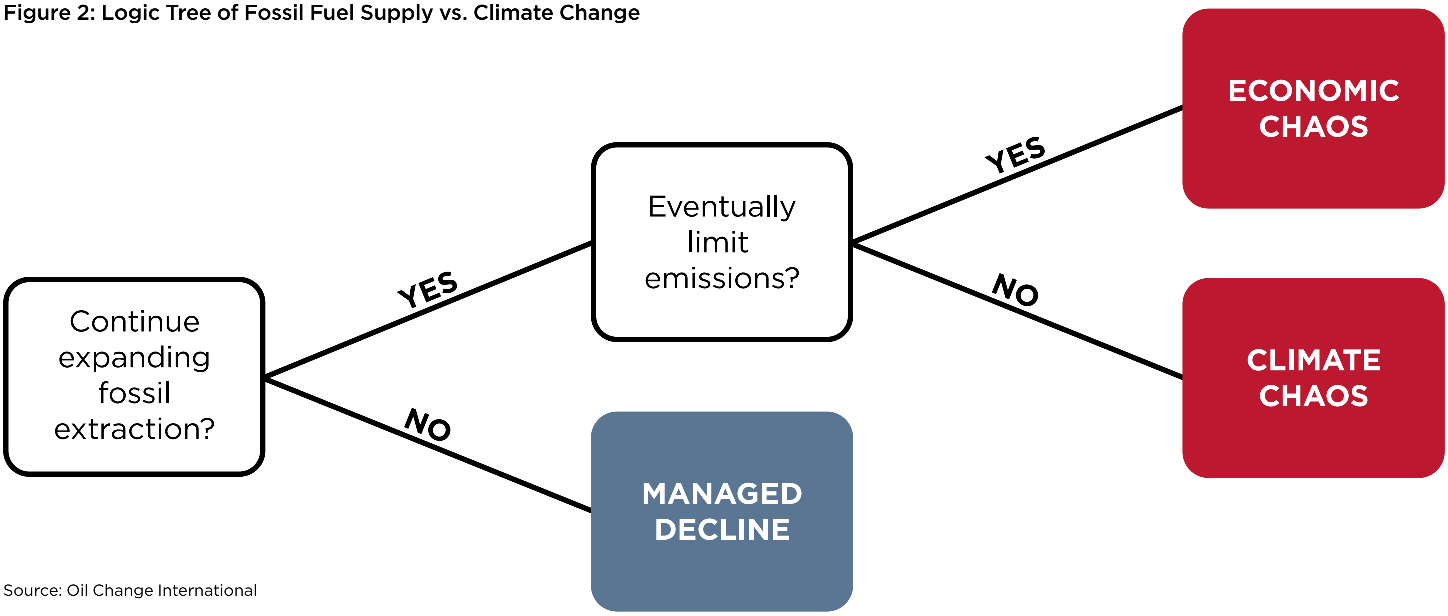
MANAGED DECLINE OR ECONOMIC AND CLIMATE CHAOS

In summary, our analysis points to three possible futures when it comes to the climate crisis, as visualized in Figure 2:

1. **Managed Decline:** We succeed in restricting new fossil fuel projects and carefully manage the decline of the fossil industry over time, while planning for a just transition for workers and communities.
2. **Economic Chaos:** We allow further fossil fuel development to continue, but eventually manage to limit emissions within carbon budgets. This would lead to a sudden and chaotic shutdown of fossil fuel production, stranding assets, damaging economies, and harming workers and communities reliant on the energy sector.
3. **Climate Chaos:** We fail to restrict emissions. New long-lived fossil fuel infrastructure locks us into a high-carbon future, causing compounding, irreparable harm for people and ecosystems around the world.

Clearly, a managed decline is the safest and most socially just path. By stopping new fossil fuel development and managing a just transition towards an economy powered by clean energy, we can achieve the brightest future. As we detail in the following section, global success in meeting the Paris climate goals could hinge on the speed at which political leaders in the United States embrace this imperative.

Figure 2: Logic Tree of Fossil Fuel Supply vs. Climate Change



Source: Oil Change International

Emergency crews respond to fires in California. Bureau of Land Management.

II. U.S. FOSSIL FUEL EXPANSION VS. THE PARIS GOALS

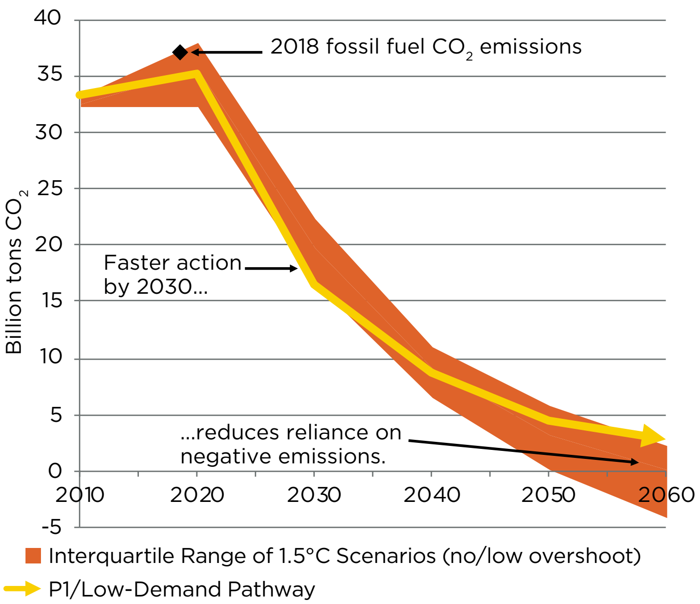
As we saw in the previous section, meeting global climate goals will require putting an end to new fossil fuel development and winding down the industry within climate limits. In this section, we examine how the current trajectory of fossil fuel production in the United States is out of step with this necessity. The United States is enabling the expansion of oil and gas production at a scale far more extreme than in any other country.

For context, it is instructive to first consider the pace of energy system transformation that aligns with the Paris goals. The IPCC special report on 1.5°C of warming indicates that global CO_2 emissions should fall by 45 percent by 2030, compared to 2010 levels, and reach net-zero around 2050 to keep warming to that threshold, based on analysis of dozens of model scenarios (Figure 3a).[68]

Hitting these benchmarks will require swift declines in fossil fuels – the primary source of emissions. As discussed in Section I, one of the biggest uncertainties in many climate scenarios is whether CCS and/or novel negative emissions technologies will be available later in the century and if so at what scale. Greater reliance on these technologies would enable a somewhat less rapid decline of fossil fuels, but at a large and irreversible cost if the technologies do not work out. The IPCC special report features four 'illustrative pathways' consistent with limiting warming to 1.5°C to represent different societal options. A key distinction between these pathways is their degree of reliance on novel negative emissions technologies: ranging from zero BECCS in the P1 pathway to a very large amount in the P4 pathway.

Figure 3: Fossil Fuel CO_2 and Energy Pathways for Limiting Warming to 1.5°C

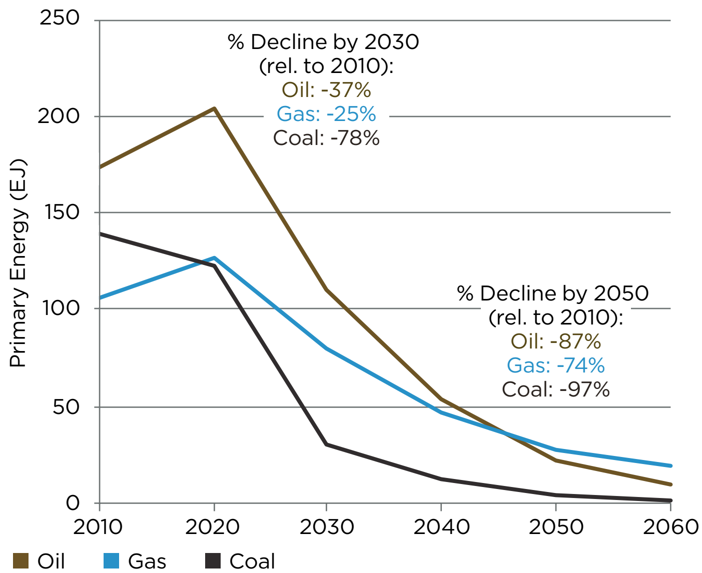
*(a) CO_2 from Energy and Industrial Processes in IPCC Pathways Consistent with Limiting Warming to 1.5°C**



**The orange area shows the 25th to 75th percentile of 53 available scenarios that keep warming to 1.5°C within this century with little to no overshoot of that threshold.*

Source: IPCC/IAMC 1.5°C Scenario Explorer and Data hosted by IIASA,[70] Global Carbon Project[71]

*(b) Decline of Oil, Gas, and Coal in the IPCC P1 Illustrative Pathway (no CCS)**



**While not relying on CCS with fossil fuels or BECCS, the P1/low-demand pathway does rely on sequestration of 246 $GtCO_2$ via planting forests. Without reliance on such large-scale afforestation, the fossil fuel declines shown here would need to occur faster.*[73]

Source: IPCC/IAMC 1.5°C Scenario Explorer and Data hosted by IIASA[72]

For the precautionary reasons outlined in Section I, we focus on the P1 pathway when making comparisons to the trajectory of U.S. fossil fuel production in the analysis that follows. In this pathway without CCS or BECCS, oil, gas, and coal peak by 2020, decline significantly by 2030, and are nearly phased out of the energy system by mid-century (Figure 3b).[69] It is important to note that, for the equity considerations further explored in Section IV, U.S. fossil fuel production and use should decline faster than these global averages.

MOVING RAPIDLY IN THE WRONG DIRECTION

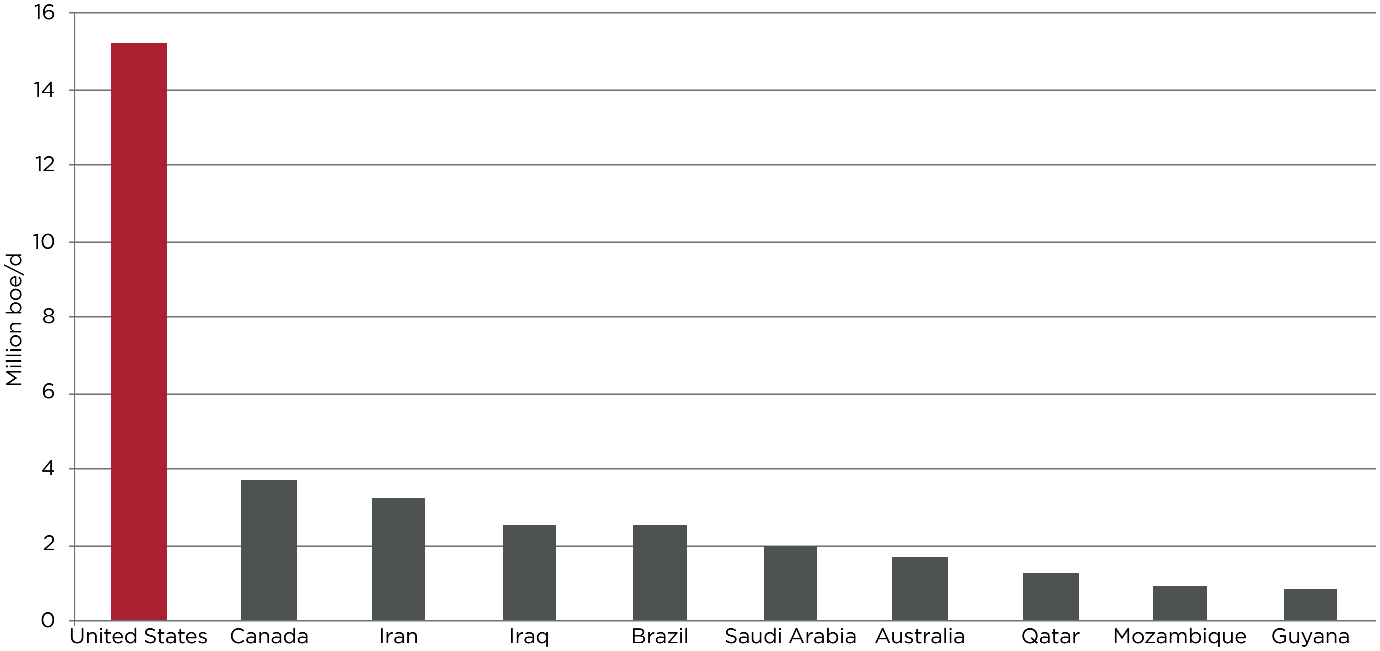
Driven by the proliferation of fracking, enabled by a massive buildout of pipeline and export infrastructure, and propped up by federal and state subsidies, oil and gas production in the United States has expanded at unprecedented rates in recent years. Production grew by 85 percent between 2010 and 2018 (in terms of barrels of oil equivalent, or BOE), making the United States the largest oil and gas producer in the world.[74] The International Energy Agency calls this growth, primarily in shale, "the largest parallel increase in oil and gas output in history."[75]

Oil pumps operate on federal land in California. John Ciccarelli, Bureau of Land Management.

Under current policies, this rapid expansion is projected to continue. Data from Rystad Energy, an independent oil and gas consultancy, indicate that U.S. oil production is on track to double by 12 million barrels per day (bp/d) between 2017 and 2030, peaking at more than 25 million bp/d. Between 2017 and 2025, U.S. gas production is on track to increase by 40 billion cubic feet per day (cf/d), peaking at close to 100 billion cf/d.[76]

Figure 4 shows that the oil and gas industry is planning to expand production more in the United States than in any other country over the coming decade. U.S. growth outpaces that of the next-closest country, Canada, by a factor of more than four. If these plans are realized, U.S. oil and gas production would be responsible for nearly 60 percent of world growth in oil and gas supply between 2017 and 2030.

Figure 4: Top Countries by Increase in Oil and Gas Production to 2030 (over 2017 baseline)



Source: Rystad Energy (November 2018)

Box 4: Methodology & Key Terms

This report relies on data from Rystad Energy for projections of future oil and gas production, both in the United States and globally. Rystad's UCube database provides production and reserves estimates for all upstream oil and gas projects in the world, both historical and through 2100. Rystad uses company reports, regulatory information, and modeling to project the volumes of oil and gas that will be commercially viable to extract over a given time period, for a given price assumption. Oil volumes include all liquids: crude oil, natural gas liquids (NGLs), and condensate. Projections in this report relate to Rystad's base case for future oil prices.

We cut off our production analysis at 2050 in this report to afford a higher degree of confidence in the projections, compared to a 2100 timeline. A 2050 cutoff also mirrors the deadline by which fossil fuel production and consumption should be approaching zero to align with climate limits. Therefore, the data analyzed in this report do not reflect the climate impact of all producible reserves in the United States. The specific basins discussed in Section III contain more reserves of oil and gas than are reflected in this report, given we consider only those reserves that would be commercially viable through 2050.

We classify oil, gas, and coal resources according to the following categories to reflect their current stage of development. We separate production projections in this way to illustrate the carbon that would be unlocked by development of new reserves, compared to the declines that would result from ceasing new development:

- **Developed:** Reserves viable to extract from projects that are already producing or under construction.[o]
- **Undeveloped:** Oil, gas, and coal that could be produced from planned or potential projects if development or exploration proceeds, including projections of likely new discoveries.

In this report's figures, we further break **undeveloped** oil and gas into sub-categories to reflect their proximity to development as well as the differing characteristics of shale oil and gas compared to conventional oil and gas.

Through 2050, the vast majority of commercially viable but not yet developed U.S. oil and gas resources are shale resources. Most of this **undeveloped shale oil and gas** is already discovered and quantified, but companies split the reserves into 'core' versus 'non-core' tiers based on their expected productivity and economics. Core reserves will likely be drilled first whereas non-core will likely be drilled later.

For **undeveloped conventional oil and gas**, reserves are traditionally divided into categories of 'discovered' versus 'undiscovered.' Discovered reserves are the estimated producible reserves in leases that companies have already explored and assessed, but for which no final investment decision has been made. The undiscovered category includes estimates of producible oil and gas in designated blocks that are yet to be leased. Through 2050, Rystad projects that this new exploration would primarily occur in the Gulf of Mexico and the North Slope of Alaska, where conventional oil and gas development has been ongoing for decades and the geology and economics of currently unsold leases are relatively well known.

In this report, we combine 'core' shale resources and 'discovered' conventional reserves into one category, while combining 'non-core' shale resources and 'undiscovered' conventional resources into another:

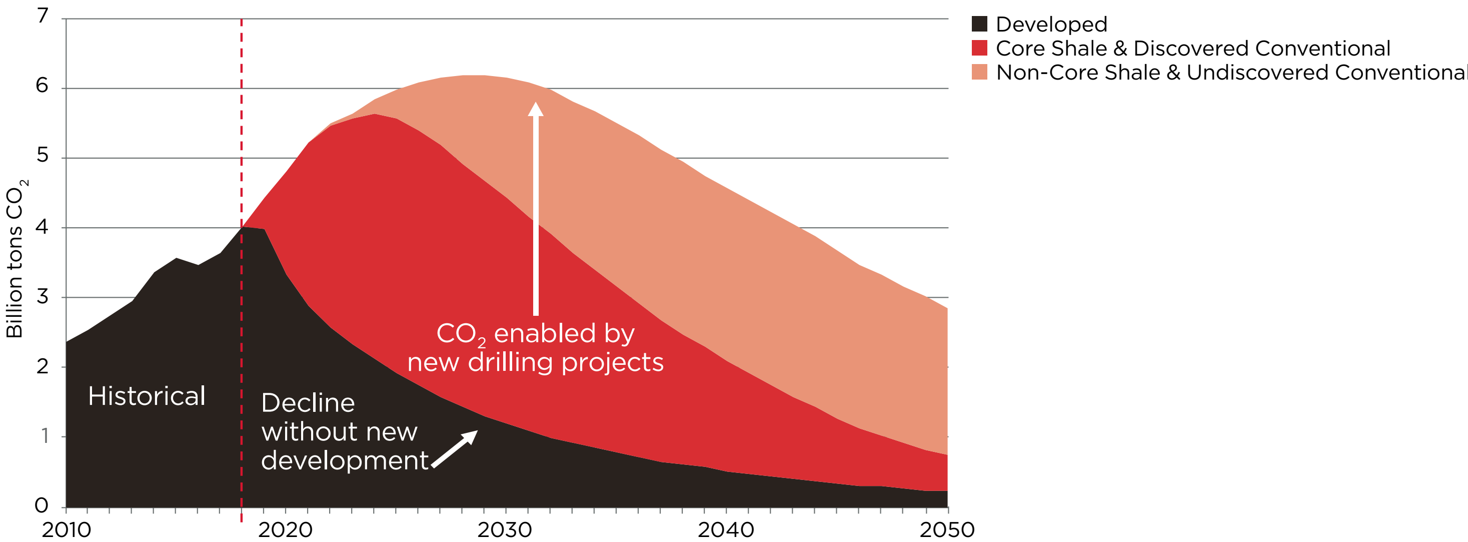
- **Core Shale & Discovered Conventional:** Reserves that are already discovered and evaluated, and already leased to a company in most cases, but for which no final development decision has yet been made. For shale oil and gas, this means reserves associated with wells that have yet to be drilled.[p] Core shale reserves are those considered closest to being drilled and expected to be most productive using current technology and current oil price expectations.
- **Non-Core Shale & Undiscovered Conventional:** This includes shale acreage that companies have under evaluation but that is not considered top-tier for productivity. This acreage may be more difficult or expensive to exploit. The production projections are therefore more speculative compared to core acreage. For conventional oil and gas, this includes resources for which field exploration has not yet been performed and estimates of the ultimate quantity of recoverable oil or gas are more speculative.

Calculating Emissions: Throughout this analysis, we count the carbon emissions that would be caused by combusting fossil fuels produced in the United States. To calculate CO_2 emissions from combustion, we use IPCC emissions factors for oil, gas, and coal respectively.[77]

Emissions of other greenhouse gases and non-combustion emissions add to the total climate impact of U.S. fossil fuel production. Boxes 2 and 5 discuss and partially quantify the additional impact of methane. Additional emissions occur in the process of extracting, transporting, and refining fuels. However, given a proportion of fuels extracted in the United States is burned in the production and processing of other fuels, combustion emission totals do capture a significant proportion of these additional CO_2 emissions. We do not calculate total, or lifecycle, emissions due to the complexity of doing so across different U.S. crude sources and the risk of double-counting emissions.[q]

o For shale this means reserves in currently producing wells or wells that have been drilled but not yet completed.
p Drilled Uncompleted wells (DUCs) are counted as developed.
q For example, a given cubic foot of gas could be extracted in one place, with the associated combustion emissions counted. But if that same cubic foot of gas is burned to power an oil pump, its emissions would also be counted as part of the lifecycle emissions of producing a given barrel of oil. This amounts to double-counting.

Figure 5: Projected Annual CO_2 Emissions of U.S.-Produced Oil and Gas, 2010-2050, by Current Stage of Development



Source: Oil Change International calculation using data from Rystad UCube (October 2018) and IPCC[78]

DRILLING THE WORLD INTO A DEEPER HOLE

Figure 5 shows the annual CO_2 emissions that would be enabled by U.S. oil and gas production through 2050 if the industry's expansion is allowed to proceed – or if it stops (see Box 4 for detailed methodology). These emissions reflect the carbon pollution that would result globally from burning oil and gas produced in the United States. The black band represents the trajectory of emissions associated with U.S. oil and gas if production is limited to already-developed projects. The red and pink bands represent the emissions that would result if the industry continues drilling into new reserves.

If new development ceases, U.S. production will begin to fall based on the natural decline rate of existing wells. The decline would be significant – nine percent annually on average between 2020 and 2050 – but it would also be a managed decline that policymakers could plan for. As discussed in Section IV, such planning can and should ensure a just transition that offers good-paying jobs to former fossil fuel workers.

However, with expansion into new oil and gas reserves, the emissions enabled by U.S. oil and gas production would *increase* by nearly 70 percent by 2030, compared to 2017 levels. Between now and 2050 – the timespan in which CO_2 emissions should be zeroing out globally – the United States would be the largest single source of new oil and gas supply in the world.

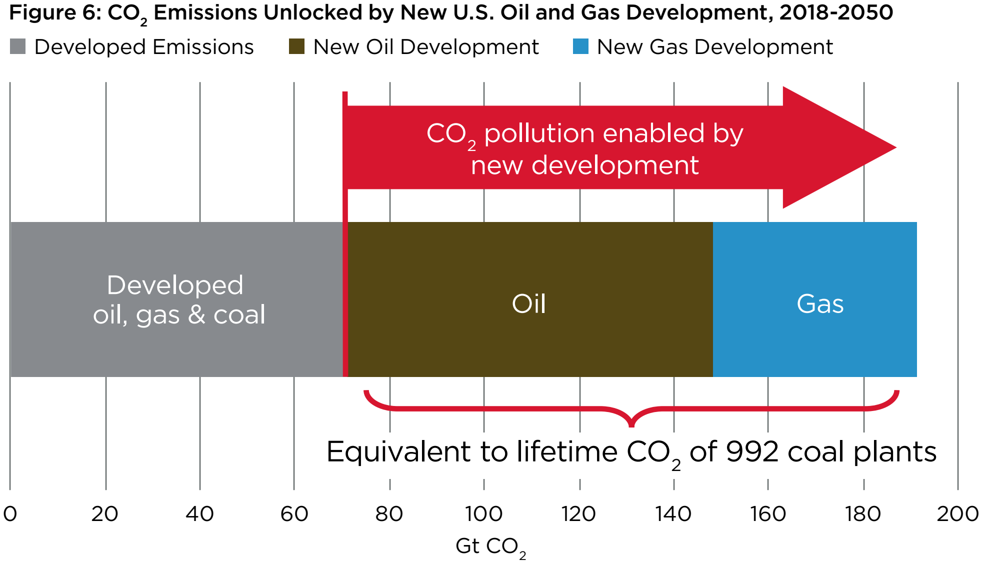
Figure 6 shows the cumulative carbon pollution that this new development would unlock through 2050. All of the emissions to the right of the red line would add to the world's stock of developed fossil fuel emissions, which already exceed safe carbon budget limits (as shown in Figure 1).

Oil expansion would enable close to 80 billion tons of carbon pollution. Gas expansion would enable more than 40 billion tons. To provide a sense of scale, the total CO_2 emissions enabled by this drilling expansion between 2018 and 2050 – 120 billion tons in total – would be equivalent to the lifetime CO_2 pollution of nearly 1,000 average U.S. coal plants.[81]

Nearly all of this expanded drilling would depend on fracking. More than 90 percent of the production from new development represented in Figure 5 would come from unconventional shale oil and gas, primarily in the Permian and Appalachian Basins, as we discuss in Section III.

Contrary to industry claims, which continue to lift up fossil gas as a "bridge fuel," expanding production and use of fossil gas is not a climate solution. While it is true that gas combustion releases less carbon pollution than coal combustion, replacing coal with gas will not produce the scale of emissions reductions needed to align with global climate goals and hinders the urgently needed transition to zero-carbon energy. Moreover, the additional methane released during fossil gas production worsens the cumulative climate pollution impact of oil and gas expansion presented in Figure 6. We discuss these issues in Box 5.

Figure 6: CO_2 Emissions Unlocked by New U.S. Oil and Gas Development, 2018-2050



Source: Oil Change International calculation using data from Rystad Energy (October 2018), EIA,[79] EPA,[80] and IPCC

Construction of the Dakota Access Pipeline near New Salem, North Dakota. Tony Webster. (CC BY-NC-SA 2.0)

Box 5: Climate Limits Require Less Gas, Not More

Methane leakage is the most widely discussed issue in the debate over the role of fossil gas in the energy transition. As discussed in Box 2, leaking methane associated with increasing oil and gas production is responsible for the majority of recent increases in the amount of methane in our atmosphere and is accelerating climate change.[82]

Methane emissions could add 10 to 24 percent to the cumulative CO_2-equivalent emissions enabled by U.S. oil and gas production from 2018 to 2050, increasing the total in Figure 6 by 16 to 39 billion metric tons of CO_2 equivalent (CO_2e). This estimate is based on an average methane leakage rate of 2.3 percent of U.S. gas production, as taken from the most recent peer reviewed study in *Science*.[83] The range of 10 to 24 percent depends on the assumption for converting methane to CO_2e.[84]

But even if methane leakage could be reduced to zero, which is virtually impossible, greater reliance on fossil gas is incompatible with climate safety. The limits of our climate system mean that we need to reduce all fossil fuel production and use, and gas is no exception. Analysis by Bloomberg New Energy Finance has found that a complete phase-out of coal by 2035 using today's combination of gas and renewables would not be sufficient to get power sector emissions onto a 2-degree trajectory.[85] We can and must make the clean energy transition with less gas not more.

Here are five key reasons why, with or without methane leakage, gas is not a transition fuel. This summary is adapted from the Oil Change International briefing *Burning the Gas 'Bridge Fuel' Myth*, which includes further analysis and references:[86]

1. **Breaking the Budget:** The coal, oil, and gas in the world's currently producing and under-construction projects, if fully extracted and burned, would take the world far beyond safe climate limits. Further development of untapped gas reserves is inconsistent with the Paris climate goals.

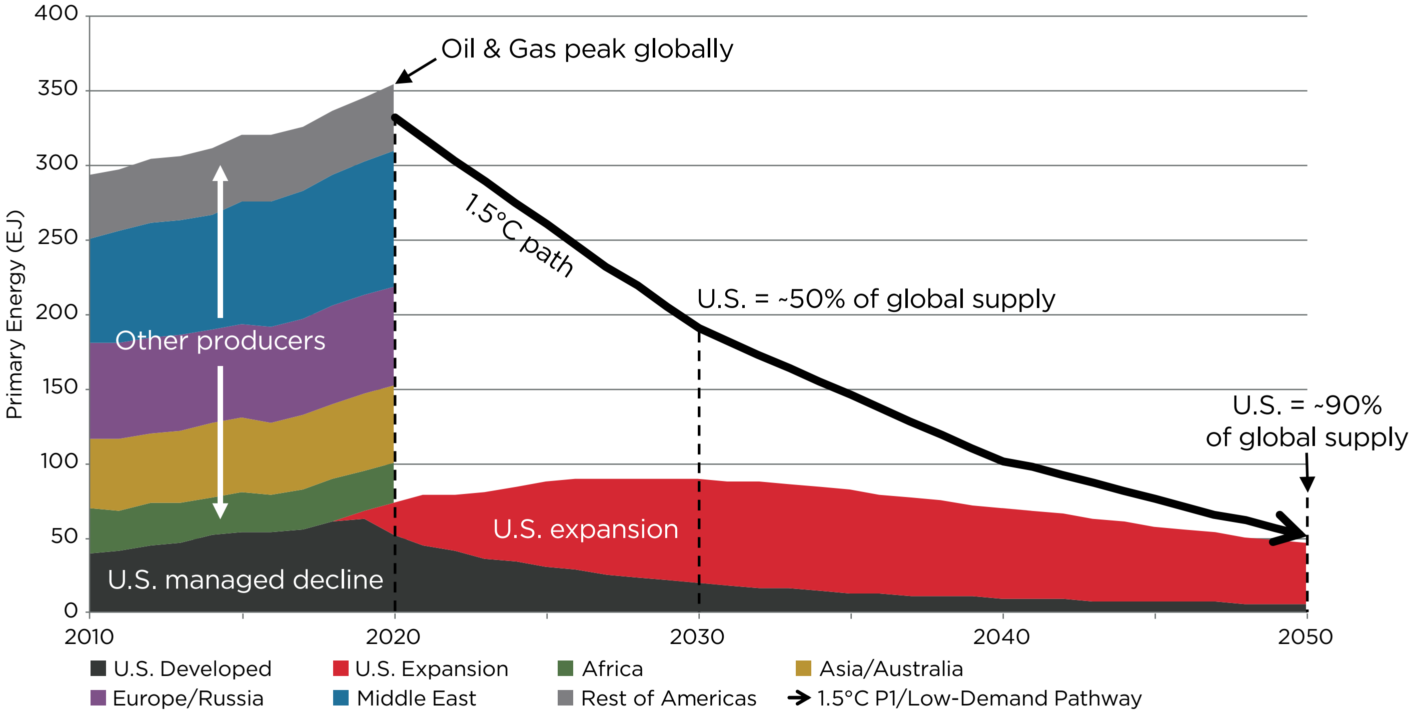
2. **Coal-to-Gas Switching Is Ineffective:** Climate goals require that the power sector be decarbonized by mid-century. This means that both coal and gas must be phased out from the power sector. Even as other sectors may continue some reliance on gas, overall gas use must be reduced.

3. **Gas and Renewables Compete:** Wind and solar are now cheaper than coal and gas in many regions. This means new gas capacity competes with new wind and solar rather than old coal.

4. **Gas Is Not Needed in the Clean Energy Transition:** Claims that more gas capacity is required for renewable energy development are exaggerated. Most grids are far from renewable energy penetration levels that would require back-up. Developing the flexible generation capacity to support high levels of renewable generation is more about power market design than adding or maintaining fossil fuel capacity.

5. **New Infrastructure Locks in Emissions:** Multibillion-dollar gas infrastructure built today is designed to operate for decades to come. Given the barriers to closing down infrastructure ahead of its expected economic lifespan, it is critical to stop building new infrastructure, the full lifetime emissions of which will not fit within Paris-aligned carbon budgets.

Figure 7: Global Oil and Gas Use in a 1.5°C Low-Demand Pathway, Compared to Projected U.S. Oil and Gas Production, 2010 to 2050



Sources: Oil Change International analysis based on data from Rystad Energy (November 2018) and IPCC/IAMC 1.5°C Scenario Explorer and Data hosted by IIASA[87]

IMPEDING A GLOBAL MANAGED DECLINE

In Figure 7, we compare the potential wind-up of U.S. oil and gas extraction to the steady global wind-down of oil and gas modeled in the 1.5°C-aligned IPCC pathway introduced in Figure 3b. Under this pathway, U.S. oil and gas production is set to take up an increasingly disproportionate share of the total global allowance for oil and gas. By 2030, U.S. production would consume nearly half of the global oil and gas budget. By 2050, U.S. supply would exhaust nearly 90 percent of the global budget.

Managing the decline of oil and gas within climate limits will require action from all of the world's major producers. However, in the scenario above, other countries could find it nearly impossible to wind down their production quickly enough to compensate for the growth in U.S. production. The United States would be pushing the burden of phasing out oil and gas onto other countries, forcing them into a potentially impossible choice: shut down their production at a pace that could cause domestic economic or social chaos, or allow the United States to push the world over the brink of climate chaos. If other countries are not able or willing to compensate for U.S. 'energy dominance,' U.S. communities would pay the price in terms of climate devastation and economic chaos.

As we discuss in Section IV, the scenario in Figure 7 would be deeply inequitable and, as such, increase the odds of global failure in meeting the Paris goals. In an equitable wind-down of the fossil fuel industry, wealthy producers such as the United States would be leading in phasing out fossil fuel production and consumption, not leading in expanding them.

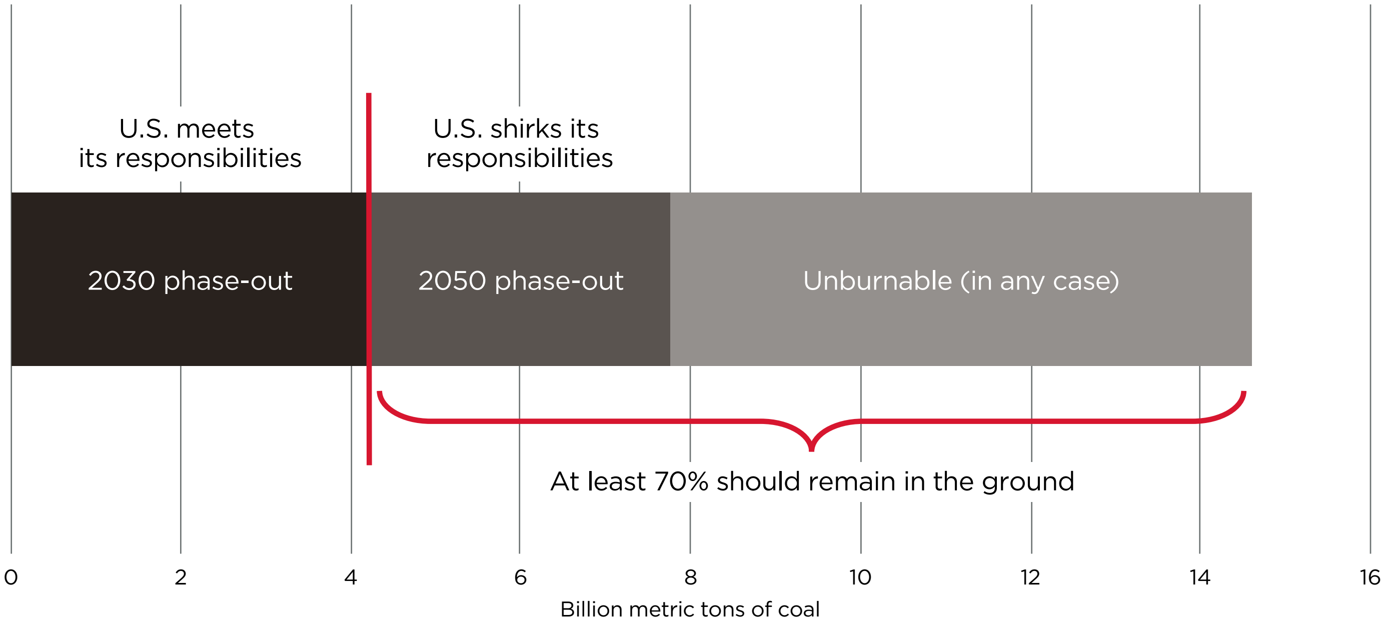
TOWARDS A FASTER U.S. COAL PHASE-OUT

In this section, we have focused first on U.S. oil and gas production because of the dramatic pace at which it is moving in the wrong direction. But U.S. policies towards coal production also bear great significance for the climate: The United States is still the world's third-largest coal producer, behind China and India.[88] The rates of global oil and gas decline represented in Figure 7 depend on an even faster global phase-out of coal.

In the United States, coal production and use are already in decline. Production peaked in 2008 and has fallen by one-third over the past decade, driven by declining power demand and competition from gas and renewable energy. It is now cheaper on average for U.S. utilities to build new wind and solar projects than to operate *existing* coal plants.[89] While most coal mined in the U.S. is burned domestically for electricity, U.S. coal exports have increased year-to-year since 2016. However, a significant ramp-up of exports would require building more export infrastructure, which communities on the U.S. West Coast have successfully resisted over the past decade.[90]

Due to these dynamics, the decline of the U.S. coal sector is likely to continue, regardless of the Trump administration's attempts to reverse it. However, leadership is needed to ensure this decline is fast enough and fair – meaning it aligns with climate goals and provides a just transition for mining communities.

Figure 8: U.S. Developed Coal Reserves, Compared to Cumulative U.S. Production under 2030 and 2050 Coal Phase-out Scenarios



Sources: Oil Change International analysis[r] based on data from EIA[96] and IPCC[97]

Existing Mines Have Too Much Already

Major new mines are no longer being developed in the United States. But mining companies continue to seek new or expanded leases on federal and state lands, as well as new permits, in order to expand or maintain the production of existing mines.[91] Around 40 percent of all U.S. coal production comes from federally leased land, compared to roughly 20 percent of U.S. oil and gas production.[92]

If federal and state policies towards coal mining were aligned with climate goals, new leases and permits would no longer be issued. Figure 8 shows that existing U.S. mines already contain far more coal than the United States can extract under a coal phase-out timeline aligned with the Paris goals.

According to the U.S. Energy Information Administration, currently producing U.S. coal mines contained nearly 15 billion metric tons of recoverable coal at the start of 2018.[93] If the United States were to phase out coal mining by 2050, in line with the global rate of coal decline from the IPCC P1 pathway (Figure 3b), then only half of those developed reserves would be minable.

However, analyses based on both economic efficiency and equity show that wealthier countries like the United States should phase out coal much faster than the global average to meet their responsibilities under the Paris goals.[94] The Powering Past Coal Alliance, which includes 28 national governments, is calling for countries within the Organization for Economic Cooperation and Development and European Union to phase out coal in their power sectors by 2030 at the latest.[95] If U.S. coal mining is to be phased out by 2030, declining on a straight line from 2017 production levels, more than 70 percent of coal reserves in existing mines would remain in the ground.

Ceasing New Leasing Is a Logical Next Step

At the federal level, the Obama administration took a step in the right direction in 2016 by putting a moratorium on new coal leases on federal lands and ordering a comprehensive review of the impacts of the federal coal program, including climate impacts. The Trump administration revoked the moratorium and ditched the associated policy review a year later.[98,99] However, across several recent court rulings, federal judges have ordered the Department of Interior to more thoroughly assess the climate pollution impact of its leasing policies.[100] For example, in 2017, the U.S. Court of Appeals for the 10th Circuit found that the Bureau of Land Management was “irrational” in finding that four massive new coal leases in the Powder River Basin, which unlocked 2 billion tons of new coal reserves, would have no effect on the climate. The court chastised the agency’s review for ignoring “basic supply and demand principles.”[101] The court agreed with environmental plaintiffs that keeping large amounts of coal in the ground would have an effect in reducing coal consumption, and that the climate benefits of not leasing the coal should have been factored into the agency’s decision.

Federal and state permitting officials should heed recent court rulings and the clear science and immediately cease new leases and permits that expand existing mining operations. If U.S. policy towards coal mining were aligned with climate safety, it would focus on phasing out mining by 2030 or sooner. Managing such a rapid transition will not be easy, particularly for the workers and communities on its front lines, but it is necessary. By ignoring or denying this need, and pursuing policies to slow the decline of mining, policymakers squander time and resources that could be used to plan for an equitable and orderly transition.

r We apply different decline assumptions to model a 2030 versus 2050 phase-out. For 2030, we assume a straight-line decline from 2017 production levels to zero. For 2050, we apply the global rates of coal decline given in the IPCC’s P1/low-demand model pathway. As shown in Figure 3b, this pathway also assumes a fast decline to 2030, such that 78 percent of global coal use is phased out relative to 2010 levels. Due to their cost-optimizing logic, the vast majority of model scenarios for keeping temperature rise within range of 1.5°C include a rapid coal decline between now and 2030. This is why the additional quantity of reserves mined under the 2050 scenario is less than double the 2030 estimate despite the phase-out taking more than twice as long.

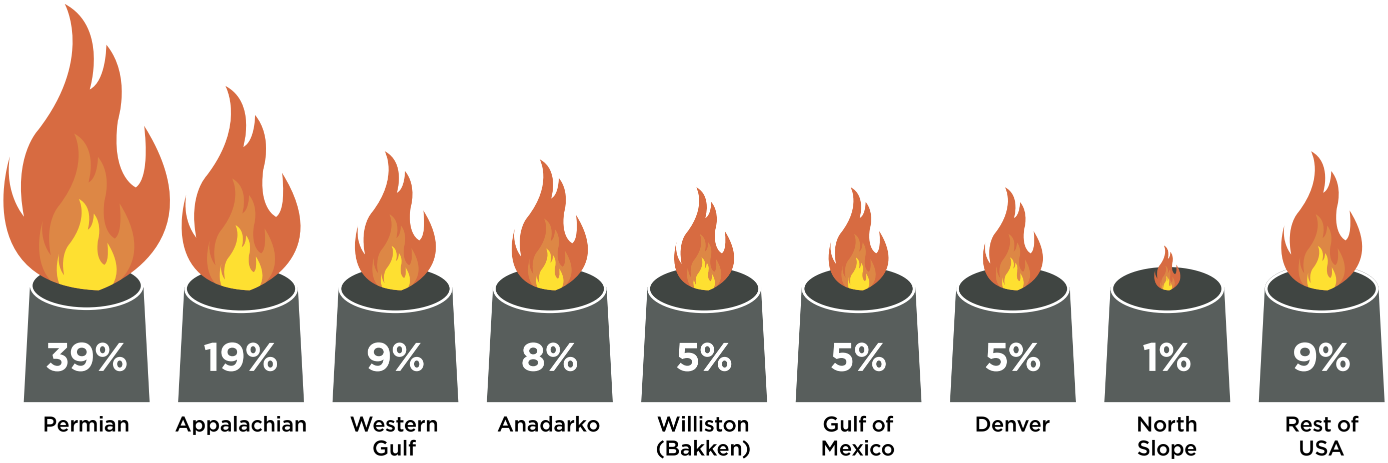
A haul truck transports coal at the North Antelope Rochelle opencut coal mine in Campbell County, Wyoming. Peabody Energy. (CC BY 3.0)

III. MAPPING U.S. OIL AND GAS EXPANSION THREATS

In this section, we look at major basins that could be the most significant sites for oil and gas industry expansion in the United States. The Permian and Appalachian basins hold the largest projected volumes of undeveloped oil and gas resources. Further development in these two basins could cause nearly 60 percent of CO_2 emissions enabled by U.S. oil and gas expansion from 2018 through 2050 (Figure 9). We briefly describe these basins and estimate the climate threat posed by their further exploitation, based on the methodology described in Box 4.

Staging area in Ohio for construction of the Rover gas pipeline. Ted Auch. May 3, 2017. Provided by FracTracker Alliance, fractracker.org/photos.

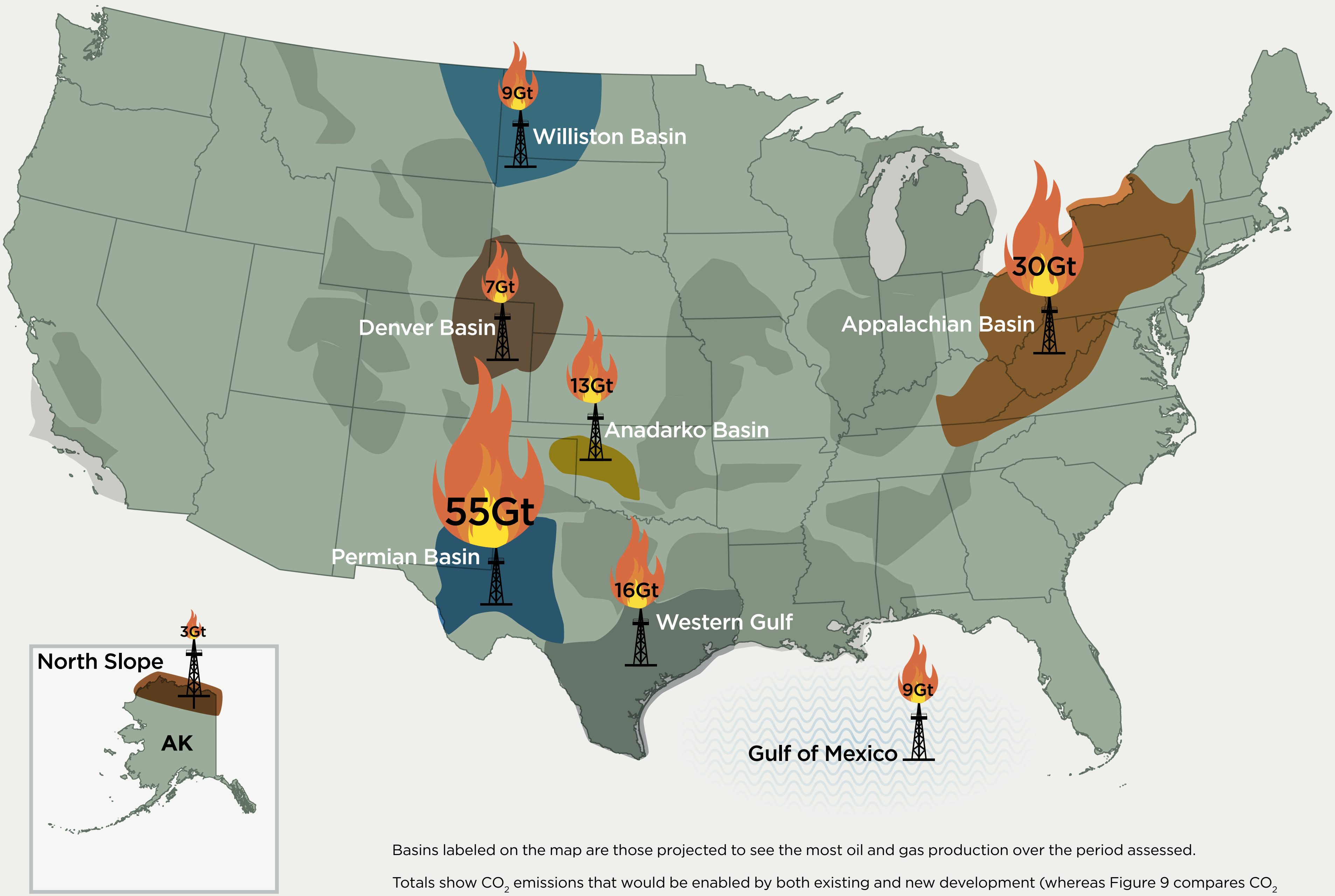
Figure 9: Sources of CO_2 Emissions from New Oil and Gas Development, by Key U.S. Basins, 2018-2050



Source: Oil Change International calculation using data from Rystad Energy (October 2018) and IPCC

Map 1: Major U.S. Oil & Gas Basins Showing CO_2 Emissions from Projected Total Production, 2018-2050

Gt = Billion metric tons of CO_2



Basins labeled on the map are those projected to see the most oil and gas production over the period assessed.

Totals show CO_2 emissions that would be enabled by both existing and new development (whereas Figure 9 compares CO_2 emissions from new development only.)

Shaded areas in the Lower 48 states show the less productive basins in the Rest of USA. Total emissions for Rest of USA = 20 Gt.

Source: Oil Change International calculation using data from Rystad Energy (October 2018) and IPCC

PERMIAN BASIN

The Permian Basin is America's most prolific oil basin. Located in northwestern Texas and the southeast corner of New Mexico, it is primarily drilled for oil through hydraulic fracturing or 'fracking,' but the same wells produce a lot of associated gas and natural gas liquids.

The Permian Basin holds the greatest potential for new oil and gas development in the United States and in the world.[s] The basin could be the source of nearly 40 percent of the emissions enabled by production of currently undeveloped oil and gas in the United States between now and 2050.

Emissions from burning the oil and gas in core shale and discovered conventional Permian reserves alone would amount to over 29 billion tons of CO_2 (Figure 10). The emissions from all currently developed and undeveloped oil and gas that could be produced and burned by 2050 could amount to close to 55 billion tons of CO_2. This is close to 10 percent of the total global carbon budget for a 50 percent chance of keeping warming within 1.5°C.

Liquids production, which includes crude oil, natural gas liquids, and condensate,[t] is projected to grow to around 11.8 million barrels per day (bpd) by the late 2020s, from 4.6 million bpd in 2018. At its projected peak year – 2029 – the Permian Basin is expected to be producing more liquids than Russia, or any other major oil producing country except for Saudi Arabia (Figure 11). Gas production is projected to reach over 19 billion cf/d by the same time, up from 8 billion cf/d today.

Companies

More than 100 companies have stakes in Permian oil and gas production. Table 1 lists the top ten companies. These ten companies could be responsible for around 55 percent of all the oil and gas produced in the basin between 2018 and 2050.

Potential Limits to Expansion

The production growth projected for the Permian Basin can only happen with the help of new pipeline and export terminal infrastructure. The availability of sand and water for fracking also poses challenges to the growth trajectory.[102]

An aerial view of frac sand mining in Wisconsin. Use of sand for fracking in the Permian Basin could rise by 200 percent by the early 2020s. Ted Auch, with aerial support from LightHawk. Oct 16, 2013. Provided by FracTracker Alliance, fractracker.org/photos.

Pipelines and Export Terminals

Three major oil pipeline expansions are underway today and a new NGL pipeline is also under construction. Five more major oil pipelines are planned as are expansions of existing networks. Many of these pipelines will link to new oil export capacity planned primarily in the Corpus Christi and Houston areas.

Additionally, one new gas pipeline is currently under construction and up to six more are planned. These would primarily serve planned and under-construction liquefied natural gas (LNG) export terminals along the Gulf Coast.

Sand and Water

Around 90 million tons of sand for fracking could be required annually in the Permian Basin by the early 2020s, up from 30 million tons in 2017. Dozens of new sand mines are opening in Texas, with production expected to more than double to 50 million tons per year in the next couple of years.[103]

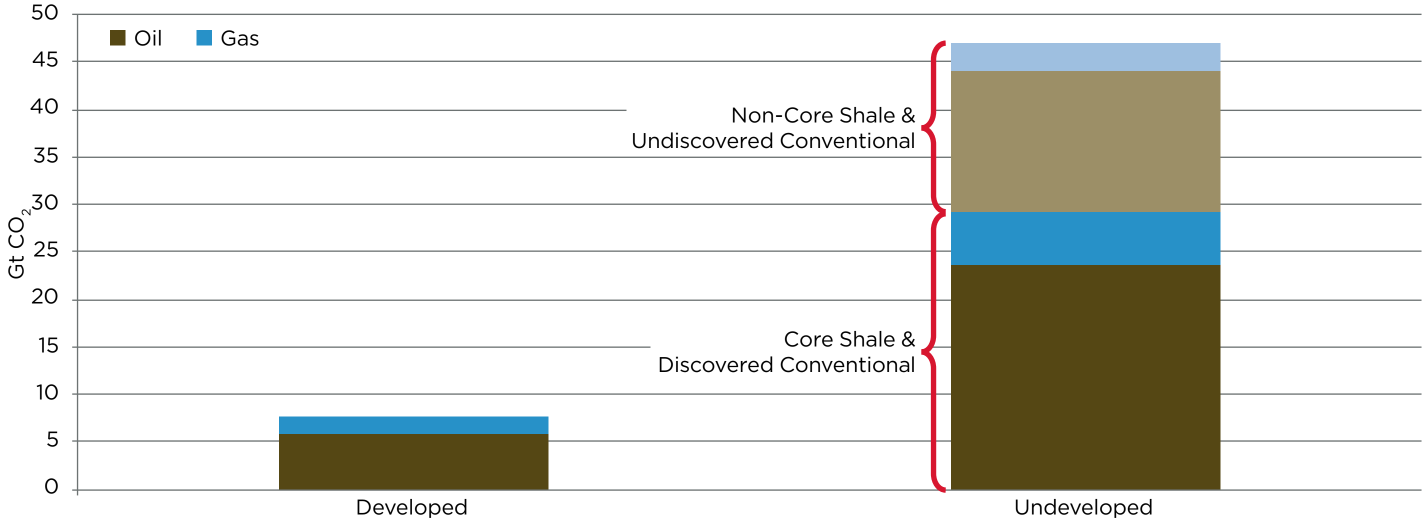
A study conducted in 2017 by researchers at Duke University found that the water intensity of fracked wells in the Permian increased 770 percent from 2011 to 2016, more than in any other basin in the United States. Water use per well in the Permian has grown from an average of 1.3 million gallons in 2011 to over 11 million gallons in 2016. While oil and gas production per well has also increased in this period, the ratio of water intensity to energy produced has increased 125 percent.[104]

Bringing the Permian Basin in line with climate and environmental limits will require a major realignment of political will within Texas, New Mexico, and the United States. In 2018, New Mexico elected a new state lands commissioner, Stephanie Garcia Richard, whose opponent received funding from oil companies including Chevron. Garcia Richard, who pledged to make "protecting our environment the priority," will have authority over oil and gas drilling decisions in state lands that overlap the Permian Basin in New Mexico.[105]

s Counting undeveloped reserves that are projected to be produced between 2018 and 2050.

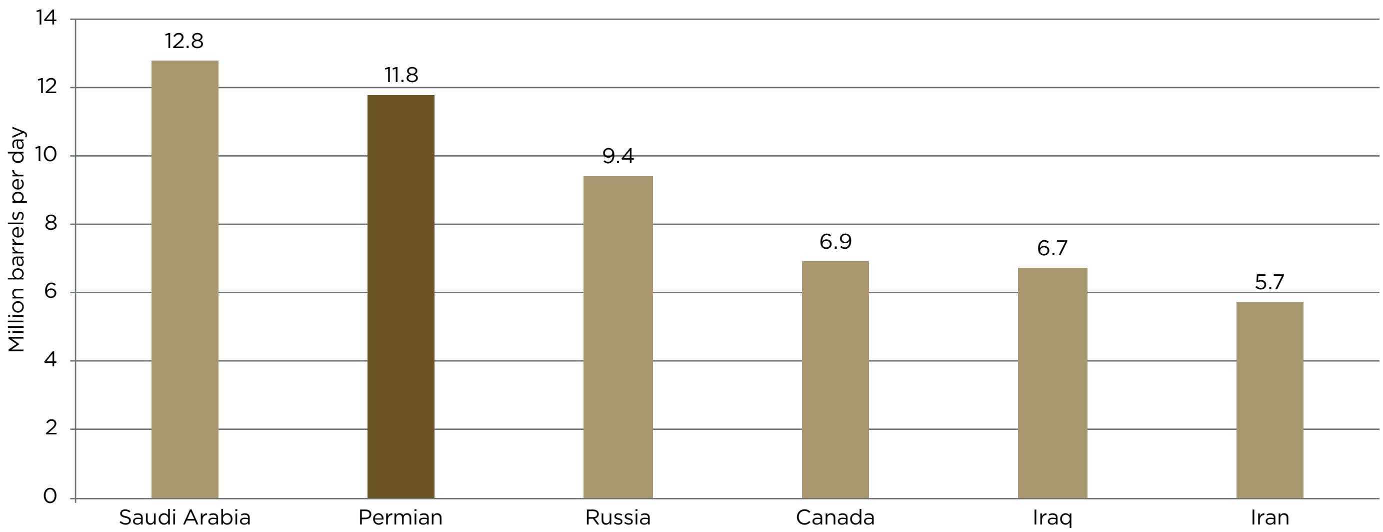
t Throughout this report, references to oil production volumes include all three liquids (crude oil, NGLs, and condensate), as is customary in energy reporting. We use the term "liquids" in this section given NGLs represent a significant proportion, nearly 30 percent, of Permian and Appalachian Basin liquids production projected over this time period.

Figure 10: Projected CO_2 Emissions from Developed and Undeveloped Oil & Gas Produced in the Permian Basin, 2018-2050



Source: Oil Change International calculation using data from Rystad Energy (October 2018) and IPCC

Figure 11: Permian Liquids Production in Projected Peak Year (2029) Compared to Major Oil Producing Countries



Source: Rystad Energy (October 2018)

Table 1: Top Ten Oil & Gas Producers in the Permian Basin

Company	Estimated Permian Oil & Gas Production 2018-2050 (MBOE)
Chevron	9,650
Pioneer Natural Resources	9,024
EOG Resources	7,377
Concho Resources	7,238
ExxonMobil	7,134
Royal Dutch Shell	4,821
Devon Energy	4,390
Anadarko	4,363
Occidental	4,282
Diamondback Energy	4,099
Total	62,378

Source: Rystad Energy (October 2018)

A fracking rig operating next to the Ohio River in Marshall County, WV. Ted Auch, with aerial support from SouthWings and pilot Dave Warner. Jan 2018. Provided by FracTracker Alliance, fractracker.org/photos.

APPALACHIAN BASIN

The Appalachian Basin is America's most prolific fossil gas basin. Production is primarily focused in Pennsylvania, West Virginia, and Ohio. State bans on fracking implemented in New York and Maryland in 2014 and 2017 respectively have prevented the further proliferation of drilling.

The Appalachian Basin is dominated by the Marcellus and Utica shale plays. The Marcellus is the biggest, located primarily in southwestern and northeastern Pennsylvania as well as in northwestern West Virginia and eastern Ohio. The Utica lies below the Marcellus in those three states. A small amount of conventional (non-fracked) production occurs across the basin today, but there is almost no expansion potential for conventional production. Some 60 percent of gas production in the basin is projected to come from Pennsylvania.

As Figures 12 and 13 illustrate, Appalachian Basin production has grown rapidly over the past decade, and this rapid growth is set to continue.

Gas production in the basin has grown aggressively since 2010, reaching nearly 28 billion cf/d in 2018, up from just 3 billion cf/d in 2010. In the absence of state or federal action to constrain expansion, gas producers are projected to continue this aggressive rate of growth for most of the coming decade, reaching over 40 billion cf/d by 2025 and maintaining that level into the mid-2030s (Figure 13).

Liquids produced in the Appalachian Basin are primarily natural gas liquids. Production could grow from around 800 thousand bpd today to around 1.3 million bpd at its peak. NGLs are primarily processed into petrochemical feedstocks. Several new processing plants are planned in western Pennsylvania and the Ohio Valley. This is triggering a boom in plastics production at precisely the time when plastic pollution is being recognized as a global crisis and solutions are being sought to reduce plastic consumption and waste.[106]

Companies

More than 75 companies have stakes in Appalachian oil and gas production. Table 2 lists the top ten. These ten companies could be responsible for around 68 percent of all the oil and gas (mostly gas) produced in the basin between 2018 and 2050.

Potential Limits to Expansion

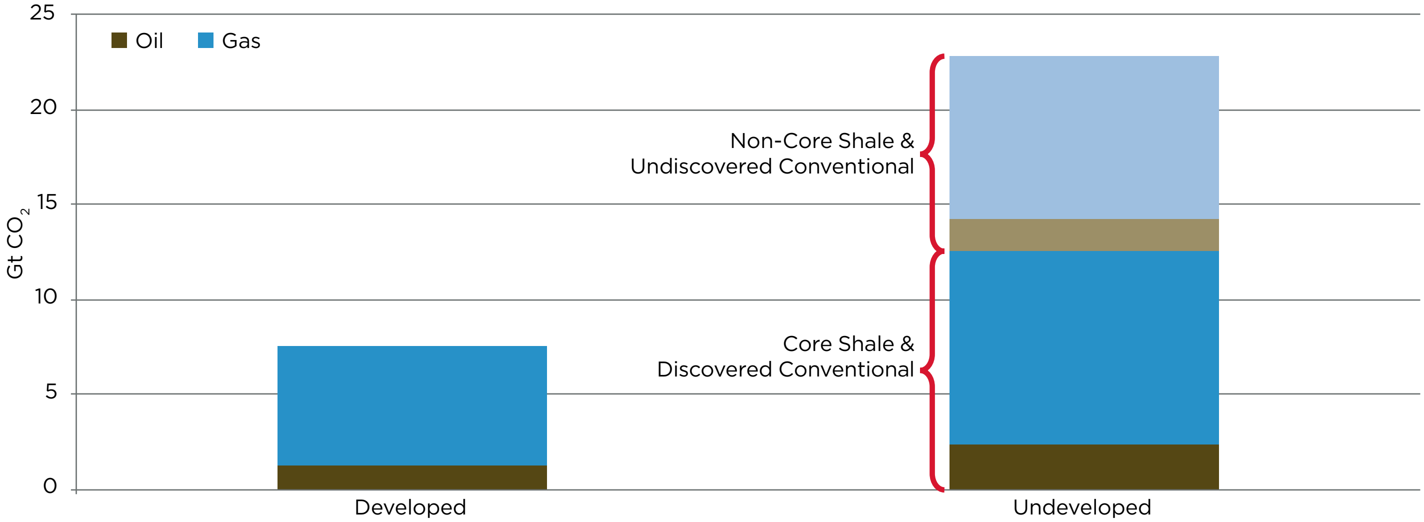
Gas companies have relied on a massive buildout of pipeline capacity to enable production growth in the Appalachian Basin. Over a dozen major projects have been completed recently and several are currently under construction. Many of these projects connect to pipeline networks feeding LNG export terminals on both the East and Gulf Coasts.

The construction of the Atlantic Coast and Mountain Valley pipelines through West Virginia, Virginia, and North Carolina has been slowed by legal challenges on behalf of impacted communities and environmental violations by the pipeline builders themselves.[107]

A lack of pipeline capacity could constrain production growth in northeastern Pennsylvania, as the state of New York has denied permits for projects such as the Constitution Pipeline.[108] Permit delays in New Jersey have also held up the PennEast Pipeline.[109]

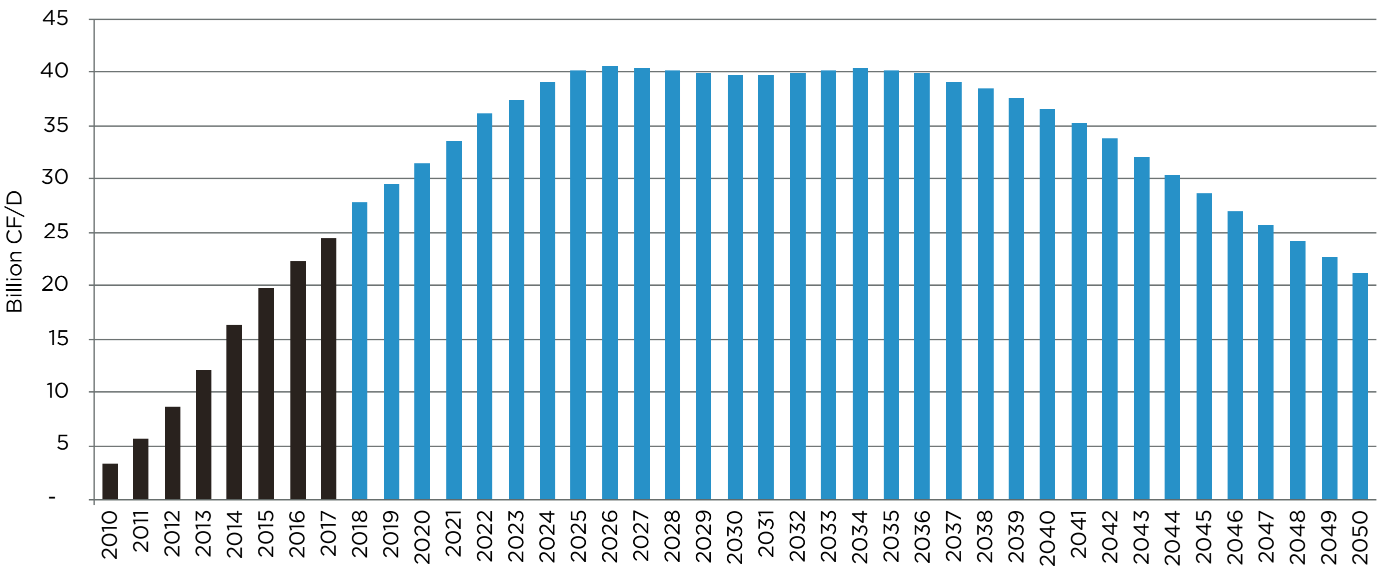
While fracking bans in New York and Maryland have placed some limits on production, the impacts of aggressive production growth and pipeline construction are being felt across the region through air and water pollution, industrialization of rural communities, and related health effects.

Figure 12: Projected CO_2 Emissions from Developed and Undeveloped Oil & Gas Produced in the Appalachian Basin, 2018-2050



Source: Oil Change International calculation using data from Rystad Energy (October 2018) and IPCC

Figure 13: Historic and Projected Gas Production in the Appalachian Basin



Source: Rystad Energy (October 2018)

Table 2: Top Ten Oil & Gas Producers in the Appalachian Basin

Company	Estimated Appalachian Oil & Gas Production 2018-2050 (MBOE)
EQT Corporation	8,916
Cabot Oil and Gas	6,297
Southwestern Energy	6,126
Ascent Resources, LLC	6,123
National Fuel Gas	5,586
Gulfport Energy	3,432
Range Resources	3,381
CNX Resources Corporation	3,014
Royal Dutch Shell	2,979
Chesapeake	2,778
Total	48,632

Source: Rystad Energy (October 2018)

OTHER KEY BASINS

Significant expansion potential also exists in basins primarily located in North Dakota, areas of Texas outside of the Permian Basin, Louisiana, Oklahoma, the Gulf of Mexico, and the Rocky Mountain states of Colorado and Wyoming.

Western Gulf Onshore

This basin encompasses the Eagle Ford shale play in southwest Texas, as well as significant ongoing production from legacy conventional oil and gas wells along the Gulf Coast in Texas and Louisiana.

The Eagle Ford holds the majority of undeveloped reserves in the basin, nearly 22 billion BOE of oil and gas. Over 50 percent of all the undeveloped reserves in the basin are core shale reserves. It is primarily a liquids basin with significant quantities of associated gas. Over 40 percent of the liquids are condensate or NGLs. Burning all the currently undeveloped oil and gas in the basin would produce over 10 billion tons of CO_2.

The top five companies operating in the Western Gulf Basin are: EOG Resources, ConocoPhillips, Magnolia Oil & Gas, BP, and Lewis Energy Group.

Anadarko Basin

The Anadarko Basin contains several shale plays and some legacy conventional oil and gas production. It is primarily located in Oklahoma with some activity in Texas and Kansas and a very small amount in Colorado. The largest undeveloped reserves are in the Woodford and Meramec shale plays, also known as the SCOOP-STACK shale plays, in Oklahoma.

There are nearly 22 billion BOE of undeveloped oil and gas in the basin. Over 55 percent of this is core shale reserves. The undeveloped reserves are mostly liquids but with substantial associated gas. About 60 percent of the liquids are condensate and NGLs. Burning all the currently undeveloped oil and gas would produce over 9 billion tons of CO_2.

Flaring from oil and gas drilling in the Bakken Formation in North Dakota. Nick Lund. May 28, 2014. Provided by FracTracker Alliance, fractracker.org/photos.

The top five companies operating in the Anadarko Basin are: Devon Energy, Climarex Energy, Continental Resources, Newfield Exploration, and Gulfport Energy.

Williston Basin (Bakken)

The Williston Basin primarily contains the Bakken-Three Forks shale play. It is located mostly in North Dakota with some activity in eastern Montana and South Dakota.

There are nearly 15 billion BOE of undeveloped oil and gas in the basin. About 55 percent of this is core shale reserves. It is primarily an oil play with some associated gas and NGLs. Burning all the currently undeveloped oil and gas would produce over 6 billion tons of CO_2.

The top five companies operating in the Williston Basin are: Continental Resources, Hess, Whiting Petroleum, Marathon Oil, and EOG Resources.

Gulf of Mexico

The Gulf of Mexico is the primary offshore oil and gas production zone in the United States, including shallow, deep, and ultra-deep-water basins. Most of the projected growth in the region is expected to come from deep water drilling. All the area is in federal waters of the outer continental shelf. Oil is more prolific than gas in these basins.

There are just over 13 billion BOE of undeveloped conventional oil and gas in the Gulf of Mexico. Forty-five percent of this is discovered while the rest is modeled to be discovered following lease sales scheduled by the federal government. Burning all the currently undeveloped oil and gas would produce nearly 6 billion tons of CO_2.

President Trump ordered a new schedule of annual lease sales in the Gulf of Mexico and rescinded rules for blowout prevention, which the Obama administration had developed in response to the Deepwater Horizon disaster.[110] This may accelerate exploration and development of currently undiscovered reserves in the coming years. The same executive order aims to open the Outer Continental Shelf in the Atlantic and Arctic oceans to drilling.

The top five companies operating in the Gulf of Mexico are: Shell, Chevron, BP, Equinor, and Anadarko.

The Denver Basin

The Denver Basin is primarily located in Colorado, with some activity in Wyoming and a small amount in Nebraska. It is dominated by the Niobrara shale play, particularly in the Wattenberg and Denver-Julesburg sub-basins in northeastern Colorado.

There are nearly 14 billion BOE of undeveloped oil and gas in the basin. Over 60 percent of this is core shale reserves. It is primarily an oil play with substantial associated gas and NGLs. Burning all the currently undeveloped oil and gas would produce nearly 6 billion tons of CO_2.

The top five companies operating in the Denver Basin are: Anadarko, Noble Energy, HighPoint Resources, Extraction Oil & Gas, and SRC Energy.

The North Slope of Alaska

The North Slope is Alaska's most active oil and gas basin. The basin includes the Arctic National Wildlife Refuge, which Congress recently opened to drilling (see Box 6). It is primarily an oil play with some associated gas. Much of the gas produced today is injected into oil wells to stimulate production, as there is little gas demand in the region and no access to gas markets outside of Alaska. A massive proposed gas pipeline and LNG terminal, the Alaska LNG Project, would change that if built, and would lead to new development of gas wells that are currently uneconomic.[111]

The North Slope's undeveloped conventional oil and gas is mostly undiscovered although planned lease sales in the next few years could trigger new development, as could the LNG project if it is built. Undeveloped oil and gas in the basin is estimated at over 4 billion BOE. Emissions would amount to nearly 2 billion tons of CO_2. This includes some of the estimates for the Arctic Refuge discussed in Box 6.

The top five companies operating in the North Slope of Alaska are: ConocoPhillips, ExxonMobil, BP, Caelus Energy, and Repsol.

Box 6: Exploiting the Arctic National Wildlife Refuge

The debate over oil and gas drilling in the Arctic National Wildlife Refuge has raged for over half-a-century.[112] The area is sacred to the Gwich'in people who rely on the natural resources of the coastal plain for their way of life.[113] With Arctic temperatures rising faster than anywhere on earth, their way of life is already threatened.[114] Opening the refuge to drilling can only compound those impacts.

Congress removed restrictions on drilling in the refuge as part of the tax bill passed in December 2017. As a result, the Department of Interior is preparing at least two lease sales before 2024.

While the U.S. Geological Survey (USGS) has estimated total mean technically recoverable oil reserves in the refuge to be around 7.7 billion barrels, the potential for production depends on many factors.[115] The Rystad Energy database models production in the refuge based on an expectation of lease sales starting in 2020[u] and continuing into the 2070s. As there is no history of drilling in the immediate area, Rystad's projections are based on USGS data and the history of production elsewhere in the North Slope Basin, as well as on the base case expectation of future oil prices. The lack of site-specific data means that production projections are more speculative than those in the rest of this report.

The database projects that production would not begin in the refuge until 2034. By 2050, the cutoff point for the analysis in this report, Rystad projects that nearly 600 million BOE of oil and gas, mostly oil, could be produced from leases in the refuge. Emissions from combusting that oil and gas would amount to over 200 million tons of CO_2.

These figures are preliminary and based on limited data, as described. The development timeline could accelerate or slow to a halt depending on economic and regulatory factors. Initiating extraction activity in the refuge opens the possibility of decades of extraction and potentially much more pollution than is described here because we cut off projections at 2050.

The opening of the Arctic Refuge to oil and gas exploration constitutes a fundamental denial of the path the United States must take to avoid climate catastrophe. Encouraging production growth in a remote and pristine environment from the mid-2030s and beyond stands in direct opposition to how U.S. leaders must respond to the growing climate crisis.

u Some reports indicate a lease sale could happen in 2019. The bill states that at least two sales should happen by 2024.

Oil rig operating next to a walk and bike way in the Signal Hill area of Los Angeles. Sarah Craig/Faces of Fracking. (CC BY-NC-ND 2.0)

Other U.S. Areas

Outside of these basins, expansion activity is dispersed in several smaller shale plays and some conventional oil and gas formations. Significant activity is ongoing outside of the basins discussed above in Louisiana, Oklahoma, and the Powder River Basin in Wyoming, among others. While California's status as a major oil producing state is fading, producers there continue to apply for new permits. Political leaders in California are coming under increasing pressure to stop new permitting and chart the state's transition off oil production to show the climate leadership they have pledged (see Box 7).

Around 26 billion BOE of undeveloped oil and gas is estimated to be in these basins. Burning all of it would lead to over 10 billion tons of CO_2.

Not included in these figures is the oil and gas that may lie in federal waters off the Atlantic coast and in the Chukchi and Beaufort seas in the Arctic. The Trump administration's April 2017 executive order called for new lease sales in these areas. Little is currently known about the quantities of oil and gas that may be viably produced in these areas, so we do not provide figures here. We do know, however, that opening these areas to exploration makes no sense from a climate perspective and is vehemently opposed by many state governments and citizens in coastal states and across the United States.

Box 7: How California Can Lead the Way Towards a Managed Decline

Political leaders in California have been particularly vocal in their commitment to the Paris goals. California has been among the leading U.S. states in growing renewable energy and strengthening fuel efficiency, most recently leading a coalition to defend vehicle efficiency standards from the Trump administration's rollbacks. Despite this, California remains a top U.S. oil producer and has no plan in place to manage its transition off oil and gas extraction, even in state-controlled lands and waters. California could set an example of urgently needed U.S. and global leadership by committing to phase out its fossil fuel production in line with climate limits.

A report released in May 2018 by Oil Change International and 14 environmental justice and climate groups proposes and analyzes three key steps California's leaders can take to chart a just transition off extraction:[116]

- **Cease issuing permits for new oil and gas extraction wells.** This would limit new oil and gas production in California, as required by the Paris goals, whereas business-as-usual permitting could enable extraction of an additional 560 million barrels of oil from 2019 to 2030.
- **Implement a statewide health and safety buffer zone in which existing wells are phased out as quickly as possible.** This would begin a proactive managed decline in a way that prioritizes the health of historically overburdened communities. Nearly 8,500 active oil and gas wells across California operate within 2,500 feet of homes, schools, and hospitals – a proximity linked to the greatest exposure to toxic air pollution.
- **Plan for and fund a just transition.** This must involve providing wage insurance, career training, and other support for people whose livelihoods are affected by the economic shift.

By establishing such policies, California would become the first significant oil producer to commit to phasing out extraction, a move that would put pressure on others to follow suit. These steps would spur significant reductions in carbon emissions, protect the health of local communities unfairly harmed by extraction now, and provide a predictable pathway around which to plan a just and equitable economic transition.

IV. THE U.S. SHOULD LEAD IN PHASING OUT FOSSIL FUELS

The data in previous sections underscore that managing the decline of U.S. fossil fuel production will be critical to global success in staying within climate limits. This is true not only because of the sheer tons of carbon that continued U.S. fossil fuel expansion could unlock, but also because of the way it could cripple efforts to forge an equitable fossil fuel phase-out.

In this section, we take a step back from detailed data analysis to discuss why the United States has a responsibility to become a world leader in phasing out fossil fuel use and production, and to lay out some policy principles that could guide that transition in an equitable way. Effective global leadership must include robust planning and investment in a just transition at home, so that people and communities whose livelihoods and local economies are entwined in the fossil fuel industry now reap the benefits of the necessary shift to renewable energy.

EQUITY IS AT THE CORE OF EFFECTIVE CLIMATE POLICY

The IPCC's report on 1.5°C of warming finds that:[117]

> Social justice and equity are core aspects of climate-resilient development pathways that aim to limit global warming to 1.5°C as they address challenges and inevitable trade-offs, widen opportunities, and ensure that options, visions, and values are deliberated, between and within countries and communities, without making the poor and disadvantaged worse off.

The report states that not only are social justice and equity desirable, they are essential: Most models "could not construct pathways characterized by lack of international cooperation, inequality and poverty" that were able to limit warming to 1.5°C.[118]

Equity must be a core consideration in managing the phase-out of fossil fuels – not only because it is morally right but also because it could be the difference between global success or failure in realizing the rapid cuts in emissions that are needed.

FOR GLOBAL EQUITY, LEAD IN PHASING OUT DEMAND AND SUPPLY

The Lofoten Declaration
Signed by more than 500 civil society organizations and leaders from 76 countries, the Lofoten Declaration affirms that, "[I]t is the urgent responsibility and moral obligation of wealthy fossil fuel producers to lead in putting an end to fossil fuel development," and that, "In particular, leadership must come from countries that are high-income, have benefitted from fossil fuel extraction, and that are historically responsible for significant emissions."[119] In addition to the United States, wealthy fossil fuel producers that should be heeding this call include Norway, Canada, Germany, Australia, and the UK.

It is a core principle of international climate policy that countries historically responsible for emitting the most climate pollution, and that have the most resources to invest in solutions, have the greatest responsibility to move first and fastest in reducing emissions. By this measure, the United States should be leading the world in deep emissions cuts: It is the world's biggest historical climate polluter and the world's largest economy.

How might we approach equity in phasing out the *supply* of fossil fuels as part of a comprehensive approach to reducing emissions? As seen in Section I, carbon budget limits leave no room for new fossil fuel development anywhere in the world. That means that the essential supply-side equity question is this: Which countries and regions should move first and fastest in phasing out *existing* extraction projects?

The following two principles offer a guide to answering this question:[v]

- **Transition first and fastest where it is least disruptive:** In particular, this would include countries that are relatively wealthy and least economically dependent on extraction. Such countries are best-positioned to invest in a robust transition plan for fossil-fuel-dependent workers and regions in a way that minimizes social and economic disruption. By contrast, poorer countries where people still lack basic human needs, where government revenues are highly dependent on extraction, and/or where a high proportion of jobs are tied to extraction face the steepest transition challenges.

v These principles are drawn from a forthcoming paper on supply-side climate equity by Greg Muttitt of Oil Change International and Sivan Kartha of the Stockholm Environment Institute. The paper will suggest a framework for approaching an equitable and just phase-out of fossil fuel extraction.

A large fire erupts at the Chevron Refinery in Richmond, California. At least 15,000 sought treatment at area hospitals. Stephen Schiller. (CC BY-NC 2.0)

This is not to discount the fact that many people in the United States and other wealthy nations also lack human needs due to domestic inequality. Rather, this points towards wealthier countries' greater capacity to shift resources towards an equitable transition, which will also provide an opportunity to address underlying social and economic inequities.

- **Respect human rights and safeguard local environment:** Extraction that violates human rights or Indigenous sovereignty, or that damages people's health or livelihoods – for example, by contaminating water used for drinking or agriculture – should be prioritized for rapid closure. Whether in coastal Louisiana or Los Angeles, the tar sands of Alberta, the Amazon forest of Ecuador, or the Niger Delta, fossil fuel projects that violate international norms of human rights or labor and environmental standards should never have been permitted in the first place and should be phased out first.

By the first criterion, the United States should be a global first mover in phasing out extraction, just as it must lead in cutting end-of-pipe emissions. In addition to being the largest economy in the world, the U.S. economy is diverse. All mining, including oil and gas extraction, accounted for only 1.4 percent of the country's gross domestic product (GDP) in 2017.[120] While phasing out the fossil fuel industry will be challenging for all workers on its frontlines, less than one half of one percent (0.3 percent) of the U.S. labor force is currently employed in fossil fuel extraction.[121] The United States has adequate resources to invest in a just transition – and guarantee a Green New Deal that provides good-paying jobs to former fossil fuel workers – if political leaders make it a priority. For example, eliminating federal and state fossil fuel subsidies could free up $20 billion each year to redirect towards transition support for workers and economic diversification.[122]

In an equitable global pathway towards climate stability, the United States should be phasing out oil, gas, and coal extraction at a pace significantly *faster* than the global rates of decline given in the model 1.5°C pathway discussed in Section II. **For example, the United States moving first and fastest would imply it phasing out coal mining by 2030 or sooner and winding down oil and gas extraction well before 2050.**

The second criterion suggests a way to prioritize where fossil fuel projects should be phased out first within the United States. For example, extraction should cease on the ancestral tribal lands of Indigenous nations, where such operations violate their sovereignty. Mountaintop removal coal mining linked to the destruction of waterways and severe health impacts in Appalachia should be prioritized for phase-out, as should neighborhood drilling happening within several hundred feet of homes and schools in primarily low-income areas and communities of color in Los Angeles and other parts of California. This is far from an exhaustive list of areas where fossil fuel production is violating people's health and human rights, but rather points towards ways in which the criteria discussed here could be applied.

FOR DOMESTIC EQUITY, INVEST IN AN AMBITIOUS JUST TRANSITION

The pace and ambition of investment in building up the clean energy economy can and should match the pace and ambition of phasing out the fossil fuel economy. In the words of the ITUC, "Transformation is not only about phasing out polluting sectors. It is about creating new clean industries, new jobs, new investment and the opportunity for a more equal and just economy."[123]

In contrast to the guaranteed humanitarian and economic disaster of runaway climate change, this is the only path that affords a livable future.[124] For example, the Fourth National Climate Assessment projects that, without adequate action, warming could cost U.S. workers $155 billion in lost wages and cause tens of thousands of premature deaths annually by the end of this century.[125]

With deep investment and political commitment – including holding new industries accountable to providing good-paying, unionized jobs – the clean energy transformation has the potential to deliver a brighter future. A 2017 study by Heidi Garrett-Peltier at the Political Economy Research Institute found that every $1 million shifted from oil, gas, or coal production towards clean energy will create a net increase of five jobs in the short-to-medium term.[126] A 2015 study commissioned by the Labor Network for Sustainability found that U.S. policies to reduce greenhouse gas emissions substantially by 2050 would lead to an average net gain of more than 550,000 jobs per year from 2016 to 2050 – in energy efficiency programs, renewable energy production, the manufacturing of electric cars, and more – while leading to net savings for U.S. families through lower electricity, transportation, and heating costs.[127]

This type of investment is overwhelmingly popular: Pew Research Center polling from 2018 found that close to 90 percent of U.S. adults want more solar panel and wind turbine farms.[128] A fall 2018 poll of U.S. voters indicated that two-thirds support guaranteeing a job "building energy-efficient infrastructure" to every unemployed U.S. worker.[129]

Markets alone will not drive this transformation at the speed required to meet climate goals or in a just and equitable way. Politicians must put policies in place that match the ambition required by science, that protect workers employed in the extraction economy now, and that target new economic opportunities towards communities where fossil fuel jobs are phased out. While the exact scope and terms of just transition policies should be negotiated with affected workers and communities and union representatives, and reflect their vision of a brighter future, we lay out broad elements of effective policies in the following section.

A Process of Social Dialogue

Economic and technological transition is nothing new, but the climate crisis requires that it occur at an unprecedented scale and pace. A rapid decline of U.S. fossil fuel production will affect thousands of workers, their families, and specific communities that currently depend on the industry for their livelihoods, and they need a seat at the table from the very beginning. The ITUC and case studies of transition experiences from around the world pinpoint early social dialogue between government policymakers, employers, workers, unions, and frontline communities and organizations as a core element of effective just transition planning.[130]

Given the pace of change that is required, federal, state, and local policymakers should waste no time in establishing inclusive planning bodies. Their mandate could include envisioning what a responsive just transition process can and should look like and mapping out the policies and resources required to support it. Both Scotland and Canada have established Just Transition Task Forces at the federal level to plan for the phase-out of those countries' coal industries.[131] At every level, such fora should learn from and lift up community-based efforts that are already leading the way towards equitable and resilient local clean energy economies.[132]

Guaranteed Protection for Workers

Many workers in the U.S. fossil fuel industry are familiar with the boom-and-bust cycle of extraction, dictated by shifting prices, technologies, and corporate profit margins. Coal mining jobs have long been in decline. Since 2011, 30,000 coal mining jobs have disappeared, with the sector employing around 50,000 workers as of 2018.[133] Between the end of 2014 and 2016, oil and gas drillers shed nearly 50,000 jobs in response to the crash in oil prices. As of 2018, 152,000 workers were employed directly in oil and gas extraction.[134] Just over 320,000 workers are additionally employed nationally in support activities for extraction.[135]

A managed and just decline of extraction must guarantee adequate social protection, including wage insurance, health benefits, and pensions, to support workers and their families as they transition to new sectors – not leave them behind. As Tony Mazzocchi of the Oil, Chemical, and Atomic Workers union (now part of the Steelworkers) put it in 1993, "Paying people to make the transition from one kind of economy – from one kind of job – to another is not welfare. Those who work with toxic materials on a daily basis … in order to provide the world with the energy and the materials it needs deserve a helping hand to make a new start in life."[136]

A recent Washington State ballot initiative that would have established a carbon tax and just transition program provides a model for what social protection policies could look like. While defeated in the wake of record-high spending by oil companies that opposed it, the initiative had broad support among both unions and environmental justice communities. It proposed providing full wage replacement, health benefits, and pension contributions for all fossil fuel workers within five years of retirement, and for younger workers for each year of service up to five years. It also would have provided wage insurance for up to five years for workers with more than five years of service, which would cover any shortfall in pay between their previous and new jobs.[137]

Job Training and Re-employment

In recent years, solar and wind have been among the fastest growing U.S. industries.[138] Wind power jobs have more than doubled since 2013, reaching 105,000 in 2017.[139] The solar industry employed just over 250,000 Americans in 2017, a growth of 75 percent since 2013 despite a slight downturn last year. At only 2 percent of overall U.S. energy generation, solar employs twice as many workers as the coal industry and nearly as many as the gas industry.[140] An additional 2.2 million Americans are employed in jobs related to energy efficiency.[141]

A just transition must ensure that fossil fuel workers can access jobs in these growing sectors – and that new jobs provide equivalent or better pay and benefits.

To help access new sectors, support would include retraining for workers who may need new skills, as well as job placement assistance for those with skills that are easily transferable to clean energy and infrastructure jobs. In many regions, such programs can build upon existing union apprenticeship programs and community college programs that have already begun serving this need. Jeremy Brecher of the Labor Network for Sustainability has proposed that transition assistance should cover up to four years of education or training, including tuition and living expenses.[142] Washington State's transition proposal would have covered up to two years of retraining costs, including community or technical college tuition.[143]

New jobs are not necessarily a win for workers if they do not provide family-sustaining wages, good benefits, job security, and a right to unionize. Many new clean energy jobs are not yet unionized and, depending on the type of job, may not yet provide the same level of wages or benefits as jobs being lost in fossil fuel sectors. Wage insurance is only a stop-gap answer. It is critical that climate justice and environmental advocates show solidarity with the labor movement in holding emerging clean energy industries accountable to providing 'high-road' jobs. If advocates wait until a sector is established to address job quality, then lower wages and working standards could get locked in, undermining the promise of a just transition.

Targeted Community Investments

The economic burden of transitioning away from the fossil fuel economy will be concentrated in communities where extraction and related industrial processes such as refining are currently centered. Just transition planning at the federal and state levels should ensure that investments in economic diversification target these regions. With coal mining, for example, this transition will disproportionately affect specific counties in states such as West Virginia, Wyoming, Kentucky, and Pennsylvania. With oil and gas extraction, the same holds for states such as Texas, Oklahoma, Pennsylvania, Louisiana, Colorado, North Dakota, and California.[144]

Some existing federal and state policies provide a blueprint to build on. The POWER+ Initiative, launched under the Obama administration, began coordinating federal investment in community-based education, economic development, and job training programs in regions hit hard by the declining economics of the coal industry.[145] A more robust federal transition policy could build on this template.

In New York State, lawmakers established a $30 million fund in 2016 to support communities facing power plant closures. The Huntley Coalition, a labor and environmental alliance formed in response to the anticipated closure of the Huntley

Community members installing a large solar array in Polk County, Nebraska, in the path of the Keystone XL pipeline. Jason Shald, 350.org. (CC BY-NC-SA 2.0)

coal-fired power plant in Tonawanda, NY, fought for the creation of the fund while also organizing their working class community to benefit from it. The funding provided money for their town, school district, and county to replace lost revenues from the plant closure for five years, protecting public education jobs and funding.[146]

It is important to recognize that many of the regions most encoiled in the fossil fuel economy at present have higher unemployment and greater poverty compared to regions with more diverse economies. Where the fossil fuel industry provides jobs and local revenue, it also leaves a legacy of pollution, with the related health and environmental costs borne disproportionately by low-income people, communities of color, and Indigenous communities. The transition to renewable energy provides an opportunity to address these historic wrongs and develop more equitable and resilient local economies.

Resources

It will require money to provide wage assistance, benefits, and job retraining for workers and to invest in communities on the front lines of the shift to a climate-safe economy. A recent study by the Political Economy Research Institute (PERI) estimated that a transition program for currently fossil fuel-dependent workers and communities, including compensation insurance, retraining support, relocation allowances, fully guaranteed pensions, and community transition support, could cost $600 million annually over 20 years.[147] This may be a modest estimate, given it assumes a high proportion of workers will age into retirement.

Politicians have numerous options for funding just transition initiatives if they make it a priority. For example, as noted previously in this report, ending subsidies to the fossil fuel industry would free up billions of dollars per year in federal and state budgets. An Oil Change International study of the path towards winding down oil extraction in California found that a modest ‘just transition fee’ on oil production could cover up to five years of wage replacement and four years of college tuition for all

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workers currently employed in oil and gas extraction in the state.[148] In Portland, Oregon, voters recently approved a ballot initiative to create a $30 million annual fund for clean energy infrastructure and jobs, targeted at underserved communities and funded by a small tax on the city’s wealthiest retail corporations.[149]

Even if transition costs run significantly higher than indicated by the PERI study, their potential price tag pales in comparison to the mounting costs of climate change in the United States.[150] For example, Hurricanes Harvey, Maria, and Irma caused $265 billion in total damage in 2017.[151] The annual cost of just transition policies estimated in the PERI study would equal less than one percent of the price tag for 2017 hurricane disasters alone.

TOWARDS A GREEN NEW DEAL

In the 2018 midterm elections, a diverse group of new U.S. House members was elected on climate platforms that included championing a Green New Deal and opposing new fossil fuel infrastructure projects. This emergence of new climate leadership on Capitol Hill, spurred on by youth-led grassroots organizing driven by the Sunrise Movement, has since led 45 Members of Congress (and counting) to support Congresswoman Alexandria Ocasio-Cortez’s proposal to establish a Select Committee for a Green New Deal, with the goal of developing a plan to decarbonize the U.S. economy within 10 years in a way that addresses entrenched economic, racial, and regional inequities.[152]

While the exact ingredients of a Green New Deal have yet to be defined, the basic premise is to pursue a mass mobilization of people and public resources, including a universal jobs guarantee and other social programs, to create a 100-percent renewable electricity grid and zero out U.S. emissions. Modeled in theory after President Roosevelt’s New Deal that used mass public investment to bring the United States out of the Great Depression, the vision of a Green New Deal is to mobilize rapid climate action with deep, large-scale investment that ensures shared prosperity.[153]

The growing momentum behind the Green New Deal concept suggests the potential of advancing climate goals and economic and social justice together. For the United States to meet its responsibility to become a world leader in phasing out fossil fuel use and extraction, it must also lead in large-scale investment in building a just and equitable clean energy future.

V. RECOMMENDATIONS: A CHECKLIST FOR CLIMATE LEADERSHIP

As the world's carbon budget rapidly dwindles, achieving the Paris goals will require that governments stop the expansion of fossil fuel production, starting now, and manage its decline over the next few decades. Climate leadership in this direction is arguably needed more urgently in the United States than anywhere else, as the U.S. oil and gas industry gears up to swing a giant wrecking ball through global climate goals.

If the United States is to start helping, rather than severely hindering, the world's chances at averting climate disaster, U.S. politicians at all levels must start flexing an underutilized muscle: their ability to say "no" to the fossil fuel industry, and to steer it towards an equitable and orderly phase-out. Comprehensive climate policy – whether at the Congressional, state, or other levels – must by definition include action to tackle the supply side of the problem, in addition to boosting renewable energy and cutting fossil fuel demand.

The good news is that opportunities for action are abundant. **Every decision around a new fossil fuel lease, permit, subsidy, or setback represents an opportunity to say "no" to new expansion and show leadership towards the Paris goals.**

CHECKLIST FOR U.S. CLIMATE LEADERSHIP

Climate leadership in the United States must include a commitment to:

- **End new leasing and permitting:** Ban new leases, licenses, or permits that enable new fossil fuel exploration or production, or new long-lived infrastructure such as pipelines, export terminals, or refineries – and reject existing proposals in the meantime. Given existing fossil fuel projects already push the world beyond safe climate limits, licensing their expansion is incompatible with climate leadership. At the federal level, ending new leasing of federal lands and waters for fossil fuel exploration or extraction would be a logical first step. Banning leases and permits for new fossil fuel exploration or production, as Maryland and New York have done for fracking, or for new fossil fuel infrastructure, as the city of Portland has done, would be the most comprehensive approach.

  Meanwhile, any new fossil fuel project typically requires a series of permits at the local, state, and federal levels, providing numerous levers for climate leaders to oppose and reject them. Climate leaders can also amend federal and state statutes that grant eminent domain to corporations seeking to build new fossil fuel infrastructure across private property and the sovereign lands of Tribal Nations, which cannot be considered in the public interest.

- **Plan for the phase-out of existing fossil fuel projects in a way that prioritizes environmental justice:** A significant portion of oil and gas fields and coal mines will need to be retired early in order to meet global climate goals. The ramp-down of existing fossil fuel projects in the United States should start in places where extraction disproportionately harms vulnerable communities and poses the greatest risks to human health (often one in the same). For example, this could mean working towards a faster phase-out of coal production by first ending the most destructive form of it: mountaintop removal mining. A policy proposal championed by environmental justice groups in Los Angeles provides another model for oil and gas: They are pushing city and state leaders to enact a 2,500-foot buffer zone around homes, schools, and hospitals in which no new wells could be permitted and existing wells would be phased out.[154]

- **End subsidies and other public finance for the fossil fuel industry:** Any policy that lowers the cost of fossil fuel production incentivizes more extraction. A study by the Stockholm Environment Institute found that nearly half of all new, yet-to-be-developed oil produced in the United States over the next several decades will depend on subsidies, given oil prices of $50/bbl.[155] The U.S. Congress moved in the wrong direction in 2018 by significantly expanding a tax break that will incentivize more production from enhanced oil recovery methods.[156] Federal and state subsidies to oil, gas, and coal companies are estimated to be around $20 billion annually.[157] This amounts to an irresponsible investment of public money in making the climate problem worse, fueling costly disasters from super-charged hurricanes to killer wildfires. Climate leadership must include a commitment to end these subsidies, redirecting funds toward solutions for a just transition to clean energy.

- **Champion a Green New Deal that ensures a rapid and just transition to 100% renewable energy:** The pace and ambition of investment in building up the clean energy economy can and should match the pace and ambition of phasing out the fossil fuel economy. For this transition to be just, it must guarantee support and good-paying jobs for former fossil fuel workers, invest in communities entwined in the fossil fuel economy now, and address longstanding inequities. An equitable clean energy transformation, via a Green New Deal or otherwise, must center the needs of low-income communities, Indigenous communities, and communities of color, which have long borne the brunt of fossil fuel pollution.

- **Reject the influence of fossil fuel industry money:** The money and influence of the oil, gas, and coal industries should have no place in U.S. politics. This would send a strong signal that the industry no longer has moral or political license to hold sway over U.S. climate policy.

LOCAL-TO-GLOBAL MOMENTUM IS GROWING

U.S. officials who embrace a comprehensive approach to climate action, and take steps to curb extraction, will bolster momentum in this direction both globally and locally.

Public opinion polling continues to show Americans across the country strongly prefer to meet our energy needs by investing in new renewable forms of energy over expanding fossil fuel production.[158] Communities across the country, including in traditionally conservative locales, have risen up to slow and stop fossil fuel projects from moving forward. Across the world, a growing list of jurisdictions is taking steps to align energy decisions with climate limits:

- Costa Rica and France have placed full bans on new oil exploration, while New Zealand and Belize have prohibited new offshore exploration, and Denmark has banned new onshore exploration.[159]

- Spain and Ireland, which recently became the first country to divest public funds from fossil fuels, are also considering proposals to ban new licenses for oil and gas extraction.[160]

- Across the United States, city councils, mayors, state legislatures, and governors have also begun to take steps away from fossil fuels, from banning new permits for fossil fuel infrastructure to rejecting pipelines to putting extraction near people's homes off limits.

U.S. leaders who recognize the stark science of climate change have a moral responsibility to steer U.S. policy in the only climate-safe direction, towards a managed and just transition off fossil fuel production. **One of the most powerful – and most underutilized – climate policy levers is also the simplest: stop digging for more fossil fuels.**

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JANUARY 2019

SEPTEMBER 21, 2023

FACT SHEET: Biden-Harris Administration Announces New Actions to Reduce Greenhouse Gas Emissions and Combat the Climate Crisis

New steps will catalyze action across the federal government to account for climate change impacts in budgeting, procurement, and other agency decisions, and save hardworking families money

From unprecedented wildfires, to extreme flooding, to record breaking hurricanes, Americans across the country are feeling the devastating impacts of the climate crisis. In just the first eight months of 2023, the U.S. experienced 23 separate billion-dollar weather and climate disasters — the highest number on record. That's why since taking office, President Biden has delivered on the most ambitious climate, conservation, and environmental justice agenda in history, including signing into law the largest climate investment ever. Today, the Biden-Harris Administration is announcing another key step to catalyze further action across the federal government and protect people from the growing impacts of the climate crisis by accounting for climate change impacts in certain key agency decisions.

The President's Day One Executive Order on *Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis* re-established an Interagency Working Group (IWG) and tasked it with identifying areas of budgeting, purchasing, and other key decisions where agencies should consider the Social Cost of Greenhouse Gases (SC-GHG) — a well-established metric for the known damages that greenhouse gas emissions cause across society. For over a decade, federal agencies have routinely applied SC-GHG values when estimating the benefits and costs of regulations. Today, the Administration is announcing that the President has approved recommendations from the IWG on the expanded use of the SC-GHG for budgeting, procurement, and other agency decisions, including reaffirming its use for environmental reviews where appropriate.

By calculating the costs of climate change impacts on sectors like agriculture, public health, labor productivity, and more, the SC-GHG allows better comparisons to other costs and benefits of agency decisions that may also be presented in dollar figures. And because the SC-GHG estimates the societal cost of the effects of various greenhouse gas pollutants emitted at distinct points in time, its use facilitates the comparison of alternative policies with different emissions profiles. The actions announced today will help protect people from the growing impacts of the climate crisis and save hardworking families money. They will build on existing work and best practices to guide agencies as they continue to make clear-eyed decisions to combat the climate crisis and protect the health and wellbeing of communities across the country in the following areas, as appropriate and consistent with applicable law:

The President is directing agencies to consider the SC-GHG in the development and implementation of their budgets.

The Office of Management and Budget (OMB) recently estimated that climate-related disasters could increase annual federal spending by over $100 billion and decrease annual federal revenue by up to $2 trillion by the end of the century. Today's announcement will further advance the Biden-Harris Administration's ongoing efforts to incorporate climate considerations into the President's budget formulation and implementation and save hardworking Americans money. Key examples of how agencies can, as appropriate, incorporate the SC-GHG into budgeting include:

- Measuring Programmatic Emissions: To value the benefits of investments that reduce emissions, first agencies must measure programmatic emissions. OMB will work with federal agencies to begin measuring baseline greenhouse gas emissions and use the SC-GHG to calculate the benefits and impacts of federal programs, starting with programs that already monitor emissions. As programmatic emission measurement practices are adopted, agencies can begin to incorporate the SC-GHG among the other considerations that inform and justify their budget proposals.

- Assessing Discretionary Grants: The Department of Transportation already recommends that applicants for discretionary infrastructure grants use the SC-GHG in the benefit-cost analyses of their project proposals. Agencies should, as appropriate, expand the application of SC-GHG estimates to assess the potential climate benefits and costs of discretionary grants.

- Considering Harm-Based Penalty Calculation Methodologies: Some administrative penalties for violations of statutory or regulatory requirements are set at monetary levels that reflect the harm to society caused by the unlawful conduct. Agencies should explore their processes for setting administrative penalties and, if found appropriate and consistent with their authorities, consider incorporating the SC-GHG into particular penalties.

- Evaluating International Assistance: Agencies that assess international assistance and financing are encouraged to work with partner countries and international financial institutions to expand use of the SC-GHG metrics as appropriate, and help ensure that such investments support the Administration's climate goals.

The President is directing agencies to consider the SC-GHG in federal procurement processes.

As the world's single largest purchaser—spending over $630 billion per year on goods and services—the federal government has the ability to move markets, invest in new ideas, and act as a model contracting partner. By integrating the SC-GHG into procurement, as appropriate and consistent with applicable law, the federal government can reduce emissions while saving taxpayer dollars, both in the short term through reduced energy consumption, and in the long term by helping to reduce the most catastrophic effects of the climate crisis. Key examples of how to incorporate the SC-GHG into procurement include:

- Focusing on High-Impact Procurements: Agencies should consider procurements of large, durable, energy-consuming products and systems that could serve as pilots for incorporating the SC-GHG. Such pilots will help agencies build the capacity and repeatable methods needed to replicate successes as they more broadly integrate the SC-GHG into federal procurement decisions over time. Some agencies have already started considering the SC-GHG in select procurements, such as through related environmental impact reviews. Notably, the U.S. Postal Service took steps to assess the climate benefits of various procurement options, which demonstrated the benefits of its transition to next-generation, low-emission delivery vehicles.

- Minimizing Climate Risk in Acquisitions: The Federal Acquisition Regulatory (FAR) Council agencies are considering a number of potential changes around the disclosure of greenhouse gas emissions and moving toward more sustainable federal purchasing. The FAR Council agencies have also sought early public input on incorporating the SC-GHG into both domestic and overseas procurement decisions. Consistent with the President's Executive Order on Climate-Related Financial Risk, EO

14030, OMB's Office of Federal Procurement Policy will continue working with the FAR Council to develop regulatory updates, as appropriate.

The President is directing agencies to consider the SC-GHG in environmental reviews conducted pursuant to the National Environmental Policy Act (NEPA) as appropriate.

This is consistent with the Council on Environmental Quality's (CEQ) January 2023 guidance on how agencies should consider greenhouse gas emissions in their NEPA analysis. Under NEPA, before agencies take major federal actions, such as permits, approvals, financial assistance, and resource planning, they must identify, disclose, and consider in their decision making the reasonably foreseeable effects of those proposals. Agencies already often quantify greenhouse gas emissions in their environmental reviews and when they do so, it is a relatively simple — yet tremendously informative — step to also apply the SC-GHG estimates to those emissions to provide context about their climate change impacts.

- Finalizing NEPA Guidance: CEQ issued interim guidance in January 2023 on how agencies should consider greenhouse gas emissions in their NEPA reviews where applicable, including through appropriate use of the SC-GHG, to help decisionmakers and the public evaluate climate change impacts and inform trade-offs between action alternatives. The period for public comment on the interim guidance closed in April 2023, and CEQ is working to finalize the guidance.

- Using the SC-GHG to Compare Climate Change Impacts: Agencies have increasingly begun to use the SC-GHG in their environmental reviews to compare the climate change impacts of proposed actions and their alternatives. For example, in its recent draft environmental impact statement to assess four alternatives for managing resources at the Grand Staircase-Escalante National Monument, the Department of the Interior showed how specific approaches to vegetation management, livestock grazing, and forestry management could result in tens of millions of dollars' worth of climate-related benefits.

By facilitating comparison of the climate consequences of alternative options in budgeting, procurement, and other agency decisions, appropriate use of the SC-GHG metrics can help agencies bolster the federal government's efforts to combat the climate crisis, further protect communities, and save hardworking families money.

###

Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide
Interim Estimates under Executive Order 13990

Interagency Working Group on Social Cost of Greenhouse Gases, United States Government

With participation by

Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Health and Human Services
Department of the Interior
Department of Transportation
Department of the Treasury
Environmental Protection Agency
National Climate Advisor
National Economic Council
Office of Management and Budget
Office of Science and Technology Policy

February 2021

Preface

The Interagency Working Group (IWG) on the Social Cost of Greenhouse Gases is committed to ensuring that the estimates agencies use when monetizing the value of changes in greenhouse gas emissions resulting from regulations and other relevant agency actions continue to reflect the best available science and methodologies. This Technical Support Document (TSD) presents interim estimates of the social cost of carbon, methane, and nitrous oxide developed under Executive Order 13990. These interim values are the same as those developed by the IWG in 2013 and 2016. The current IWG will take comment on recent developments in the science and economics for use in a more comprehensive update, to be issued by January 2022, which will more fully address the recommendations of the National Academies of Sciences, Engineering, and Medicine as reported in Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide (2017) and other pertinent scientific literature. As a part of that request for comment, the IWG will seek comment on the discussion of advances in science and methodology included in this TSD and how those advances can best be incorporated into the revised final estimates.

Executive Summary

A robust and scientifically founded assessment of the positive and negative impacts that an action can be expected to have on society provides important insights in the policy-making process. The estimates of the social cost of carbon (SC-CO_2), social cost of methane (SC-CH_4), and social cost of nitrous oxide (SC-N_2O) presented here allow agencies to understand the social benefits of reducing emissions of each of these greenhouse gases, or the social costs of increasing such emissions, in the policy making process. Collectively, these values are referenced as the "social cost of greenhouse gases" (SC-GHG) in this document. The SC-GHG is the monetary value of the net harm to society associated with adding a small amount of that GHG to the atmosphere in a given year. In principle, it includes the value of all climate change impacts, including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-GHG, therefore, should reflect the societal value of reducing emissions of the gas in question by one metric ton. The marginal estimate of social costs will differ by the type of greenhouse gas (such as carbon dioxide, methane, and nitrous oxide) and by the year in which the emissions change occurs. The SC-GHGs are the theoretically appropriate values to use in conducting benefit-cost analyses of policies that affect GHG emissions.

Federal agencies began regularly incorporating social cost of carbon (SC-CO_2) estimates in benefit-cost analyses conducted under Executive Order (E.O.) 12866[1] in 2008, following a court ruling in which an agency was ordered to consider the value of reducing CO_2 emissions in a rulemaking process. The U.S. Ninth Circuit Court of Appeals remanded a fuel economy rule to DOT for failing to monetize CO_2 emission reductions, stating that "while the record shows that there is a range of values, the value of carbon emissions reduction is certainly not zero."[2] In 2009, an interagency working group (IWG) was established to ensure that agencies were using the best available science and to promote consistency in the values used across agencies. The IWG published SC-CO_2 estimates in 2010 that were developed from an ensemble of three widely cited integrated assessment models (IAMs) that estimate global climate damages using highly aggregated representations of climate processes and the global economy combined into a single modeling framework. The three IAMs were run using a common set of input assumptions in each model for future population, economic, and GHG emissions growth, as well as equilibrium climate sensitivity (ECS) – a measure of the globally averaged temperature response to increased atmospheric CO_2 concentrations. These estimates were updated in 2013 based on new versions of each IAM. In August 2016 the IWG published estimates of the social cost of methane (SC-CH_4) and nitrous oxide (SC-N_2O) using methodologies that are consistent with the methodology underlying the SC-CO_2 estimates. In January 2017, the National Academies of Sciences, Engineering, and Medicine issued recommendations for an updating process to ensure the estimates continue to reflect the best available science. In March 2017, Executive Order 13783 disbanded the IWG and instructed agencies when monetizing the value of changes

[1] Under E.O. 12866, agencies are required, to the extent permitted by law and where applicable, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." As indicated in the discussion above, many statutes also require agencies to conduct at least some of the same analyses required under E.O. 12866, such as the Energy Policy and Conservation Act which mandates the setting of fuel economy regulations.

[2] *Ctr. for Biological Diversity v. Nat'l Highway Traffic Safety Admin.*, 538 F.3d 1172, 1200 (9th Cir. 2008).

in greenhouse gas emissions resulting from regulations to follow the Office of Management and Budget's (OMB) Circular A-4.

On January 20, 2021, President Biden issued E.O. 13990 which re-established the IWG and directed it to ensure that SC-GHG estimates used by the U.S. Government (USG) reflect the best available science and the recommendations of the National Academies (2017) and work towards approaches that take account of climate risk, environmental justice, and intergenerational equity. The IWG was tasked with first reviewing the SC-GHG estimates currently used by the USG and publishing interim estimates within 30 days of the E.O. that reflect the full impact of GHG emissions, including taking global damages into account. In this initial review, the IWG finds that the SC-GHG estimates used since E.O. 13783 fail to reflect the full impact of GHG emissions in multiple ways. First, the IWG found previously and is restating here that a global perspective is essential for SC-GHG estimates because climate impacts occurring outside U.S. borders can directly and indirectly affect the welfare of U.S. citizens and residents. Thus, U.S. interests are affected by the climate impacts that occur outside U.S. borders. Examples of affected interests include: direct effects on U.S. citizens and assets located abroad, international trade, tourism, and spillover pathways such as economic and political destabilization and global migration. In addition, assessing the benefits of U.S. GHG mitigation activities requires consideration of how those actions may affect mitigation activities by other countries, as those international mitigation actions will provide a benefit to U.S. citizens and residents by mitigating climate impacts that affect U.S. citizens and residents. Second, the IWG found previously and is restating here that the use of the social rate of return on capital to discount the future benefits of reducing GHG emissions inappropriately underestimates the impacts of climate change for the purposes of estimating the SC-GHG (see Section 3.1). Consistent with the findings of the National Academies (2017) and the economic literature, the IWG continues to conclude that the consumption rate of interest is the theoretically appropriate discount rate in an intergenerational context (IWG 2010, 2013, 2016). The IWG recommends that discount rate uncertainty and relevant aspects of intergenerational ethical considerations be accounted for in selecting future discount rates.

While the IWG works to assess how best to incorporate the latest, peer reviewed science to develop an updated set of SC-GHG estimates, it is setting interim estimates to be the most recent estimates developed by the IWG prior to the group being disbanded in 2017. The IWG concludes that these interim estimates represent the most appropriate estimate of the SC-GHG until the revised estimates have been developed. This update reflects the immediate need to have an operational SC-GHG for use in regulatory benefit-cost analyses and other applications that was developed using a transparent process, peer-reviewed methodologies, and the science available at the time of that process. Those estimates were subject to public comment in the context of dozens of proposed rulemakings as well as in a dedicated public comment period in 2013.

At the same time, consistent with its continuing commitment to a transparent process and a desire to move quickly to update SC-GHG estimates to better reflect the recent science, the IWG will be taking comment on how to incorporate the recommendations of the National Academies (2017) and other recent science , including the advances discussed in this Technical Support Document (TSD), both during the development of the fully updated SC-GHG estimates to be released by January of 2022 and in subsequent updates. The IWG will soon issue a Federal Register notice with a detailed set of requests for public comments on the new information presented in this TSD, as well as other topics and issues the IWG will address as we develop the next set of updates.

This TSD presents the IWG's interim findings and provides interim estimates of the SC-CO_2, SC-CH_4, and SC-N_2O that should be used by agencies until a comprehensive review and update is developed in line with the requirements in E.O. 13990. The TSD maintains the same methodological approach as has been used for global USG SC-GHG estimation to date. The estimates rely on the same models and harmonized inputs and are calculated using a range of discount rates. At this time, the IWG has determined that it is appropriate for agencies to revert to the same set of four values drawn from the SC-GHG distributions based on three discount rates (2.5 percent, 3 percent, and 5 percent) as were used in regulatory analyses between 2010 and 2016 and subject to public comment. However, as described below, based on the IWG's initial review, new data and evidence strongly suggests that the discount rate regarded as appropriate for intergenerational analysis is lower.

Tables ES-1, ES-2, and ES-3 summarize the interim SC-CO_2, SC-CH_4, and SC-N_2O estimates, respectively, for the years 2020 through 2050. These estimates are reported in 2020 dollars but are otherwise identical to those presented in the previous version of the TSD and its Addendum, released in August 2016. For purposes of capturing uncertainty around the SC-GHG estimates in analyses, the IWG emphasized previously and reemphasizes here the importance of considering all four of the SC-GHG values. In particular, this TSD discusses how the understanding of discounting approaches suggests discount rates appropriate for intergenerational analysis in the context of climate change that are lower than 3 percent. Consistent with the guidance in E.O. 13990 for the IWG to ensure that the SC-GHG reflect the interests of future generations, the latest scientific and economic understanding of discount rates discussed in this TSD, and the recommendation from OMB's Circular A-4 to include sensitivity analysis with lower discount rates when a rule has important intergenerational benefits or costs, agencies may consider conducting additional sensitivity analysis using discount rates below 2.5 percent. Furthermore, the IAMs used to produce these interim estimates do not include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature. For these same impacts, the science underlying their "damage functions" – i.e., the core parts of the IAMs that map global mean temperature changes and other physical impacts of climate change into economic (both market and nonmarket) damages – lags behind the most recent research. Likewise, the assumptions regarding equilibrium climate sensitivity and socioeconomic and emissions scenarios used as inputs to the model runs in this TSD will need to be updated. It is the IWG's judgment that, taken together, these limitations suggest that the range of four interim SC-GHG estimates presented in this TSD likely underestimate societal damages from GHG emissions.

Table ES-1: Social Cost of CO_2, 2020 – 2050 (in 2020 dollars per metric ton of CO_2)[3]

Emissions Year	Discount Rate and Statistic 5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	14	51	76	152
2025	17	56	83	169
2030	19	62	89	187
2035	22	67	96	206
2040	25	73	103	225
2045	28	79	110	242
2050	32	85	116	260

Table ES-2: Social Cost of CH_4, 2020 – 2050 (in 2020 dollars per metric ton of CH_4)

Emissions Year	Discount Rate and Statistic 5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	670	1500	2000	3900
2025	800	1700	2200	4500
2030	940	2000	2500	5200
2035	1100	2200	2800	6000
2040	1300	2500	3100	6700
2045	1500	2800	3500	7500
2050	1700	3100	3800	8200

[3] The values reported in this TSD are identical to those reported in the 2016 TSD adjusted for inflation to 2020 dollars using the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9: 113.626 (2020)/ 92.486 (2007) = 1.228575 (U.S. BEA 2021). Values are the average across models and socioeconomic emissions scenarios for each of three discount rates (2.5%, 3%, and 5%), plus a fourth value, selected as the 95th percentile of estimates based on a 3 percent discount rate. Values of SC-CO_2 are rounded to the nearest dollar; SC-CH_4 and SC-N_2O are rounded to two significant figures. The annual unrounded estimates are available on OMB's website for use in regulatory and other analyses: https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs

Table ES-3: Social Cost of N_2O, 2020 – 2050 (in 2020 dollars per metric ton of N_2O)

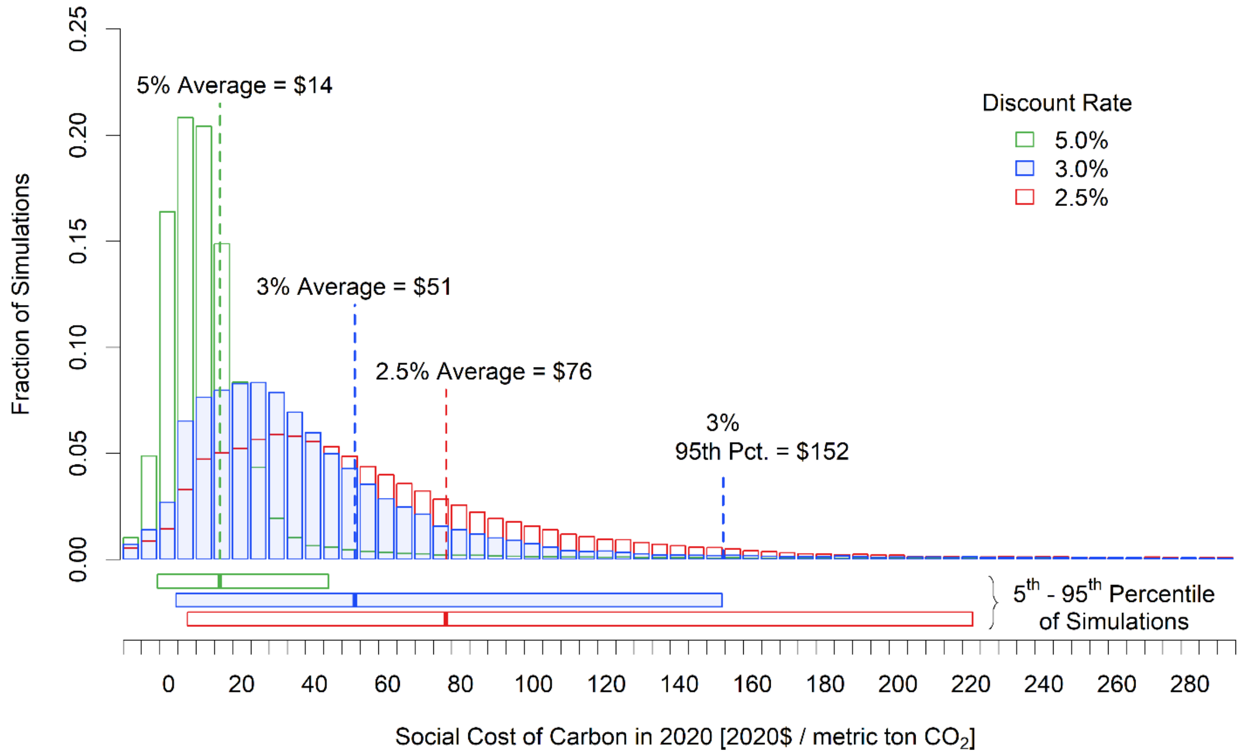
	Discount Rate and Statistic			
Emissions Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	5800	18000	27000	48000
2025	6800	21000	30000	54000
2030	7800	23000	33000	60000
2035	9000	25000	36000	67000
2040	10000	28000	39000	74000
2045	12000	30000	42000	81000
2050	13000	33000	45000	88000

While point estimates are important for providing analysts with a tractable approach for regulatory analysis, they do not fully quantify uncertainty associated with the SC-GHG estimates. Figures ES-1 through ES-3 present the quantified sources of uncertainty in the form of frequency distributions for the SC-GHG estimates for emissions in 2020. The distributions of SC-GHG estimates reflect uncertainty in key model parameters chosen by the IWG such as the equilibrium climate sensitivity, as well as uncertainty in other parameters set by the original model developers. To highlight the difference between the impact of the discount rate and other quantified sources of uncertainty, the bars below the frequency distributions provide a symmetric representation of quantified variability in the SC-GHG estimates for each discount rate. There are other sources of uncertainty that have not yet been quantified and are thus not reflected in these estimates. When an agency determines that it is appropriate to conduct additional quantitative uncertainty analysis, it should follow best practices for probabilistic analysis.[4] The full set of information that underlies the frequency distributions in Figures ES-1 through ES-3 is available on OMB's website[5].

[4] See e.g. OMB's Circular A-4, section on *Treatment of Uncertainty*. Available at: https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/circulars/A4/a-4.pdf.

[5] Available at https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs

Figure ES-1: Frequency Distribution of SC-CO_2 Estimates for 2020[6]



[6] Although the distributions and numbers in Figures ES-1, ES-2, and ES-3 are based on the full set of model results (150,000 estimates for each discount rate and gas), for display purposes the horizontal axis is truncated with 0.02 to 0.68 percent of the estimates falling below the lowest bin displayed and 0.12 to 3.11 percent of the estimates falling above the highest bin displayed, depending on the discount rate and GHG.

Figure ES-2: Frequency Distribution of SC-CH_4 Estimates for 2020

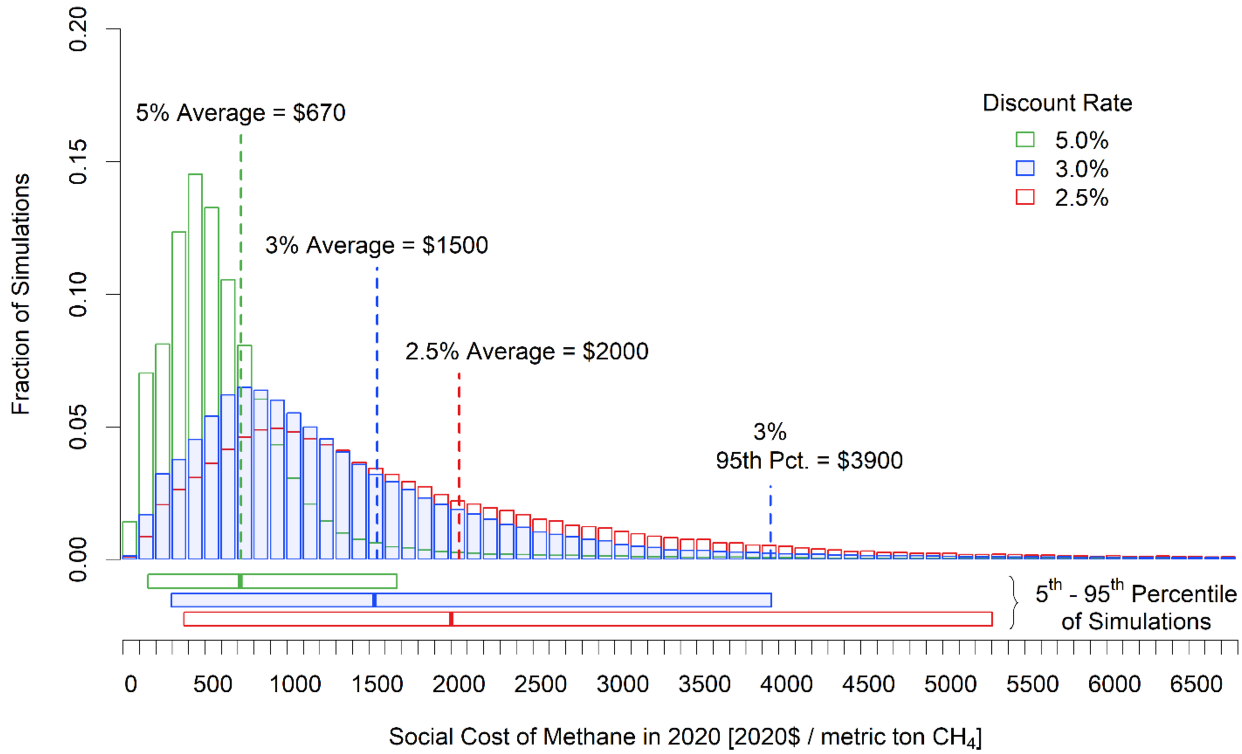
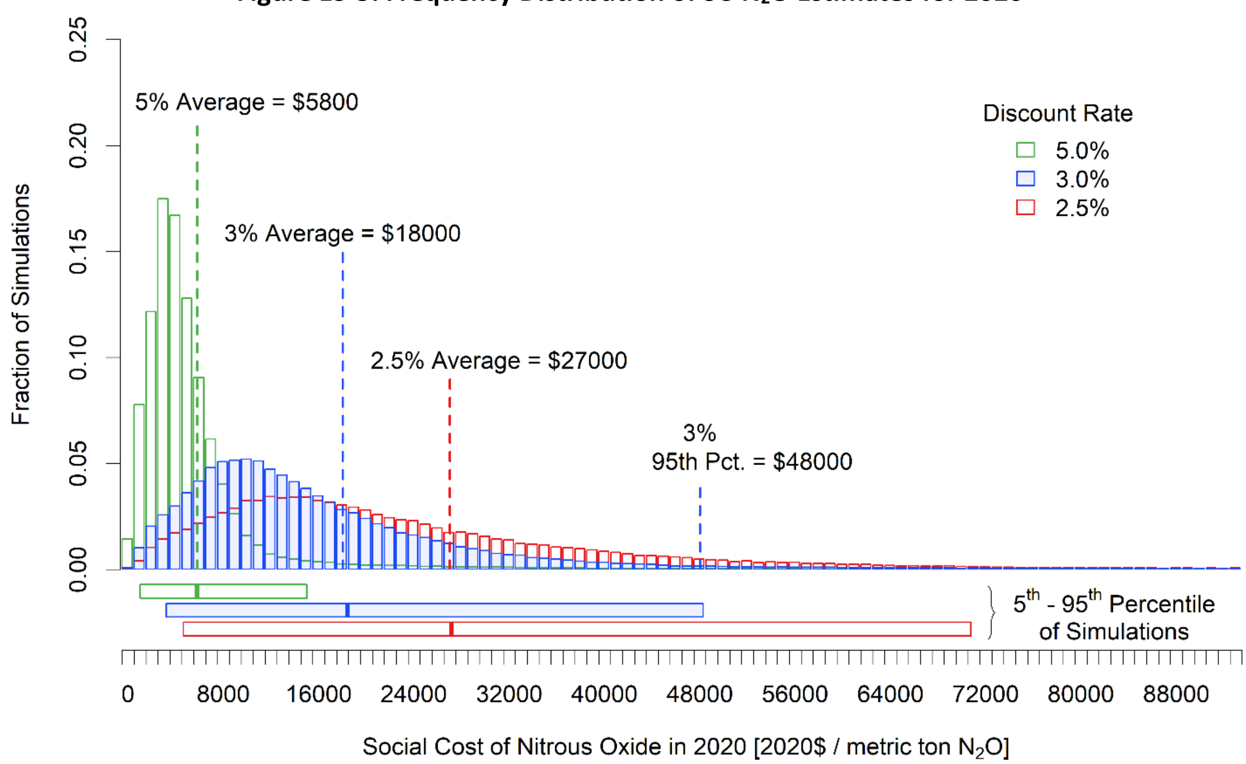


Figure ES-3: Frequency Distribution of SC-N_2O Estimates for 2020



1 Background

The estimates of the social cost of carbon (SC-CO_2), social cost of methane (SC-CH_4), and social cost of nitrous oxide (SC-N_2O) presented here allow agencies to incorporate the social benefits of reducing emissions of each of these greenhouse gases, or the social costs of increasing such emissions, in decision making. Collectively, these values are referenced as the "social cost of greenhouse gases" (SC-GHG) in this document. The SC-GHG is the monetary value of the net harm to society associated with adding a small amount of that GHG to the atmosphere in a given year. In principle, it includes the value of all climate change impacts, including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-GHG, therefore, should reflect the societal value of reducing emissions of the gas in question by one ton. The marginal estimate of social costs will differ by the type of greenhouse gas (such as carbon dioxide, methane, and nitrous oxide) and by the year in which the emissions change occurs. The SC-GHGs are calculated along a baseline path and provide a measure of the marginal benefit of GHG abatement. Thus, they are the theoretically appropriate values to use when conducting benefit-cost analyses of policies that affect GHG emissions.[7]

1.1 Overview of U.S. Government SC-GHG Estimates to Date

Estimates of the social cost of carbon and other greenhouse gases have been published in the academic literature for many years. Meta-reviews of SC-CO_2 estimates were available as early as 2002 (Clarkson and Deyes 2002). Federal agencies began regularly incorporating SC-CO_2 estimates in regulatory impact analyses in 2008, following a court ruling in which an agency was ordered to consider the SC-CO_2 in the rulemaking process. The U.S. Ninth Circuit Court of Appeals remanded a fuel economy rule to the Department of Transportation (DOT) for failing to consider the value of reducing CO_2 emissions, stating that "while the record shows that there is a range of values, the value of carbon emissions reduction is certainly not zero."[8]

[7] These estimates of social damages should not be confused with estimates of the costs of attaining a specific emissions or warming limit. Specifically, there is another strand of research that investigates the costs of setting a specific climate target (e.g., capping emissions or temperature increases to a certain level). If total emissions are capped, IAM models can estimate the costs of limiting emissions or temperature increase to that cap. Similarly, other models simulate market trading in a cap and trade system. The price of a permit to emit one ton of carbon provides a measure of the marginal cost of GHG abatement, which can be useful in evaluating policy cost-effectiveness but is not an alternative way to value damages from GHG emissions in benefit-cost analysis. Moreover, a policy that specifies an environmental target implicitly requires a valuation of damages when setting the constraint even though it is not explicitly modeled or estimated. For example, a target set to keep temperature increases below a certain threshold implicitly places value on damages incurred beyond that threshold. For more on how these concepts (e.g., a predetermined target-based approach and a damage (SC-GHG) based approach) can be used when designing climate policy see, for example, Hansel et al. (2020) and Stern and Stiglitz (2021).

[8] *Ctr. for Biological Diversity v. Nat'l Highway Traffic Safety Admin.*, 538 F.3d 1172, 1200 (9th Cir. 2008).

In 2009, an interagency process was launched, under the leadership of the Office of Management and Budget (OMB) and the Council of Economic Advisers (CEA), that sought to harmonize a range of different SC-CO_2 values being used across multiple Federal agencies. The purpose of this process was to ensure that agencies were using the best available information and to promote consistency in the way agencies quantify the benefits of reducing CO_2 emissions in regulatory impact analyses. This included the establishment of an IWG which represented perspectives and technical expertise from many federal agencies and a commitment to following the peer-reviewed literature. In 2010, the IWG finalized a set of four SC-CO_2 values for use in regulatory analyses and presented them in a TSD that also provided guidance for agencies on using the estimates (IWG 2010). Three of these values were based on the average SC-CO_2 from three widely cited integrated assessment models (IAMs) in the peer-reviewed literature – DICE, PAGE, and FUND[9] – at discount rates of 2.5, 3, and 5 percent. The fourth value was included to represent higher-than-expected economic impacts from climate change further out in the tails of the SC-CO_2 distribution. For this purpose, it used the SC-CO_2 value for the 95th percentile at a 3 percent discount rate.

In May of 2013, the IWG provided an update of the SC-CO_2 estimates to incorporate new versions of the IAMs used in the peer-reviewed literature (IWG 2013). The 2013 update did not revisit other IWG modeling decisions (i.e., the discount rates or harmonized inputs for socioeconomic and emission scenarios and equilibrium climate sensitivity). Improvements in the way damages are modeled were confined to those that had been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature.[10] In August of 2016, the IWG published estimates of the social cost of methane (SC-CH_4) and nitrous oxide (SC-N_2O) that are consistent with the methodology underlying the SC-CO_2 estimates (IWG 2016a, 2016b).

Over the course of developing and updating the USG SC-GHG, through both the IWG and individual agencies, there were extensive opportunities for public input on the estimates and underlying methodologies. There was a public comment process associated with each proposed rulemaking that used the estimates, and OMB initiated a separate comment process on the IWG TSD in 2013. Commenters offered a wide range of perspectives on all aspects of process, methodology, and final estimates and diverse suggestions for improvements. The U.S. Government Accountability Office (GAO) also reviewed the development of the USG SC-CO_2 estimates and concluded that the IWG processes and methods reflected three principles: consensus-based decision making, reliance on existing academic literature and models, and disclosure of limitations and incorporation of new information (U.S. GAO 2014).

[9] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy was widely used to study climate impacts (e.g., Tol 2002a, Tol 2002b, Anthoff et al. 2009, Tol 2009).

[10] The IWG subsequently provided additional minor technical revisions in November of 2013 and July of 2015, as explained in Appendix B of the 2016 TSD (IWG 2016a).

In 2015, as part of the IWG response to the public comments received in the 2013 solicitation, the IWG announced a National Academies of Sciences, Engineering, and Medicine review of the IWG estimates (IWG 2015). Specifically, the IWG asked the National Academies to conduct a multi-discipline, two-phase assessment of the IWG estimates and to offer advice on how to approach future updates to ensure that the estimates continue to reflect the best available science and methodologies. The National Academies' interim (Phase 1) report (National Academies 2016a) recommended against a near term update of the SC-CO_2 estimates within the existing modeling framework. For future revisions, the National Academies recommended the IWG move efforts towards a broader update of the climate system module consistent with the most recent, best available science and offered recommendations for how to enhance the discussion and presentation of uncertainty in the SC-CO_2 estimates. In addition to publishing estimates of SC-CH_4 and SC-N_2O, the IWG's 2016 TSD revision responded to the National Academies' Phase 1 report recommendations regarding presentation of uncertainty. The revisions included: an expanded presentation of the SC-GHG estimates that highlights a symmetric range of uncertainty around estimates for each discount rate; new sections that provide a unified discussion of the methodology used to incorporate sources of uncertainty; detailed explanation of the uncertain parameters in both the FUND and PAGE models; and making the full set of SC-CO_2 estimates easily accessible to the public on OMB's website.

In January 2017, the National Academies released their final report, *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide*, and recommended specific criteria for future updates to the SC-CO_2 estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process (National Academies 2017). A description of the National Academies' recommendations for near-term updates are described in Section 1.2 of this document. Shortly thereafter, in March 2017, President Trump issued Executive Order (E.O.) 13783 which called for the rescission and review of several climate-related Presidential and regulatory actions as well as for a review of the SC-GHG estimates used for regulatory impact analysis. E.O. 13783 disbanded the IWG, withdrew the previous TSDs, and directed agencies to ensure SC-GHG estimates used in regulatory analyses are consistent with the guidance contained in OMB's Circular A-4, "including with respect to the consideration of domestic versus international impacts and the consideration of appropriate discount rates" (E.O. 13783, Section 5(c)). Benefit-cost analyses following E.O. 13783 used SC-GHG estimates that attempted to focus on the domestic impacts of climate change as estimated by the models to occur within U.S. borders and were calculated using two discount rates recommended by OMB's Circular A-4, 3 percent and 7 percent.[11] All other methodological decisions and model versions used in SC-GHG calculations remained the same as those used by the IWG in 2010 and 2013, respectively.

On January 20, 2021, President Biden issued E.O. 13990, which re-established the IWG and directed it to ensure that USG SC-GHG estimates reflect the best available science and the recommendations of the National Academies (2017). The IWG was tasked with first reviewing the SC-GHG estimates currently used by the USG and publishing interim estimates within 30 days of the E.O. that reflect the full impact of GHG emissions, including by taking global damages into account. The E.O. instructs the IWG to develop final SC-GHG estimates by January 2022. Section 1.3 describes requirements established by E.O. 13990 in greater detail. In addition, the E.O. instructs the IWG to provide recommendations to the President by

[11] OMB Circular A-4 (2003) indicates that sensitivity analysis using lower discount rates than 3 percent and 7 percent may be appropriate where intergenerational effects are important. See Section 3 for further discussion.

September 2021, regarding areas of decision-making, budgeting, and procurement by the Federal Government where the SC-GHG should be applied. The SC-GHG has been used previously in non-regulatory Federal analysis, such as in federal procurement,[12] grant programs,[13] and National Environmental Policy Act (NEPA) analysis,[14] as well as in state level applications; the latter is discussed further in Section 5.

1.2 Recommendations from the National Academies of Sciences, Engineering, and Medicine

In 2015, the IWG requested that the National Academies of Sciences, Engineering, and Medicine review and recommend potential approaches for improving its SC-CO_2 estimation methodology. In response, the National Academies convened a multidisciplinary committee, the Committee on Assessing Approaches to Updating the Social Cost of Carbon. In addition to evaluating the IWG's overall approach to SC-CO_2 estimation, the committee reviewed its choices of IAMs and damage functions, climate science assumptions, future baseline socioeconomic and emission projections, presentation of uncertainty, and discount rates.

In its final report (National Academies 2017), the National Academies committee recommended that the IWG pursue an integrated modular approach to the key components of SC-CO_2 estimation to allow for independent updating and review and to draw more readily on expertise from the wide range of scientific disciplines relevant to SC-CO_2 estimation. Under this approach, each step in SC-CO_2 estimation is developed as a module—socioeconomic projections, climate science, economic damages, and discounting—that reflects the state of scientific knowledge in the current, peer-reviewed literature. In the longer-term, it recommended that the IWG also fund research on ways to better capture interactions and feedbacks between these components. In addition, the committee noted that, while the IWG harmonized assumptions across the IAMs for socioeconomic and emission projections, climate sensitivity, and discount rates when estimating the SC-CO_2, using a single climate module in the nearer-term (2-3 years) and eventually transitioning to a single IAM framework will enhance transparency, improve consistency with the underlying science, and allow for more explicit representation of uncertainty. It recommended these three criteria also be used to judge the value of other updates to the methodology. In addition, it recommended that the IWG update SC-CO_2 estimates at regular intervals, suggesting a five-year cycle.

Regarding the key components of the SC-CO_2, the committee recommended the following improvements in the nearer-term:

- Socioeconomic and emissions projections: Use accepted statistical methods and elicit expert judgment to project probability distributions of future annual growth rates of per-capita GDP and

[12] For example, SC-CO_2 estimates have been used in Domestic Delivery Services contracts for USG parcel shipping (https://westcoastclimateforum.com/sites/westcoastclimateforum/files/related_documents/FedGSA_DDS3_green_features_fact_sheet.pdf).
[13] For example, in 2016 DOT's Transportation Investment Generating Economic Recovery (TIGER) discretionary grant program required a demonstration that benefits justify costs for proposed projects, and the guidance DOT provides to applicants for how to conduct such an analysis specified that they should use the USG SC-CO_2 estimates (https://www.transportation.gov/sites/dot.gov/files/docs/BCARG2016March.pdf).

[14] See Howard and Schwartz (2019) for examples of the use of SC-CO_2 estimates in NEPA analyses.

population, bearing in mind potential correlation between economic and population projections. Then using expert elicitation, guided by information on historical trends and emissions consistent with different climate outcomes, project emissions for each forcing agent of interest conditional on population and income scenarios. Additional recommendations were offered for improving the socioeconomic module centered on four broad criteria: time horizon, future policies, disaggregation, and feedbacks.

- Climate science: Adopt or develop a simple Earth system model (such as the Finite Amplitude Impulse Response (FaIR) model) to capture relationships between CO_2 emissions, atmospheric CO_2 concentrations, and global mean surface temperature change over time while accounting for non-CO_2 forcing and allowing for the evaluation of uncertainty. It also recommended the IWG adopt or develop a sea level rise component in the climate module that: (1) accounts for uncertainty in the translation of global mean temperature to global mean sea level rise and (2) is consistent with sea level rise projections available in the literature for similar forcing and temperature pathways. It also noted the importance of generating spatially and temporally disaggregated climate information as inputs into damage estimation. It recommended the use of linear pattern scaling (which estimates linear relationships between global mean temperature and local climate variables) to achieve this goal in the near-term.
- Economic damages: Improve and update existing formulations of individual sectoral damage functions when feasible; characterize damage function calibrations quantitatively and transparently; present spatially disaggregated damage projections and discuss how they scale with temperature, income, and population; and recognize any correlations between formulations when multiple damage functions are used.
- Discounting: Account for the relationship between economic growth and discounting; explicitly recognize uncertainty surrounding discount rates over long time horizons using a Ramsey-like approach; select parameters to implement this approach that are consistent with theory and evidence to produce certainty-equivalent discount rates consistent with near-term consumption rates of interest; use three sets of Ramsey parameters to generate a low, central, and high certainty-equivalent near-term discount rate, and three means and ranges of SC-CO_2 estimates; discuss how the SC-CO_2 estimates should be combined with other cost and benefit estimates that may use different discount rates in regulatory analysis.

Additional details on each of these recommendations as well as longer term research needs are provided in the National Academies' final report (National Academies 2017).

1.3 Executive Order 13990

On January 20, 2021, President Biden issued E.O. 13990, "Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis." Echoing one of the general principles of E.O. 12866 that an Agency "shall base its decisions on the best reasonably obtainable scientific, technical, economic, and other information", E.O. 13990 states that it is essential for Agencies to account for the benefits of reducing GHG emissions as accurately as possible. It emphasizes that a full global accounting of the costs of GHG emissions "facilitates sound decision-making, recognizes the breadth of climate impacts, and supports the international leadership of the United States on climate issues" (E.O. 13990 2021). Specifically, E.O. 13990 reinstates the IWG as the Interagency Working Group on the Social Cost of Greenhouse Gases, names the Chair of the CEA, Director of OMB, and Director of the Office of Science and Technology Policy (OSTP) as co-chairs of the IWG, and specifies the membership of the IWG to include the following officials, or their designees: the Secretary of the Treasury; the Secretary of the Interior; the Secretary of Agriculture; the Secretary of Commerce; the Secretary of Health and Human Services; the Secretary of Transportation; the Secretary of Energy; the Chair of the Council on Environmental Quality; the Administrator of the Environmental Protection Agency; the Assistant to the President and National Climate Advisor; and the Assistant to the President for Economic Policy and Director of the National Economic Council.

E.O. 13990 tasks the reinstated IWG with the following:

(1) publish an interim update to the SC-GHG (SC-CO_2, SC-CH_4, and SC-N_2O) estimates by February 19, 2021, for agencies to use when monetizing the value of changes in greenhouse gas emissions resulting from regulations and other relevant agency actions until final values are published;

(2) publish a final update to the SC-GHG estimates by no later than January 2022;

(3) provide recommendations, by no later than September 1, 2021, regarding areas of decision-making, budgeting, and procurement by the Federal Government where the SC-GHG estimates should be applied;

(4) provide recommendations, by no later than June 1, 2022, regarding a process for reviewing and, as appropriate, updating the SC-GHG estimates to ensure that these estimates are based on the best available economics and science; and

(5) provide recommendations, to be published with the interim SC-GHG estimates if feasible and by no later than June 1, 2022, to revise methodologies for SC-GHG calculations to the extent that current methodologies do not adequately take account of climate risk, environmental justice, and intergenerational equity.

Finally, the E.O. specifies that in carrying out its activities, the IWG shall consider the recommendations of the National Academies (2017) and other pertinent scientific literature; solicit public comment; engage with the public and stakeholders; seek the advice of ethics experts; and ensure that the SC-GHG estimates reflect the interests of future generations in avoiding threats posed by climate change.

This TSD presents the interim SC-GHG estimates called for in the first of these tasks. It also provides preliminary discussion of how at least one component of SC-GHG estimation, discounting, warrants reconsideration in the more comprehensive update by January 2022 to reflect the advice of the National Academies (2017) and other recent scientific literature.

2 The Importance of Accounting for Global Damages

Benefit-cost analyses of U.S. Federal regulations have traditionally focused on the benefits and costs that accrue to individuals that reside within the country's national boundaries. This is a natural result of the fact that most regulations have a limited impact on individuals residing outside of the United States and do not reflect any other scientific, legal, or other rationale. According to OMB's Circular A-4 (2003), an "analysis should focus on benefits and costs that accrue to citizens and residents of the United States."[15] While Circular A-4 does not elaborate, this guidance towards a focus on U.S. populations in domestic policy analysis is broadly consistent with the fact that the authority to regulate only extends to a nation's own residents who have consented to adhere to the same set of rules and values for collective decision-making (EPA 2010; Kopp et al. 1997; Whittington and MacRae 1986). However, guidance towards a focus on impacts to U.S. citizens and residents is different than recommending that analysis be limited to the impacts that occur within the borders of the U.S. Furthermore, OMB Circular A-4 states that when a regulation is likely to have international effects that "these effects should be reported" though the guidance recommends this be done separately. There are many reasons, as summarized in this TSD, why it is appropriate for agencies to use the global value of damages in making decisions that affect, or may be affected by, GHG emissions. Courts have upheld the use of global damages in estimating the social cost of GHGs, in part in recognition of the diverse ways in which U.S. interests, businesses, and residents may be impacted by climate change beyond U.S. borders.[16]

Unlike many environmental problems where the causes and impacts are distributed more locally, climate change is a true global challenge making GHG emissions a global externality. GHG emissions contribute to damages around the world regardless of where they are emitted. The global nature of GHGs means that U.S. interests, and therefore the benefits to the U.S. population of GHG mitigation, cannot be defined solely by the climate impacts that occur within U.S. borders. Impacts that occur outside U.S. borders as a result of U.S. actions can directly and indirectly affect the welfare of U.S. citizens and residents through a multitude of pathways. Over 9 million U.S. citizens lived abroad as of 2016[17] and U.S. direct investment positions abroad totaled nearly $6 trillion in 2019.[18] Climate impacts occurring outside of U.S. borders will have a direct impact on these U.S. citizens and the investment returns on those assets owned by U.S. citizens and residents. The U.S. economy is also inextricably linked to the rest of the world. The U.S. exports over $2 trillion worth of goods and services a year and imports around $3 trillion.[19] Climate impacts that occur outside U.S. borders can thus impact the welfare of individuals and firms that reside in the United States through their effect on international markets, trade, tourism, and other activities. Furthermore, additional spillovers can occur through pathways such as economic and political destabilization and global migration that can lead to adverse impacts on U.S. national security, public health, and humanitarian concerns (DoD 2014, CCS 2018). As described by the National Academies (2017), to correctly assess the total damages to U.S. citizens and residents, one must account for these spillover effects on the United States.

As an empirical matter, the development of a domestic SC-GHG is greatly complicated by the relatively few region- or country-specific estimates of the SC-CO_2 in the literature. At present, the only quantitative

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[15] OMB's Circular A-4 provides guidance to Federal agencies on the development of regulatory analysis conducted pursuant to Executive Order 12866.

[16] *Zero Zone, Inc. v. Dep't of Energy*, 832 F.3d 654, 678-79 (7th Cir. 2016) (rejecting a petitioner's challenge to DOE's use of a global (rather than domestic) social cost of carbon in setting an efficiency standard under the Energy Policy and Conservation Act, holding that DOE had reasonably identified carbon pollution as "a global externality" and concluding that, because "national energy conservation has global effects, . . . those global effects are an appropriate consideration when looking at a national policy.").

[17] U.S. Department of State's Bureau of Consular Affairs.

[18] BEA Direct Investment by Country and Industry 2019, https://www.bea.gov/data/intl-trade-investment/direct-investment-country-and-industry

[19] BEA National Income and Product Accounts Table 1.1.5.

characterization of domestic damages from GHG emissions, as represented by the domestic SC-GHG, is based on the share of damages arising from climate impacts occurring within U.S. borders as represented in current IAMs. This is both incomplete and an underestimate of the share of total damages that accrue to the citizens and residents of the U.S. because these models do not capture the regional interactions and spillovers discussed above. A 2020 U.S. GAO study observed that "[a]ccording to the National Academies, the integrated assessment models were not premised or calibrated to provide estimates of the social cost of carbon based on domestic damages, and more research would be required to update the models to do so. The National Academies stated it is important to consider what constitutes a domestic impact in the case of a global pollutant that could have international implications that affect the United States" (U.S. GAO 2020).

The global nature of GHGs means that damages caused by a ton of emissions in the U.S. are felt globally and that a ton emitted in any other country harms those in the U.S. Therefore, assessing the benefits of U.S. GHG mitigation activities will require consideration of how those actions may affect mitigation activities by other countries since those international actions will provide a benefit to U.S. citizens and residents. A wide range of scientific and economic experts have emphasized the issue of reciprocity as support for considering global damages of GHG emissions (e.g., Kopp and Mignone 2013, Pizer et al. 2014, Howard and Schwartz 2019, Pindyck 2017, Revesz et al. 2017, Carleton and Greenstone 2021). Carleton and Greenstone (2021) discuss examples of how historic use of a global SC-CO_2 may have plausibly contributed to additional international action. Houser and Larson (2021) estimate that under the Paris Agreement, other countries pledged to reduce 6.1 to 6.8 tons for every ton pledged by the U.S. Kotchen (2018) offers a theoretical perspective showing that non-Nash game theoretic behavior can lead countries to optimally chose a social cost of carbon higher than their domestic value to encourage additional reductions from other countries. Using a global estimate of damages in U.S. analyses of regulatory and other actions allows the U.S. to continue to actively encourage other nations, including emerging major economies, to take significant steps to reduce emissions.

The IWG found previously and is restating here that because of the distinctive global nature of climate change that analysis of Federal regulatory and other actions should center on a global measure of SC-GHG. This approach is the same as that taken in regulatory analyses over 2009 through 2016. In the 2015 response to comments, the IWG noted that the only way to achieve an efficient allocation of resources for emissions reduction on a global basis is for all countries to base their policies on global estimates of damages (IWG 2015). Therefore, the IWG continues to recommend the use of global SC-GHG estimates in analysis of Federal regulatory and other actions. The IWG also continues to review developments in the literature, including more robust methodologies for estimating SC-GHG values based on purely domestic damages, and explore ways to better inform the public of the full range of carbon impacts, both global and domestic.

3 Discounting in Intergenerational Analyses

GHG emissions are stock pollutants, where damages are associated with what has accumulated in the atmosphere over time, and they are long lived such that subsequent damages resulting from emissions today occur over many decades or centuries depending on the specific greenhouse gas under consideration.[20] In calculating the SC-GHG, the stream of future damages to agriculture, human health, and other market and non-market sectors from an additional unit of emissions are estimated in terms of reduced consumption (or consumption equivalents). Then that stream of future damages is discounted to its present value in the year when the additional unit of emissions was released. Given the long time horizon over which the damages are expected to occur, the discount rate has a large influence on the present value of future damages. However, the choice of a discount rate also raises highly contested and exceedingly difficult questions of science, economics, ethics, and law.

In 2010, in light of disagreements in the literature on the appropriate discount rate to use in this context, and uncertainty about how rates may change over time, the IWG elected to use three discount rates to span a plausible range of certainty-equivalent constant consumption discount rates: 2.5, 3, and 5 percent per year. The IWG at that time determined that these three rates reflected reasonable judgments under both descriptive and prescriptive approaches to selecting the discount rate.

The 3 percent value was included as consistent with estimates provided in OMB's Circular A-4 (OMB 2003) guidance for the consumption rate of interest. The IWG found that the consumption rate of interest is the correct discounting concept to use when future damages from elevated temperatures are estimated in consumption-equivalent units as is done in the IAMs used to estimate the SC-GHG (National Academies 2017). The upper value of 5 percent was included to represent the possibility that climate-related damages are positively correlated with market returns, which would imply a certainty equivalent value higher than the consumption rate of interest. The low value, 2.5 percent, was included to incorporate the concern that interest rates are highly uncertain over time. It represents the average certainty-equivalent rate using the mean-reverting and random walk approaches from Newell and Pizer (2003) starting at a discount rate of 3 percent. Using this approach, the certainty equivalent is about 2.2 percent using the random walk model and 2.8 percent using the mean reverting approach. Without giving preference to a particular model, the average of the two rates is 2.5 percent. Additionally, a rate below the consumption rate of interest would also be justified if the return to investments in climate mitigation are negatively correlated with the overall market rate of return. Use of this lower value was also deemed responsive to certain judgments based on the prescriptive or normative approach for selecting a discount rate and to related ethical objections that have been raised about rates of 3 percent or higher. Further details about the process for selecting these rates is presented in the 2010 TSD (IWG 2010). Finally, it is important to note that, while the consumption discount rate is the conceptually correct rate for discounting the SC-GHG, and the three rates originally selected were based on this concept, the latest data as well as recent discussion in the economics literature indicates that the 3 percent discount rate used by the IWG to develop its range of discount rates is likely an overestimate of the appropriate discount rate and warrants reconsideration in future updates of the SC-GHG.

This section discusses three issues related to the selected discount rates: (1) why the social rate of return to capital, estimated to be 7 percent in OMB's Circular A-4, is not appropriate for use in calculating the SC-GHG, (2) new evidence on the consumption rate of interest, which may inform the future updates to the SC-GHG, and (3) analytic consistency across discounting within an analysis.

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[20] "GHGs, for example, CO_2, methane, and nitrous oxide, are chemically stable and persist in the atmosphere over time scales of a decade to centuries or longer, so that their emission has a long-term influence on climate. Because these gases are long lived, they become well mixed throughout the atmosphere" (IPCC 2007).

3.1 Social Rate of Return on Capital and Intergenerational Analyses

When analyzing policies and programs that result in GHG emission reductions, it is important to account for the difference between the social and private rate of return on any capital investment affected by the action. Society is not indifferent between a regulation that displaces consumption versus investment in equal amounts. Market distortions, in large part taxes on capital income, cause private returns on capital investments to be different from the social returns. In well-functioning capital markets, arbitrage opportunities will be dissipated, and the cost of investments will equal the present value of future private returns on those investments. Therefore, an individual forgoing consumption or investment of equal amounts as the result of a regulation will face an equal private burden. However, because the social rate of return on the investment is greater than the private rate of return, the overall social burden will be greater in the case where investment is displaced.

OMB's Circular A-4 points out that "the analytically preferred method of handling temporal differences between benefits and costs is to adjust all the benefits and costs to reflect their value in equivalent units of consumption and to discount them at the rate consumers and savers would normally use in discounting future consumption benefits" (OMB 2003). The damage estimates developed for use in the SC-GHG are estimated in consumption-equivalent terms. An application of OMB Circular A-4's guidance for regulatory analysis would then use the consumption discount rate to calculate the SC-GHG, while also developing a more complete estimate of social cost to account for the difference in private and social rates of return on capital for any investment displaced as a result of the regulation. This more complete estimate of social costs can be developed using either the shadow price of capital approach or by estimating costs in a general equilibrium framework, for example by using a computable general equilibrium model. In both cases, displaced investment would be converted into a flow of consumption equivalents.

In cases where the costs are not adjusted to be in consumption-equivalent terms, OMB's Circular A-4 recommends that analysts provide a range of estimates for net benefits based on two approaches. The first approach is based on using the consumption rate of interest to discount all costs and benefits. This approach is consistent with the case where costs are primarily borne as reduced consumption. The second approach, the social opportunity cost of capital (SOC) approach, focuses on the case where the main effect of a regulation is to displace or alter the use of capital in the private sector (OMB 2003). When interpreting the SOC approach from the point of view of whether to invest in a single government project, it is asking whether the benefits from the project would at least match the returns from investing the same resources in the private sector. Interpreting the approach from the standpoint of a benefit-cost analysis of regulation, the approach focuses on adjusting estimates of benefits downward by discounting at a higher rate to offset additional social costs not reflected in the private value of displaced investment.

Harberger (1972) derived a more general version of the social opportunity cost of capital approach, recognizing that policies will most likely displace a mix of consumption and investment and therefore a blended discount rate would be needed to adjust the benefits to account for the omitted costs. In his partial equilibrium approach, the blended discount rate is a weighted average of the consumption interest rate and social rate of return on capital, where the weights are the share of a policy's costs borne by consumption versus investment. This general result has been extended to the general equilibrium context by Sandmo and Drèze (1971) and Drèze (1974) and can be extended to account for changes in foreign direct investment (CEA 2017). This highlights that using the social rate of return for benefits and costs is at best creating a lower bound on the estimate of net benefits that would only be met in an extreme case where regulatory costs fully displace investment. If the beneficial impacts of the regulation induce private investment whose social returns have not been quantified and fully converted to consumption equivalents, then the net benefits calculated using the social rate of return on capital is not even a lower bound.[21] Li and Pizer (2021) further generalize the SOC framework and demonstrate that temporal pattern of benefits is important and that when benefits occur far in the future discounting using the social rate of return on capital again is not even a lower bound on net benefits.

For regulations whose benefits and costs occur over a relatively short time frame, the range of net benefits computed using the two discounting approaches will be relatively narrow. Therefore, there is less risk in maintaining an uninformed prior over the share of regulatory costs that will displace investment and using the potential bounding cases for net benefits. However, for cases where the costs are borne early in the time horizon and benefits occur for decades or even centuries, such as with GHG mitigation, the two estimates of net benefits will differ significantly. In this case, the risk to society of maintaining an uninformed prior over the share of regulatory costs borne by investment is significantly higher. In turn, the preferred approach is to discount benefits using the consumption rate of interest and strive to provide a more complete measure of costs, accounting for displacement of investment whose social rate of return exceeds the private rate of return, either by using a shadow price of capital approach or a general equilibrium framework, like a computable general equilibrium model.

It is important to note that even if an appropriately specified blended SOC rate could be calculated based on the share of regulatory costs that are expected to displace investment that would not obviate the need to carefully consider issues of uncertainty and ethics when discounting in an intergenerational context, pointing to a lower rate.

For these reasons, the IWG is returning to the approach of calculating the SC-GHG based on the consumption rate of interest, consistent with the findings of the National Academies (2017)[22].

3.2 New Evidence on the Consumption Discount Rate

The three discount rates selected by the IWG in 2010 are centered around the 3 percent estimate of the consumption interest rate published in OMB's Circular A-4 in 2003. That guidance was based on the real rate of return on 10-year Treasury Securities from the prior 30 years (1973 through 2002), which averaged 3.1 percent. Over the past four decades there has been a substantial and persistent decline in real interest rates (see Figure 1). Recent research has found that this decline has been driven by decreases in the equilibrium real interest rate (Bauer and Rudebusch 2020).

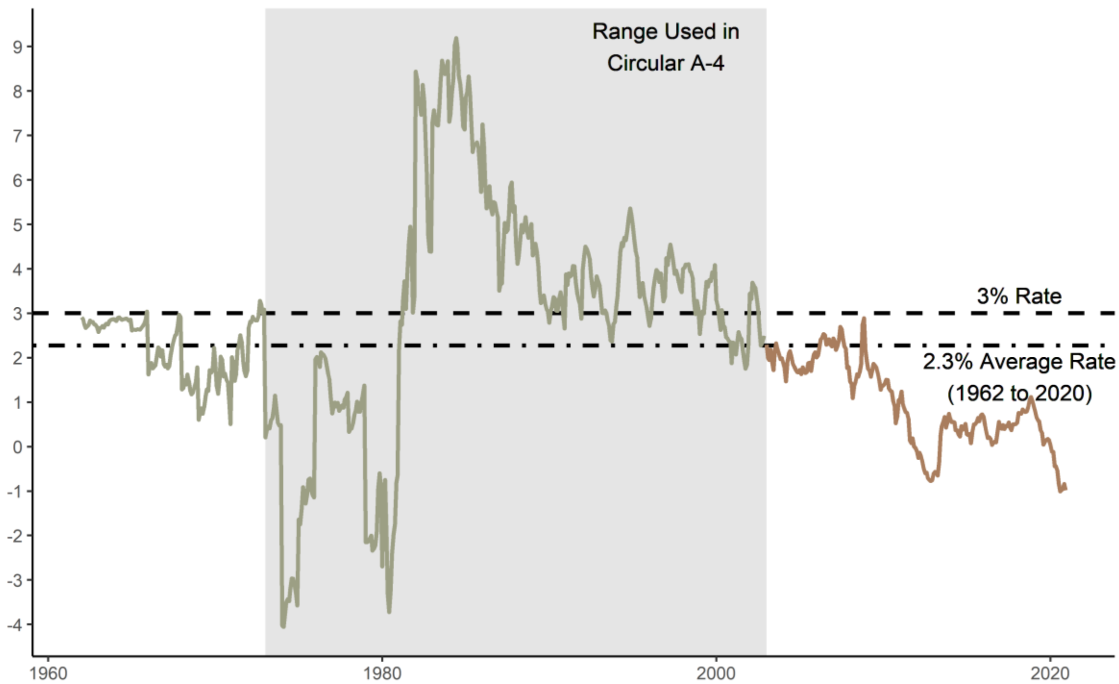
Re-estimating the consumption rate of interest following the same approach applied in Circular A-4, including using data from the most recent 30 years, yields a substantially lower result. The average rate

[21] The SOC approach as outlined in OMB's Circular A-4 is most applicable to cases where the benefits are represented as consumption equivalents and costs may not be. If the benefits of the policy include the inducement of new private investment, discounting both benefits and costs at the social rate of return for capital is no longer appropriate. The results of Bradford (1975) show that in a case where regulatory costs are primarily borne through reduced consumption and the beneficial impacts of the policy may induce private investment the appropriate rate under the SOC approach could be below the consumption interest rate.

[22] NAS (2017) stated "The estimates that result from the SC-IAMs are measured in consumption- equivalent units: thus, a discount rate that reflects how individuals trade off current and future consumption is defensible in this setting" (p. 236-7).

of return on inflation adjusted 10-year Treasury Securities over the last 30 years (1991-2020) is 2.0 percent. These rates are not without historic precedent, such that over the last 60 years the inflation adjusted 10-year Treasury Securities is 2.3 percent. Current real rates of returns below 2 percent are expected to persist. The U.S. Congressional Budget Office (CBO) in its September 2020 Long Term Budget Outlook forecasts real rates of return on 10-Year Treasury Securities to average 1.2 percent over the next 30 years (U.S. CBO 2020). This new information suggests that the consumption rate of interest is notably lower than 3 percent. CEA (2017) examined additional forecasts of 10-Year Treasury Securities and data on futures contracts, reaching the conclusion that the appropriate consumption discount rate should be at most 2 percent.

Figure 1: Monthly 10-Year Treasury Security Rates, Inflation-Adjusted[23]



Several surveys have been conducted in recent years to elicit experts' views on the appropriate discount rates to use in an intergenerational context (e.g., Drupp et al. 2018; Howard and Sylvan 2020). For example, Drupp et al. (2018) offers confirming evidence that the economics profession generally agrees that the appropriate social discount rate is below 3 percent as reflected in the recent trends in data. They surveyed over 200 experts and found a "surprising degree of consensus among experts, with more than three-quarters finding the median risk-free social discount rate of 2 percent acceptable" (Drupp et al. 2018).[24]

[23] Monthly 10-Year Treasury Security returns, adjusted for inflation. Real interest rates prior to 2003 (green line) are calculated by subtracting the annual rate of inflation as measured by the CPI-U from the nominal rate of return on 10-Year constant maturity Treasury Securities. Interest rates from 2003 onwards (brown line) are based on the 10-Year Treasury Inflation-Protected Securities.

[24] For a detailed explanation of discounting concepts and terminology see EPA's *Guidelines for Preparing Economic Analysis* (2010). https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses

It is important to note that the new information pointing to a lower consumption rate of interest, lower than 3 percent, does not obviate the need to carefully consider issues of uncertainty and ethics when discounting in an intergenerational context.[25] If 2 percent was used as the consumption interest rate and adjusted for uncertainty using the results of Newell and Pizer (2003) as was done in the 2010 TSD, the process would yield a discount rate lower than 2 percent. Therefore, a consideration of discount rates below 3 percent, including 2 percent and lower, are warranted when discounting intergenerational impacts.

This is consistent with the 2003 recommendation in OMB's Circular A-4 that noted "[a]lthough most people demonstrate time preference in their own consumption behavior, it may not be appropriate for society to demonstrate a similar preference when deciding between the well-being of current and future generations" and found that certainty equivalent discount rates as low as 1 percent could be appropriate for intergenerational problems (OMB 2003). Similarly, if implementing a declining discount rate schedule to account for uncertainty (see next section), an updated consumption rate of interest, based on additional data presented above, may be a starting point for an update.

In light of the evidence and discussion on discount rates presented in this TSD and elsewhere, the recommendation from OMB's Circular A-4 to include further sensitivity analysis with lower discount rates when a rule has important intergenerational benefits or costs, and the direction to the IWG in E.O. 13990 to ensure that the SC-GHG reflect the interest of future generations, the IWG finds it appropriate as an interim recommendation that agencies may consider conducting additional sensitivity analysis using discount rates below 2.5%.

3.3 Analytic Consistency and Declining Discount Rates

While the consumption rate of interest is an important driver of the benefits estimate, it is uncertain over time, as may be observed in Figure 1. Weitzman (1998, 2001) showed theoretically and Newell and Pizer (2003) and Groom et al. (2005) confirmed empirically that discount rate uncertainty can have a large effect on net present values. A main result from these studies is that if there is a persistent element to the uncertainty in the discount rate (e.g., the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. This is because lower discount rates tend to dominate over the very long term (see Weitzman 1998, 1999, 2001; Newell and Pizer 2003; Groom et al. 2005; Gollier 2009; Summers and Zeckhauser 2008; Gollier and Weitzman 2010; Arrow et al. 2013; Cropper et al. 2014; and Arrow et al. 2014).

The proper way to specify a declining discount rate schedule remains an active area of research. One approach is to develop a stochastic model of interest rates that is empirically estimated and used to calculate the certainty equivalent declining discount rate schedule (e.g., Newell and Pizer 2003; Groom et al. 2007). An alternative approach is to use the Ramsey equation based on a forecast of consumption growth rates that accounts for uncertainty (e.g., Cropper et al. 2014; Arrow et al. 2013). If the shocks to consumption growth are positively correlated over time then the result of the Ramsey equation will be a certainty-equivalent discount rate schedule that declines over time (Goiller 2014). Others have argued for a less structural approach to specify a declining discount rate schedule (e.g., Weitzman 2001, the United

[25] For a more detailed explanation of ethical and uncertainty considerations around discounting see National Academies (2017) and the 2010 TSD (IWG 2010).

Kingdom's "Green Book" for regulatory analysis (HM Treasury 2020), the declining discount schedule in France (Lebègue 2005) and varying the discount rate based on the time period in Germany (Schwermer 2012, U.S. GAO 2020)). This approach uses a higher discount rate initially, like the current estimate of the consumption interest rate, but applies a graduated scale of lower discount rates further out in time.[26]

Instead of explicitly specifying a declining discount rate schedule, the IWG in 2010 elected to use a constant but lower discount rate to capture the directional effect of the literature on discounting under uncertainty. Specifically, the IWG considered two declining discount rate schedules based on the mean-reverting and random walk models from Newell and Pizer (2003) starting at a discount rate of 3 percent. The 2.5 percent discount rate selected by the IWG in 2010 reflected the midpoint between the average certainty equivalent discount rates of both models. The approach of using a lower, but constant, discount rate to capture the effect of uncertainty has led to inconsistency in regulatory analyses, where impacts occurring in a given year are discounted at different rates depending on whether they are related to climate change (Arrow et al. 2014). The National Academies (2017) and EPA's Science Advisory Board (2021) have recommended that the U.S. Government establish an explicit declining discount rate schedule that is applied to all regulatory impacts in an analysis to capture the effect of uncertainty on long-term discount rates, while also maintaining consistency across impact categories in the analysis. The IWG will consider the literature on declining discount rates and the recommendations of the National Academies (2017) and EPA's Science Advisory Board (2021) as it develops future updates to the SC-GHG. In the interim, the IWG is returning to the use of the 2.5, 3, and 5 percent discount rates in calculating the SC-GHG but recommends that agencies describe potential limitations in their analyses to ensure transparency. As noted above, agencies may also consider discount rates below 2.5 percent as part of a sensitivity analysis.

4 Interim Estimates of SC-CO_2, SC-CH_4, SC-N_2O

The interim SC-GHG estimates presented in this TSD rely on the same models and harmonized inputs for the socioeconomic emissions scenarios and equilibrium climate sensitivity distribution used for USG SC-GHG estimates since 2013. Specifically, the SC-GHG estimates rely on an ensemble of three IAMs: Dynamic Integrated Climate and Economy (DICE) 2010 (Nordhaus 2010); Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) 3.8 (Anthoff and Tol 2013a, 2013b); and Policy Analysis of the Greenhouse Gas Effect (PAGE) 2009 (Hope 2013). IAMs are useful because they combine climate processes, economic growth, and feedback between the climate and the global economy into a single modeling framework. They gain this advantage at the expense of a more detailed representation of underlying climatic and economic systems. DICE, PAGE, and FUND all take stylized, reduced-form approaches and have been widely used in the economic and scientific literature since the 1990s. They are periodically updated by the model developers, but as discussed further in Section 5, the versions of the three models used in the 2013 and 2016 TSDs do not reflect the tremendous increase in the scientific and economic understanding of climate-related damages that has occurred in the past decade. The three IAMs

[26] For instance, the United Kingdom applies a discount rate of 3.5 percent to the first 30 years; 3 percent for years 31 - 75; 2.5 percent for years 76 - 125; 2 percent for years 126 - 200; 1.5 percent for years 201 - 300; and 1 percent after 300 years. As a sensitivity, it recommends a discount rate of 3 percent for the first 30 years, also decreasing over time.

were run using a common set of assumptions in each model for future population, economic, and GHG emissions growth, as well as equilibrium climate sensitivity (ECS) – a measure of the globally averaged temperature response to increased atmospheric CO_2 concentrations. The socioeconomic and emission projections included five reference scenarios based on the Stanford Energy Modeling Forum EMF-22 modeling exercise (Clarke, et al. 2009; Fawcett, et al. 2009). The models were run using a probability distribution for ECS, calibrated to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report findings using the Roe and Baker (2007) distribution. Details on these versions of the IAMs and the harmonized inputs are presented in the 2016 TSD and Addendum and 2010 TSD. (IWG 2010, 2016a, 2016b). The 2016 Addendum also describes the methodology used to calculate the SC-CH_4 and SC-N_2O estimates in greater detail.[27] Finally, for the reasons set forth in Section 3 above, the interim estimates were based on three constant discount rates of 2.5, 3, and 5 percent.

The combination of three models and five scenarios produced 15 separate frequency distributions of SC-GHG estimates for each discount rate in a given year, with each distribution consisting of 10,000 estimates based on draws from the standardized ECS distribution (as well as distributions of parameters treated as uncertain in two of the models (FUND and PAGE)). For each discount rate, the IWG combined the distributions across models and socioeconomic emissions scenarios (applying equal weight to each) and then selected a set of four values for use in benefit-cost analyses: an average value resulting from the model runs for each of three discount rates (2.5%, 3%, and 5%), plus a fourth value, selected as the 95th percentile of estimates based on a 3 percent discount rate. The fourth value was included to provide information on potentially higher-than-expected economic impacts from climate change, conditional on the 3% estimate of the discount rate. For this purpose, the SC-GHG value for the 95th percentile at a 3 percent discount rate was presented.[28] For the purposes of capturing the uncertainties involved in analyses, the IWG emphasized previously and emphasizes in this TSD the importance and value of including all four SC-GHG values. In particular, values based on lower discount rates are consistent with the latest scientific and economic understanding of discounting approaches relevant for intergenerational analysis (described in Section 3).

Tables 1-3 show the four selected values for SC-CO_2, SC-CH_4, and SC-N_2O, respectively, in five-year increments from 2020 to 2050. These estimates are reported in 2020 dollars but are otherwise identical to those presented in the previous version of the TSD and its Addendum, released in August 2016.[29] The

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[27] The IWG calculated the SC-CH_4 and SC-N_2O estimates following the approach used in Marten et al. (2015). In order to develop SC-CH_4 and SC-N_2O estimates consistent with the methodology underlying the SC-CO_2 estimates, Marten et al. (2015) needed to augment the IWG modeling framework in two respects: (1) augment the climate model of two of the IAMs to explicitly consider the path of additional radiative forcing from a CH_4 or N_2O perturbation, and (2) add more specificity to the assumptions regarding post-2100 baseline CH_4 and N_2O emissions. See IWG (2016b) for more discussion of these two modeling modifications and the peer review and public comment processes accompanying their development.

[28] A detailed set of percentiles by model and scenario combination and additional summary statistics for the 2020 values is available in the 2016 TSD and Addendum (IWG 2016a, 2016b).

[29] The values in Tables 1-3 are the same as those reported in the 2016 TSD and Addendum adjusted for inflation to 2020 dollars using the annual GDP Implicit Price Deflator values in U.S. Bureau of Economic Analysis (BEA) NIPA Table 1.1.9: 113.626 (2020)/ 92.486 (2007) = 1.228575 (U.S. BEA 2021). Values of SC-CO_2 presented in this TSD are rounded to the nearest dollar; SC-CH_4 and SC-N_2O are rounded to two significant figures. The annual unrounded estimates are available on OMB's website for use in regulatory and other analyses: https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs.

full set of annual SC-GHG values between 2020 and 2050, calculated using linear interpolation between the numbers shown in Tables 1-3, is reported in the Appendix and the full set of model results are available on the OMB website.[30] The SC-GHG estimates increase over time within the models – i.e., the societal harm from one metric ton emitted in 2030 is higher than the harm caused by one metric ton emitted in 2025 – because future emissions produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change, and because GDP is growing over time and many damage categories are modeled as proportional to GDP.

Table 1: Social Cost of CO_2, 2020 – 2050 (in 2020 dollars per metric ton of CO_2)[31]

	Discount Rate and Statistic			
Emissions Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	14	51	76	152
2025	17	56	83	169
2030	19	62	89	187
2035	22	67	96	206
2040	25	73	103	225
2045	28	79	110	242
2050	32	85	116	260

Table 2: Social Cost of CH_4, 2020 – 2050 (in 2020 dollars per metric ton of CH_4)

	Discount Rate and Statistic			
Emissions Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	670	1500	2000	3900
2025	800	1700	2200	4500
2030	940	2000	2500	5200
2035	1100	2200	2800	6000
2040	1300	2500	3100	6700
2045	1500	2800	3500	7500
2050	1700	3100	3800	8200

[30] https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs

[31] The values reported in this TSD are identical to those reported in the 2016 TSD adjusted for inflation to 2020 dollars using the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9: 113.626 (2020)/ 92.486 (2007) = 1.228575 (U.S. BEA 2021). The IWG combined the distributions across models and socioeconomic emissions scenarios for each of three discount rates (2.5%, 3%, and 5%), plus a fourth value, selected as the 95th percentile of estimates based on a 3 percent discount rate. Values of SC-CO_2 are rounded to the nearest dollar; SC-CH_4 and SC-N_2O are rounded to two significant figures. The annual unrounded estimates are available on OMB's website for use in regulatory and other analyses: https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs.

Table 3: Social Cost of N_2O, 2020 – 2050 (in 2020 dollars per metric ton of N_2O)

	Discount Rate and Statistic			
Emissions Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	5800	18000	27000	48000
2025	6800	21000	30000	54000
2030	7800	23000	33000	60000
2035	9000	25000	36000	67000
2040	10000	28000	39000	74000
2045	12000	30000	42000	81000
2050	13000	33000	45000	88000

Multiplying the SC-GHG in year *t* by the change in emissions in year *t* yields the monetized value of future emission changes from a year *t* perspective. This value must then be discounted to the present before being included in an analysis. For this purpose, the monetized value of future emission changes should be discounted at the same rate used to calculate the initial SC-GHG to ensure internal consistency—i.e., future damages from climate change using the SC-GHG at 2.5 percent should be discounted to the base year of the analysis using the same 2.5 percent rate.

As noted above, to correctly assess the total climate damages to U.S. citizens and residents, an analysis must account for both the impacts that occur within U.S. borders and spillover effects from climate action elsewhere. For the reasons discussed in Section 2 above, estimates focusing on the climate impacts occurring within U.S. borders are an underestimate of the benefits of GHG mitigation accruing to U.S. citizens and residents and, therefore, are not equivalent to a domestic estimate of the SC-GHG. (Section 2 also discusses why analyses should center their attention on a global measure of the SC-GHG). Additionally, models differ in their treatment of regional damages[32] with one of the model developers recently noting that regional damages are "both incomplete and poorly understood" (Nordhaus 2017). The IWG further notes that the domestic focused SC-GHG estimates used under E.O. 13783[33] did not

[32] Both the PAGE and FUND model contain a U.S. region and so the damages for this region are reported directly for those models. The DICE 2010 model does not explicitly include a separate U.S. region in the model. For the domestic focused SC-GHG estimates used under E.O. 13783, the DICE model damages occurring within U.S. borders were approximated as 10 percent of the global estimate from the DICE model runs, based on the results from a regionalized version of the model (RICE 2010) reported in Table 2 of Nordhaus (2017). Although the regional shares reported in Nordhaus (2017) are specific to SC-CO_2, they were also used in approximating the share of marginal damages from CH_4 and N_2O emissions occurring within U.S. borders. Direct transfer of the U.S. share from the SC-CO_2 likely understate the U.S. share of the IWG global SC-CH_4 estimates based on DICE due to the combination of three factors: a) regional damage estimates are known to be highly correlated with output shares (Nordhaus 2017, 2014), b) the U.S. share of global output decreases over time in all five EMF-22 based socioeconomic scenarios used for the model runs, and c) the bulk of the temperature anomaly (and hence, resulting damages) from a perturbation in emissions in a given year will be experienced earlier for CH_4 than CO_2 due to the shorter lifetime of CH_4 relative to CO_2.

[33] For emissions occurring in 2020, the average estimates of marginal damages occurring within the U.S. borders for CO_2, CH_4, and N_2O emissions across all model runs that were used in 2017-2020 regulatory analyses were \$7/mtCO_2,

benefit from a consensus-based IWG process, were not documented in a dedicated TSD, subjected to a SC-GHG specific notice and comment period, or considered by National Academies in their 2017 review. The IWG will request public comments on the new information presented in this TSD, as well as other topics and issues the IWG will address as we develop the next set of updates (see Section 6).

4.1 Treatment of Uncertainty

Uncertainty about the value of the SC-GHGs is in part inherent, as with any analysis that looks into the future, but it is also driven by current data gaps associated with the complex physical, economic, and behavioral processes that link GHG emissions to human health and well-being. Some sources of uncertainty pertain to aspects of the natural world, such as quantifying the physical effects of greenhouse gas emissions on Earth systems. Other sources of uncertainty are associated with current and future human behavior and well-being, such as population and economic growth, GHG emissions, the translation of Earth system changes to economic damages, and the potential extent and costs of adaptation. It is important to note that even in the presence of uncertainty, scientific and economic analysis can provide valuable information to the public and decision makers. Such uncertainty should, however, be acknowledged, communicated as clearly as possible, and taken into account in the analysis whenever possible.

The 2016 TSD and the 2017 National Academies report provide detailed discussions of the ways in which the modeling underlying the development of the SC-GHG estimates addressed quantified sources of uncertainty.

In developing the SC-CO_2 estimates, the IWG considered various sources of uncertainty through a combination of a multi-model ensemble, probabilistic analysis, and scenario analysis. For example, the three IAMs used collectively span a wide range of Earth system and economic outcomes to help reflect the uncertainty in the literature and in the underlying dynamics being modeled. The use of an ensemble of three different models is also intended to, at least partially, address the fact that no single model includes all of the quantified economic damages. It also helps to reflect structural uncertainty across the models, which is uncertainty in the underlying relationships between GHG emissions, Earth systems, and economic damages that are included in the models. Bearing in mind the different limitations of each model (discussed in the 2010 TSD) and lacking an objective basis upon which to differentially weight the models, the three IAMs were given equal weight in the analysis.

The IWG used Monte Carlo techniques to run the IAMs a large number of times. In each simulation the uncertain parameters are represented by random draws from their defined probability distributions. In all three models the equilibrium climate sensitivity is treated probabilistically based on the probability distribution described in the 2010 TSD. The equilibrium climate sensitivity is a key parameter in this

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\$190/mtCH_4, and \$2,300/mtN_2O (in 2020 dollars), respectively, using a 3 percent discount rate, and \$1/mtCO_2, \$59/mtCH_4, and \$380/mtN_2O (in 2020 dollars) using a 7 percent discount rate. These values increased over time; for 2050 emissions, the average estimates of marginal damages occurring within the U.S. borders are \$11/mtCO_2, \$380/mtCH_4, and \$4,000/mtN_2O (in 2020 dollars) using a 3% discount rate and \$3/mtCO_2, \$160/mtCH_4, and \$1,000/mtN_2O (in 2020 dollars) using a 7% discount rate. Using the same approach with a 2.5 percent discount rate, the average estimates of marginal damages occurring within the U.S. borders of CO_2, CH_4, and N_2O for emissions in 2020 are \$10/mtCO_2, \$240/mtCH_4, and \$3,300/mtN_2O (in 2020 dollars), respectively; for 2050 emissions, these values increase to \$15/mtCO_2, \$450/mtCH_4, and \$5,300/mtN_2O (in 2020 dollars).

analysis because it helps define the strength of the climate response to increasing GHG concentrations in the atmosphere. In addition, the FUND and PAGE models define many of their parameters with probability distributions instead of point estimates. For these two models, the model developers' default probability distributions are maintained for all parameters other than those superseded by the IWG's harmonized inputs (i.e., equilibrium climate sensitivity, socioeconomic and emissions scenarios, and discount rates). More information on the uncertain parameters in PAGE and FUND is presented in Appendix C of the 2016 TSD (IWG 2016a).

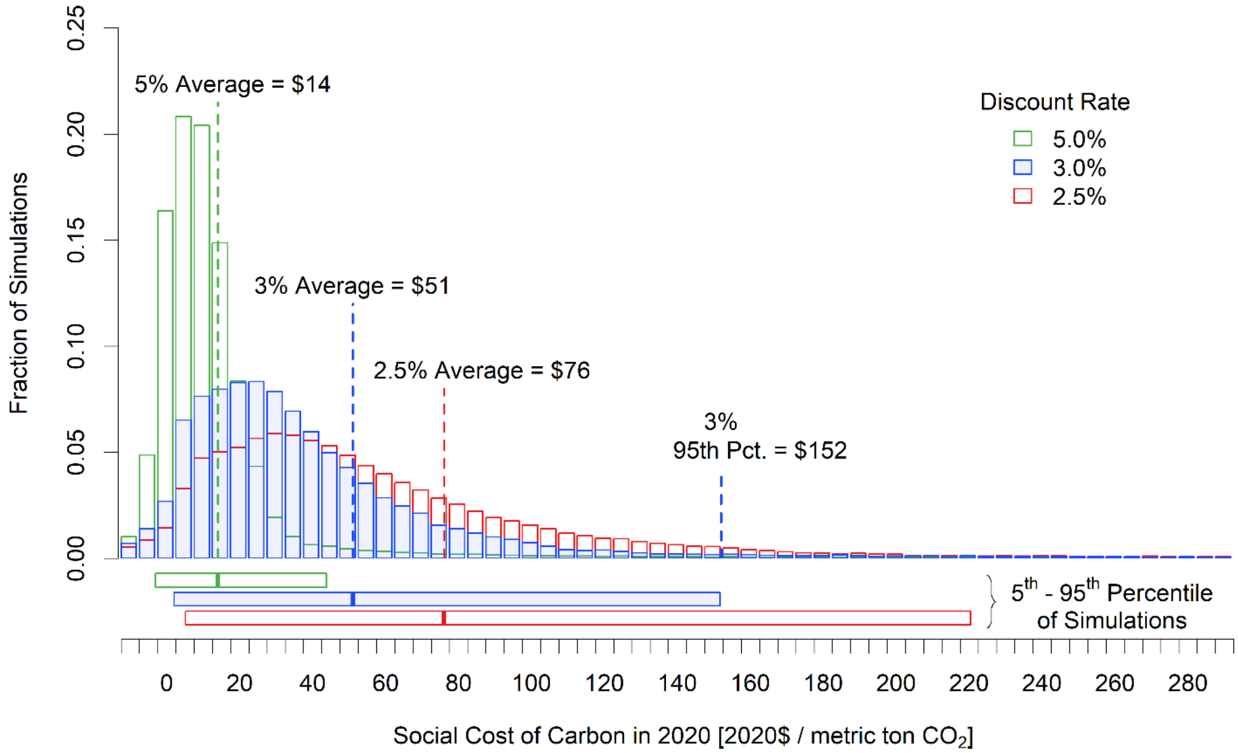
Finally, based on the review of the literature, the IWG chose discount rates that reflect reasonable judgements under both prescriptive and descriptive approaches to intergenerational discounting. As discussed in the 2010 TSD, in light of disagreement in the literature on the appropriate discount rate to use in this context and uncertainty about how rates may change over time, the IWG selected three certainty-equivalent constant discount rates to span a plausible range: 2.5, 3, and 5 percent per year. However, unlike the approach taken for consolidating results across models and socioeconomic and emissions scenarios, the SC-GHG estimates are not pooled across different discount rates because the range of discount rates reflects both uncertainty and, at least in part, different policy or value judgements.

The outcome of accounting for various sources of uncertainty using the approaches described above is a frequency distribution of the SC-CO_2 estimates for emissions occurring in a given year for each of the three discount rates. These frequency distributions reflect the uncertainty around the input parameters for which probability distributions were defined, as well as from the multi-model ensemble and socioeconomic and emissions scenarios where probabilities were implied by the equal weighting assumption. It is important to note that the probability distribution for the SC-GHG calculated using the modeling approach outlined above does not fully characterize uncertainty about the SC-GHG due to impact categories omitted from the models and sources of uncertainty that have not been fully characterized due to data limitations. To name just one example of many known GHG-induced damages omitted in the three IAMs, none of the models include damages associated with ocean acidification, and, therefore, naturally the models do not reflect uncertainty as to the potential severity of those damages.

Figures Figure ***2*** through Figure ***4*** present the frequency distribution of the interim SC-CO_2, SC-CH_4, and SC-N_2O estimates, respectively, for emissions in 2020 and for each discount rate. Each distribution represents 150,000 estimates based on 10,000 simulations for each combination of the three models and five socioeconomic and emissions scenarios. In general, the distributions are skewed to the right and have long right tails, which tend to be longer for lower discount rates. To highlight the difference between the impact of the discount rate on the SC-GHG and other quantified sources of uncertainty, the bars below the frequency distributions provide a symmetric representation of quantified variability in the SC-GHG estimates conditioned on each discount rate. The full set of SC-GHG results through 2050 is available on OMB's website.

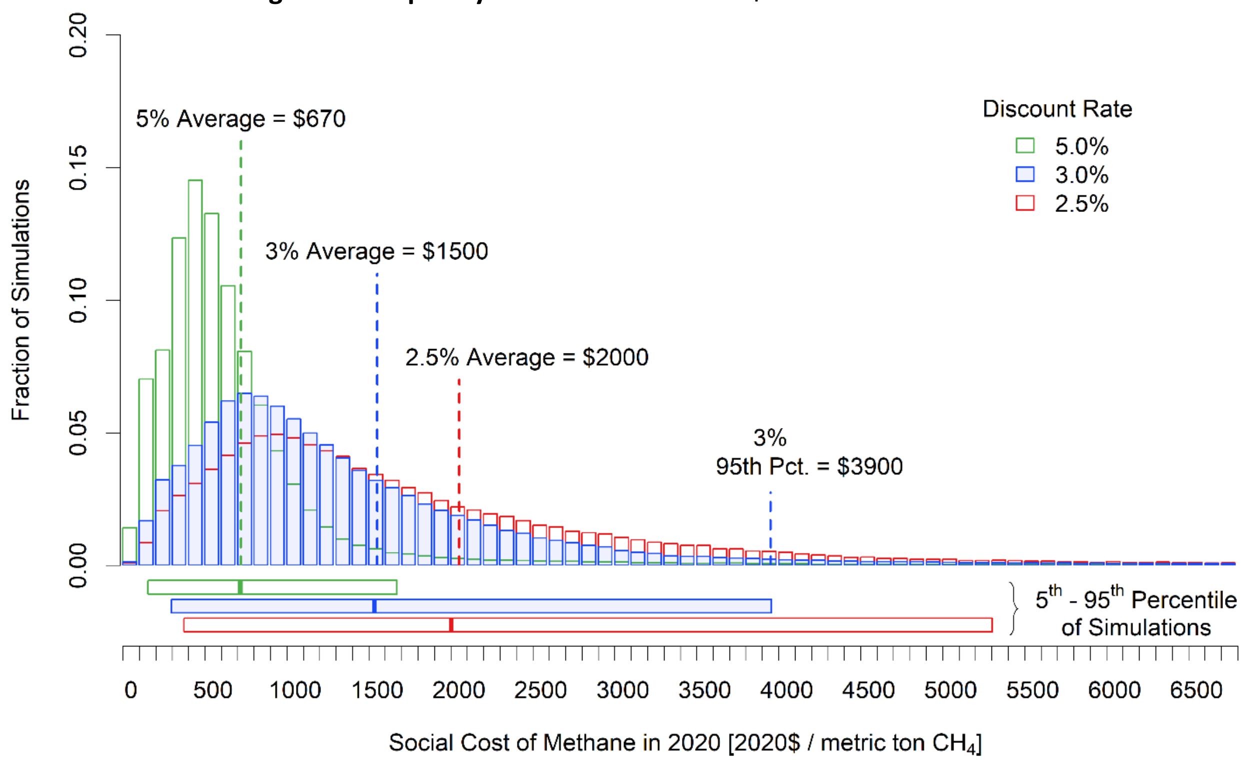
As illustrated by the frequency distributions in Figures Figure ***2*** through Figure ***4*** , the assumed discount rate plays a critical role in the ultimate estimate of the SC-GHG. As explained in Section 3, this is because GHG emissions today continue to impact society far out into the future, so with a higher discount rate, costs that accrue to future generations are weighted less, resulting in a lower estimate. As discussed in Section 3.1, new data and evidence strongly suggest that the consumption interest rate is likely to be less than 3, near 2 percent or lower.

Figure 2: Frequency Distribution of SC-CO_2 Estimates for 2020[34]



[34] Although the distributions and numbers in Figure 2 are based on the full set of model results (150,000 estimates for each discount rate), for display purposes the horizontal axis is truncated with 0.81 percent of the estimates falling below the lowest bin displayed and 3.56 percent of the estimates falling above the highest bin displayed.

Figure 3: Frequency Distribution of SC-CH_4 Estimates for 2020[35]



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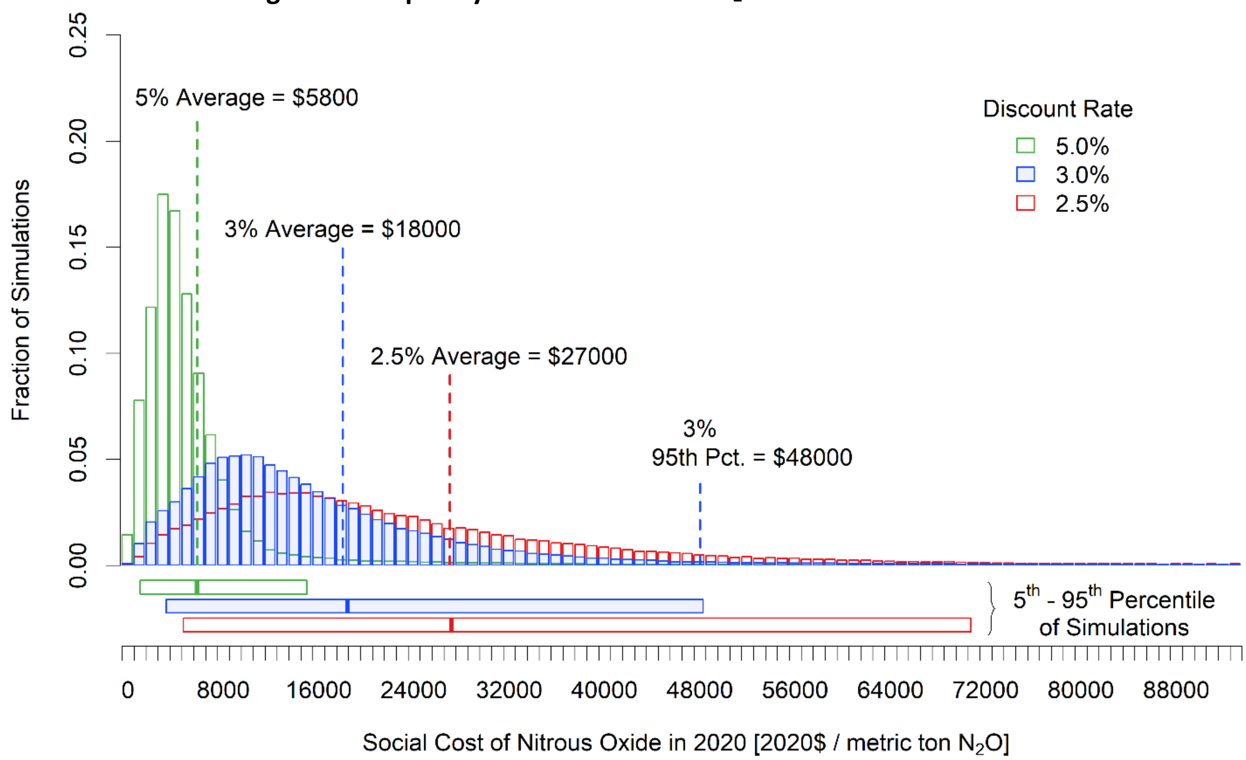
[35] Although the distributions and numbers in Figure 3 are based on the full set of model results (150,000 estimates for each discount rate), for display purposes the horizontal axis is truncated with 0.12 percent of the estimates falling below the lowest bin displayed and 2.84 percent of the estimates falling above the highest bin displayed.

Figure 4: Frequency Distribution of SC-N_2O Estimates for 2020[36]



While the figures above reflect the uncertainties that are explicitly considered in a quantitative manner, there are other areas of uncertainty that are not quantitatively reflected in the interim SC-GHG estimates. The scientific and economics literature has further explored known sources of uncertainty related to estimates of the SC-GHG. For example, published studies explore the sensitivity of IAMs and the resulting SC-GHG estimates to different assumptions embedded in the models (see, e.g., Hope 2013, Anthoff and Tol 2013a, and Nordhaus 2014). However, there remain additional sources of uncertainty that have not been fully characterized and explored due to data limitations and lack of consensus in the scientific or economic literature about how to represent them. Additional research is needed to expand the quantification of various sources of uncertainty in estimates of the SC-GHG (e.g., developing explicit probability distributions for more inputs pertaining to climate impacts and their valuation).

4.2 Other Modeling Limitations

The interim SC-GHG estimates presented in this TSD have a number of limitations, as would be expected for any modeling exercise that covers such a broad scope of scientific and economic issues across the complex global landscape. These include the incomplete treatment of catastrophic and non-catastrophic impacts in the IAMs, their incomplete treatment of adaptation and technological change, the incomplete way in which inter-regional and intersectoral linkages are modeled, uncertainty in the extrapolation of

[36] Although the distributions and numbers in Figure 4 are based on the full set of model results (150,000 estimates for each discount rate), for display purposes the horizontal axis is truncated with 0.1 percent of the estimates falling below the lowest bin displayed and 2.85 percent of the estimates falling above the highest bin displayed.

damages to high temperatures, and inadequate representation of the relationship between the discount rate and uncertainty in economic growth over long time horizons.

There are newer versions available of each of the IAMs used to calculate the interim SC-GHG estimates in this TSD that offer improvements in some of these areas beyond the version of the models used for the interim estimates. For example, the latest version of the PAGE model, PAGE-ICE (Yumashev et al. 2019, Yumashev 2020), extends PAGE09 (Hope 2013) with representation of two nonlinear Arctic feedbacks (permafrost carbon feedback and surface albedo feedback) on the global climate system and economy, among other changes. The newest version of the DICE model, DICE2016-R3 (Nordhaus 2017), includes numerous updates, including changes to the carbon cycle (to better simulate the long-run behavior of larger models with full ocean chemistry) and updated methods for estimating economic activity.[37] At comparable discount rates, DICE2016-R3 would result in SC-CO_2 estimates roughly twice that of the interim estimates presented in this TSD. For example, using a 3% constant discount rate and other IWG modeling assumptions, DICE2016-R3 yields an average SC-CO_2 of $104 (2018 international dollars) for 2020 emissions (Nordhaus 2019a). However, even DICE2016 and PAGE-ICE do not include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature and the science underlying their damage functions lags behind the most recent research. Likewise, the socioeconomic and emissions scenarios used as inputs to the models in this TSD do not reflect new information from the last decade of scenario generation or the full range of projections.

The modeling limitations discussed above do not all work in the same direction in terms of their influence on the SC-GHG estimates. However, it is the IWG's judgment that, taken together, the limitations suggest that the interim SC-GHG estimates presented in this TSD likely underestimate the damages from GHG emissions. In particular, the IPCC's Fourth Assessment Report (IPCC 2007), which was the most current IPCC assessment available at the time when the IWG decision over the ECS input was made, concluded that SC-CO_2 estimates "very likely…underestimate the damage costs" due to omitted impacts. Since then, the peer-reviewed literature has continued to support this conclusion, as noted in the IPCC's Fifth Assessment report (IPCC 2014) and other recent scientific assessments (e.g., IPCC 2018, 2019a, 2019b; U.S. Global Change Research Program (USGCRP) 2016, 2018; and National Academies 2016b, 2019). These assessments confirm and strengthen the science, updating projections of future climate change and documenting and attributing ongoing changes. For example, sea level rise projections from the IPCC's Fourth Assessment report ranged from 18 to 59 centimeters by the 2090s relative to 1980-1999, while excluding any dynamic changes in ice sheets due to the limited understanding of those processes at the time (IPCC 2007). A decade later, the Fourth National Climate Assessment projected a substantially larger sea level rise of 30 to 130 centimeters by the end of the century relative to 2000, while not ruling out even more extreme outcomes (USGCRP 2018). Section 5 briefly previews some of the recent advances in the

[37] Relative to the previous version of DICE, DICE2013, the DICE2016 updates to the carbon cycle and the methods for estimating economic activity had the greatest impact on the SC-CO_2. Based on Archer et al. (2009), DICE2016's three-box carbon cycle model aims to better simulate the long-run behavior of larger models with full ocean chemistry. In measuring economic activity, one of the important changes in DICE2016 was to move from market exchange rates to measures adjusted for purchasing power parity when comparing monetary values across countries. See Nordhaus (2017, 2019a) for more discussion of these and other updates included in DICE2016-R3. Nordhaus has also recently explored side extensions of DICE2016. For example, DICE-GIS extends DICE2016 to include representation of sea level rise from melting of the Greenland Ice Sheet (Nordhaus 2019b, Pizer 2019).

scientific and economic literature that the IWG is actively following and that could provide guidance on, or methodologies for, addressing some of the limitations with the interim SC-GHG estimates.

5 Scientific and Economic Advances

The research community has made considerable progress in developing new data and methods that will provide a path forward for bringing the USG SC-GHG estimates closer to the current frontier of climate science and economics and could address many of the National Academies' (2017) recommendations. This research since 2010/2013 has advanced knowledge regarding each key component in the process of estimating the SC-GHG. This TSD does not intend to provide a detailed review of all these advancements, but this section does highlight some of the key research and new information that the IWG will be reviewing as it works to improve the SC-GHG estimates. As part of the process for updating the SC-GHG estimates by January 2022, the IWG will survey the scientific literature, including the economic literature, to identify advances to address the National Academies (2017) recommendations.

Climate system representation. There have been advancements in climate science since the publication of the IPCC's Fourth Assessment Synthesis report (IPCC 2007), which was the basis for the IWG decision on what equilibrium climate sensitivity (ECS) input to use in the IAM model runs. The conclusions of recent scientific assessments, e.g., from the IPCC (2014, 2018, 2019a, 2019b), the USGCRP (2016, 2018), and the National Academies (2016b, 2019), confirm and strengthen the science, updating projections of future climate change and documenting and attributing ongoing changes. In addition, there are reduced complexity climate models that could offer meaningful improvement over current representation of climate dynamics in existing IAMs (Nicholls et al. 2020). For example, the National Academies (2017) stated that the FAIR model (Smith et al., 2018) satisfies all of the criteria set by National Academies (2017) recommendations related to the representation of climate system dynamics, generates projections of future warming consistent with more complex, state of the art models, can be used to accurately characterize current best understanding of uncertainty, and can be easily implemented and transparently documented. Reduced complexity sea level rise models are also being developed that can provide projections for damage functions that require sea level estimates, including the contributions of thermal expansion and glacial and ice sheet melting based on recent scientific research (e.g., Wong et al. 2017).

***Damage functions*.** At the core of IAMs are "damage functions" that map global mean temperature changes and other physical impacts of climate change into economic (both market[38] and nonmarket[39]) damages. Relative to how much progress has been made in modeling and improving our understanding of climate system dynamics and the physical impacts resulting from temperature change, efforts involved in, and the public resources targeted at, understanding how these physical changes translate into economic impacts have been significantly smaller (Auffhammer 2018). Even so, as illustrated in Figure 5, in the time since the versions of the IAMs used in this TSD were published, there has been an explosion of research on climate impacts and damages.

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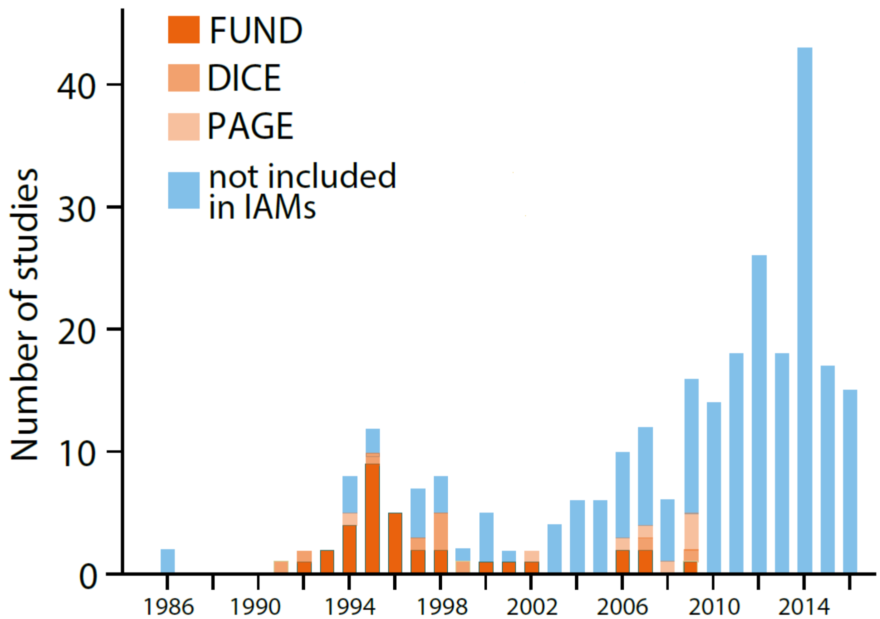
[38] Examples of market damages include changes in net agricultural productivity, energy use, and property damage from increased flood risk.

[39] Examples of nonmarket damages include services that natural ecosystems provide to society.

Figure 5. New Research on Climate Impacts[40]



Source: Greenstone (2016).

Several efforts are underway to draw on recent literature for improving damage functions and to generate new damage estimates. In particular, the Climate Impact Lab is undertaking an effort to quantify and monetize damages at a fine spatial scale, relying on rigorous empirical methods to develop plausibly causal estimates for several sectors, including health (Carleton et al. 2020), energy (Rode et al. 2021), labor productivity (Rode et al. 2020), agriculture, conflict, and sea level rise.[41] Other research efforts have sought to update the damage function for one sector in an existing IAM based on an updated review of the empirical literature on climate impacts pertaining to that sector (e.g., Moore et al. (2017) for agriculture damages in the FUND model). Damage functions specific to impacts within the U.S. have also been developed and improved for a number of sectors, such as impacts on coastal property, mortality due to extreme temperatures, transportation infrastructure, electricity supply and demand, water quality, recreation, and allergies (Neumann et al. 2020) and impacts of climate change on air quality and human health (Fann et al. 2021). There is also an emerging literature focused on incorporating interactions among

[40] In many cases, the three IAMs used different studies for calibration. This is particularly true of FUND, which used studies relating to different subsectors of the model, whereas DICE and PAGE did not have as detailed a sectoral breakdown. That means that summing across these different models is likely valid in all but a few isolated cases. The blue bars include studies uncovered from a comprehensive literature review in the economics literature (and a few others in public health or relevant disciplines) by the Climate Impact Lab (CIL) through early 2016. Each of the studies counted in blue was determined by CIL to have employed a research design that allowed for the causal interpretation of results (Greenstone 2016).

[41] The Climate Impact Lab is a multidisciplinary collaboration of climate scientists, economists, computational experts, researchers, analysts, and students working to build empirically derived, local-level estimates of climate change damages and an empirically based SC-CO_2. More information on the Climate Impact Lab can be found at: http://www.impactlab.org/.

regions and impacts. For example, biodiversity loss (e.g., animal pollinators) as a result of climate-driven ecosystem stress could amplify impacts of climate change on agriculture. See National Academies (2017) for more discussion of recent research addressing these and other types of interactions.

Related to the development of damage functions, damages from climate change are uncertain and hence pose additional risks. Reductions in GHG emissions reduce not only expected damages, but also reduce the uncertainty and risks of catastrophic events. Evaluating the damages using the mean outcome does not account for the benefits of reducing uncertainty. Some researchers have raised the need to include this consideration in the SC-GHG (e.g., Carleton and Greenstone 2021) consistent with the observation that individuals are regularly willing to pay for insurance against bad outcomes.

Furthermore, E.O. 13990 instructs the IWG to consider how best to reflect environmental justice and intergenerational equity concerns in assessing climate damages. In the context of climate policy, equity considerations are discussed by economists, ethicists, and others in several ways: distributional effects within a specific country, effects across countries, and intergenerational equity impacts. Economists, ethicists, and others have proposed potential ways to incorporate equity into the SC-GHG. For example, IAM developers have introduced the use of equity weights potentially incorporate these concerns (e.g., Hope 2008; Anthoff and Emmerling 2019).

Socioeconomic and Emissions Projections. The socioeconomic and emissions projections underlying current USG SC-GHG estimates were developed around 2007. Since that time, there have been efforts to develop updated baseline scenarios. Several researchers have started using deterministic scenarios available as part of the IPCC's Fifth Assessment Report Working Group 3 database and the Shared Socioeconomic Pathways (SSPs) linked with the Representative Concentration Pathway (RCP) emissions scenarios (Riahi et al. 2017 and Moss et al. 2010) as benchmark scenarios. Resources for the Future (RFF) has engaged in a research effort to implement each of the National Academies' (2017) recommendations, in collaboration with research partners.[42] One part of this effort is focused on developing probability distributions for future paths of population, GDP, and emissions via using econometrics and expert elicitation techniques. For example, economic growth projections are being built off the results of a formal expert elicitation of leading growth economists together with recent research by Muller, Stock and Watson (2020), who have refined a foundational statistical methodology for generating long-run projections of economic growth at the country level. RFF plans to make these probabilistic scenarios easily usable on Mimi.jl, an open-source modular computing platform used for creating, running, and performing analyses on IAMs.[43]

Discounting. Another area of active research relates to discounting, including the best available evidence on the consumption rate of interest and the application of discount rates to regulations in which some costs and benefits accrue intra-generationally while others accrue inter-generationally. As described in Section 3.2, new empirical evidence suggests that consumption interest rates are now below the previous estimate of 3 percent presented in OMB's Circular A-4. This empirical evidence is also consistent with long-term forecasts by the Congressional Budget Office, suggesting these lower rates will persist (U.S. CBO

[42] For more information on RFF's Social Cost of Carbon Initiative, see: https://www.rff.org/topics/scc/.

[43] Mimi.jl was developed by a team of researchers at UC Berkeley led by David Anthoff in response to a core recommendation from the National Academies (2017) to create an integrated modular approach to draw more readily on expertise from the wide range of scientific disciplines relevant to SC-CO_2 estimation. Mimi.jl provides an interface for defining components and building models in a modularized, transparent way (mimiframework.org).

2020). Future updates to the SC-GHGs estimates will need to reflect the best available evidence from the time series of risk-free rate data and expectations of these rates into the future.

As described in Section 3.3 uncertainty in the discount rate over time yields a declining certainty-equivalent discount rate schedule and can have a dramatic effect on the size of the SC-GHG. While this is not a new theoretical result, new literature has proposed methods for how to incorporate discount rate uncertainty (e.g., Arrow et al., 2013; Cropper et al., 2014) and other nations have implemented declining discount rate schedules for policy analysis (e.g., United Kingdom, France, and Germany). Recent recommendations by the National Academies (2017) and EPA's Science Advisory Board (2021) have encouraged the development and use of a declining certainty-equivalent discount rate schedule as theoretically appropriate and as a method of introducing consistency into analyses that have both near-term and long-term impacts.

In light of new science and evidence, including many of those highlighted in the paragraphs above, other jurisdictions are already considering or have implemented some of the scientific and economic advances discussed above. For example, some states that use SC-GHG estimates in policy analysis have recently updated their approach to discounting based on the increasing evidence that a 3% discount rate is too high for intergenerational analysis. In December 2020, New York issued guidance recommending state agencies use SC-GHG estimates based the same IWG modeling and input decisions as presented in this TSD but with lower discount rates: 2 percent in central scenarios (\$125/mtCO_2 for 2020 emissions (2020 dollars), along with sensitivity analysis at 1 percent and 3 percent (New York Department of Environmental Conservation 2020). Similarly, in Washington state an April 2019 law required utilities to use estimates based on the IWG methodology with a 2.5% discount rate when developing "lowest-cost analyses" for its integrated resource planning and clean energy plans.[44]

Canada is also in the process of updating the SC-GHG estimates used in their regulatory analyses. While the update is underway, they are continuing to use the estimates they adopted in 2016 (which are an adaptation of the IWG global SC-GHG estimates presented in this TSD) as well as a side analysis based on more recent estimates from the academic literature. Based on their review of the literature and latest climatological and economic evidence, they present their current estimates as a "likely underestimate [of] climate-related damages to society" and the side analysis as a way "to illustrate a range of plausible values if the Department were to update its [social cost of carbon] estimate based on new versions of the models currently used."[45] Specifically, the side analysis includes SC-CO_2 estimates based on DICE2016 and PAGE-ICE (\$135 and \$440/mtCO_2 for 2020 emissions (2019 Canadian dollars)).[46]

The IWG will consider the new science and evidence as it works towards a more comprehensive update, including the new research and information described in this section.

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[44] Wash. Sen. Bill. 5116 (signed by Gov. Inslee on May 7, 2019). More information on Washington and other states' use of SC-GHG estimates is compiled by the Institute for Policy Integrity at NYU School of Law (see http://www.costofcarbon.org/states) and discussed in U.S. GAO (2020).

[45] Proposed Clean Fuel Regulations (published for public comment on 12/20/20) http://www.gazette.gc.ca/rp-pr/p1/2020/2020-12-19/pdf/g1-15451.pdf.

[46] Proposed Clean Fuel Regulations (published for public comment on 12/20/20) http://www.gazette.gc.ca/rp-pr/p1/2020/2020-12-19/pdf/g1-15451.pdf.

6 Path Forward

E.O. 13990 reaffirms that "[a]n accurate social cost is essential for agencies to accurately determine the social benefits of reducing greenhouse gas emissions when conducting cost-benefit analyses of regulatory and other actions" (E.O. 13990 2021). The E.O. instructs the IWG to publish interim SC-CO_2, SC-CH_4, and SC-N_2O estimates (collectively, SC-GHG estimates) within 30 days and to publish a set of final estimates by no later than January 2022.[47] In doing so, the E.O. instructs the IWG to consider the recommendations of the National Academies of Science, Engineering, and Medicine as reported in Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide (2017) and other pertinent scientific literature; solicit public comment; engage with the public and stakeholders; seek the advice of ethics experts; and ensure that the SC-GHG estimates reflect the interests of future generations in avoiding threats posed by climate change.

In developing the SC-GHG estimates in 2010, 2013, and 2016 the IWG used consensus-based decision making, relied on peer-reviewed literature and models, and took steps to disclose limitations and incorporate new information by considering public comments and revising the estimates as updated research became available (U.S. GAO 2014). Going forward the IWG commits to maintaining a consensus driven process for making evidence-based decisions that are guided by the best available science and input from the public, stakeholders, and peer reviewers.

While the IWG assesses the current state of the science in each component of the SC-GHG modeling exercise, the IWG is beginning by asking for public comment on how best to incorporate the latest, peer reviewed science to develop an updated set of SC-GHG estimates. The IWG will soon issue a Federal Register notice with a detailed set of requests for public comments on the new information presented in this TSD, as well as other topics and issues the IWG will address as we develop the next set of updates. Among other things, the IWG will ask for public comment on how to incorporate the best available science in the updated SC-GHG estimates, due to be published by January 2022, and how to incorporate the recommendations of the National Academies (2017).

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[47] The Executive Order also requests that the IWG assess the application of the SC-GHG to inform government decision making beyond regulations, in addition to recommending a robust long-term structure for ensuring the SC-GHGs continue to reflect the best available science and economic and that long-term research needs are met.

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Appendix – Annual SC-CO_2, SC-CH_4, and SC-N_2O Values, 2020-2050

The values in Tables A-1 through A-3 are the same as those reported in the 2016 TSD and Addendum adjusted for inflation to 2020 dollars using the annual GDP Implicit Price Deflator values in U.S. Bureau of Economic Analysis (BEA) NIPA Table 1.1.9: 113.626 (2020)/ 92.486 (2007) = 1.228575 (U.S. BEA 2021). Values of SC-CO_2 presented in this TSD are rounded to the nearest dollar; SC-CH_4 and SC-N_2O are rounded to two significant figures. The annual unrounded estimates are available on OMB's website for use in regulatory and other analyses: https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs.

Table A-1: Annual SC-CO_2, 2020 – 2050 (in 2020 dollars per metric ton of CO_2)

	Discount Rate and Statistic			
Emissions Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	14	51	76	152
2021	15	52	78	155
2022	15	53	79	159
2023	16	54	80	162
2024	16	55	82	166
2025	17	56	83	169
2026	17	57	84	173
2027	18	59	86	176
2028	18	60	87	180
2029	19	61	88	183
2030	19	62	89	187
2031	20	63	91	191
2032	21	64	92	194
2033	21	65	94	198
2034	22	66	95	202
2035	22	67	96	206
2036	23	69	98	210
2037	23	70	99	213
2038	24	71	100	217
2039	25	72	102	221
2040	25	73	103	225
2041	26	74	104	228
2042	26	75	106	232
2043	27	77	107	235
2044	28	78	108	239
2045	28	79	110	242
2046	29	80	111	246
2047	30	81	112	249
2048	30	82	114	253
2049	31	84	115	256
2050	32	85	116	260

Table A-2: Annual SC-CH_4, 2020 – 2050 (in 2020 dollars per metric ton of CH_4)

Emissions Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	670	1500	2000	3900
2021	690	1500	2000	4000
2022	720	1600	2100	4200
2023	750	1600	2100	4300
2024	770	1700	2200	4400
2025	800	1700	2200	4500
2026	830	1800	2300	4700
2027	860	1800	2300	4800
2028	880	1900	2400	4900
2029	910	1900	2500	5100
2030	940	2000	2500	5200
2031	970	2000	2600	5300
2032	1000	2100	2600	5500
2033	1000	2100	2700	5700
2034	1100	2200	2800	5800
2035	1100	2200	2800	6000
2036	1100	2300	2900	6100
2037	1200	2300	3000	6300
2038	1200	2400	3000	6400
2039	1200	2500	3100	6600
2040	1300	2500	3100	6700
2041	1300	2600	3200	6900
2042	1400	2600	3300	7000
2043	1400	2700	3300	7200
2044	1400	2700	3400	7300
2045	1500	2800	3500	7500
2046	1500	2800	3500	7600
2047	1500	2900	3600	7700
2048	1600	3000	3700	7900
2049	1600	3000	3700	8000
2050	1700	3100	3800	8200

Table A-3: Annual SC-N_2O, 2020 – 2050 (in 2020 dollars per metric ton of N_2O)

	Discount Rate and Statistic			
Emissions Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	5800	18000	27000	48000
2021	6000	19000	28000	49000
2022	6200	19000	28000	51000
2023	6400	20000	29000	52000
2024	6600	20000	29000	53000
2025	6800	21000	30000	54000
2026	7000	21000	30000	56000
2027	7200	21000	31000	57000
2028	7400	22000	32000	58000
2029	7600	22000	32000	59000
2030	7800	23000	33000	60000
2031	8000	23000	33000	62000
2032	8300	24000	34000	63000
2033	8500	24000	35000	64000
2034	8800	25000	35000	66000
2035	9000	25000	36000	67000
2036	9300	26000	36000	68000
2037	9500	26000	37000	70000
2038	9800	27000	38000	71000
2039	10000	27000	38000	73000
2040	10000	28000	39000	74000
2041	11000	28000	39000	75000
2042	11000	29000	40000	77000
2043	11000	29000	41000	78000
2044	11000	30000	41000	80000
2045	12000	30000	42000	81000
2046	12000	31000	43000	82000
2047	12000	31000	43000	84000
2048	13000	32000	44000	85000
2049	13000	32000	45000	87000
2050	13000	33000	45000	88000

SEPTEMBER 2016

THE SKY'S LIMIT

WHY THE PARIS CLIMATE GOALS REQUIRE A MANAGED DECLINE OF FOSSIL FUEL PRODUCTION

OIL CHANGE INTERNATIONAL

PUBLISHED IN COLLABORATION WITH

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The author is grateful for feedback from the following reviewers: Andrew Grant and James Leaton of Carbon Tracker Initiative, Mohamed Adow of Christian Aid, Wendel Trio of Climate Action Network Europe, Fabio Sferra of Climate Analytics, Mark Fulton of Energy Transition Advisers, György Dallos of Greenpeace International, Nnimmo Bassey of the Health of Mother Earth Foundation, Joeri Rogelj of IIASA, Andrea Bassi of IISD, Red Constantino of the Institute for Climate and Sustainable Cities, Anabella Rosemberg of ITUC, Jeremy Brecher and Joe Uehlein of the Labor Network for Sustainability, Malte Meinshausen of Melbourne University, Franz Matzner of NRDC, Elizabeth Bast and Janet Redman of Oil Change International, Shelagh Whitley of the Overseas Development Institute, Alex Pfeiffer of Oxford University, Lena Moffitt of the Sierra Club, Pete Erickson and Sivan Kartha of the Stockholm Environment Institute, and Brett Fleishman and Duncan Meisel of 350.org.

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Cover Image: Looking west from Qian'an, iron and steel plant smokestacks. Hebei Province, China, 2014.
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September 2016

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IF YOU'RE IN A HOLE, STOP DIGGING

CONTENTS

ABBREVIATIONS USED IN THIS REPORT

AR5	Fifth Assessment Report of the IPCC
Bbl	Barrel
Bn Bbl	Billion Barrel
Bcf/d	Billion Cubic Feet Per Day
BNEF	Bloomberg New Energy Finance
°C	degrees Celsius
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
EV	Electric Vehicle
GDP	Gross Domestic Product
Gt	Billion Metric Tons
Gtce	Billion Metric Tons of Coal Equivalent
$GtCO_2$	Billion Metric Tons of Carbon Dioxide
GW	Billion Watts (A Measure of Power)
GWh	Billion Watt-Hours (A Measure of Energy, or Power Supplied/Used Over Time)
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land Use Change and Forestry
mbd	Million Barrels Per Day
Mt	Million Metric Tons
Mtoe	Million Tons of Oil Equivalent
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
SEI	Stockholm Environment Institute
Tcf	Trillion Cubic Feet
TW	Terawatts
UNFCCC	United Nations Framework Convention on Climate Change


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EXECUTIVE SUMMARY

In December 2015, world governments agreed to limit global average temperature rise to well below 2°C, and to strive to limit it to 1.5°C. This report examines, for the first time, the implications of these climate boundaries for energy production and use. Our key findings are:

- The potential carbon emissions from the oil, gas, and coal in the world's currently operating fields and mines would take us beyond 2°C of warming.
- The reserves in currently operating oil and gas fields alone, even with no coal, would take the world beyond 1.5°C.
- With the necessary decline in production over the coming decades to meet climate goals, clean energy can be scaled up at a corresponding pace, expanding the total number of energy jobs.

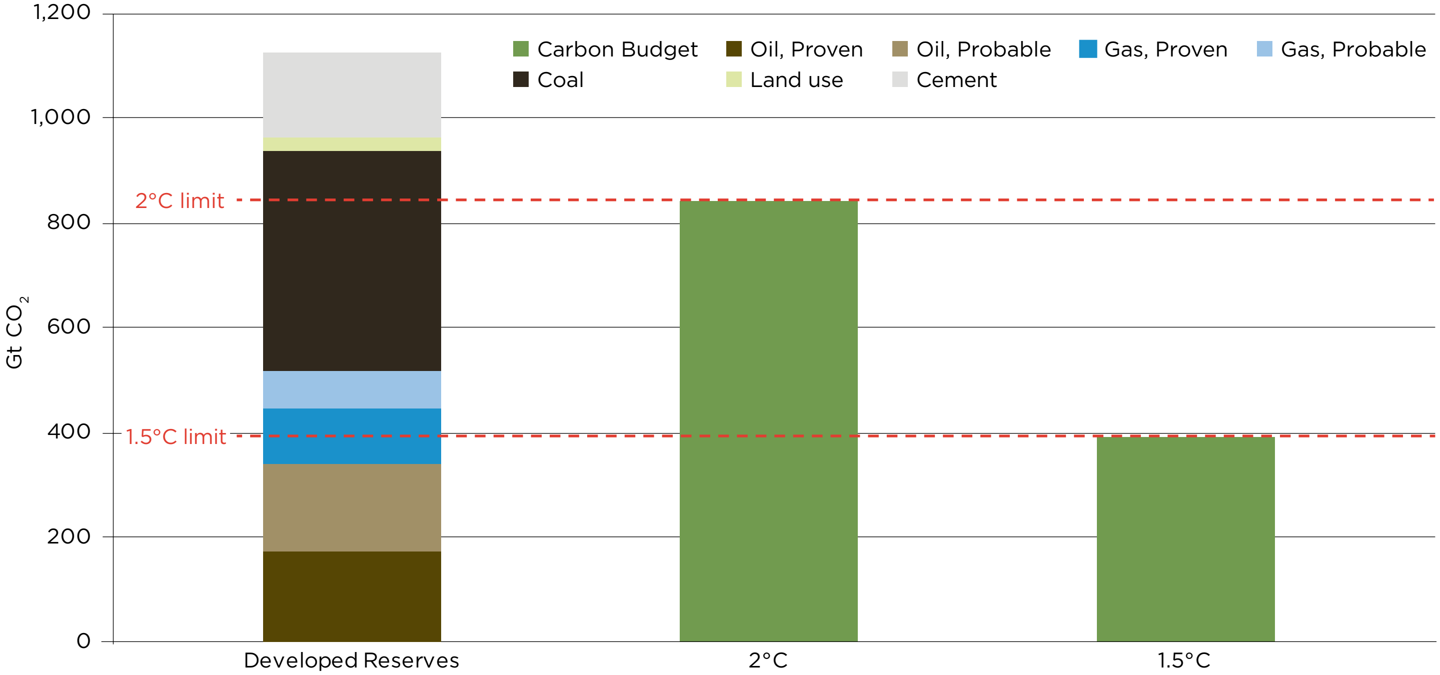
One of the most powerful climate policy levers is also the simplest: stop digging for more fossil fuels. We therefore recommend:

- No new fossil fuel extraction or transportation infrastructure should be built, and governments should grant no new permits for them.
- Some fields and mines – primarily in rich countries – should be closed before fully exploiting their resources, and financial support should be provided for non-carbon development in poorer countries.
- This does not mean stopping using all fossil fuels overnight. Governments and companies should conduct a managed decline of the fossil fuel industry and ensure a just transition for the workers and communities that depend on it.

In August 2015, just months before the Paris climate talks, President Anote Tong of the Pacific island nation of Kiribati called for an end to construction of new coal mines and coal mine expansions. This report expands his call to all fossil fuels.

View of Suncor Millennium tailings pond and tar sands mining operations north of Fort McMurray.

Figure ES-1: Emissions from Developed Fossil Fuel Reserves, Plus Projected Land Use and Cement Manufacture



Sources: Rystad Energy, International Energy Agency (IEA), World Energy Council, Intergovernmental Panel on Climate Change (IPCC)

ENOUGH ALREADY

The Paris Agreement aims to help the world avoid the worst effects of climate change and respond to its already substantial impacts. The basic climate science involved is simple: cumulative carbon dioxide (CO_2) emissions over time are the key determinant of how much global warming occurs.[a] This gives us a finite *carbon budget* of how much may be emitted in total without surpassing dangerous temperature limits.

We consider carbon budgets that would give a likely (66%) chance of limiting global warming below the 2°C limit beyond which severe dangers occur, or a medium (50%) chance of achieving the 1.5°C goal. Fossil fuel reserves – the known below-ground stocks of extractable fossil fuels – significantly exceed these budgets. For the 2°C or 1.5°C limits, respectively 68% or 85% of reserves must remain in the ground.

This report focuses on the roughly 30% of reserves in oil fields, gas fields, and coal mines that are already in operation or under construction. These are the sites where the necessary wells have been (or are being) drilled, the pits dug, and the pipelines, processing facilities, railways, and export terminals constructed. These *developed reserves* are detailed in Figure ES-1, along with assumed future emissions from the two major non-energy sources of emissions: land use and cement manufacture.

We see that – in the absence of a major change in the prospects of carbon capture and storage (CCS):[b]

- The oil, gas, and coal in already-producing fields and mines are more than we can afford to burn while keeping likely warming below 2°C.

- The oil and gas alone are more than we can afford for a medium chance of keeping to 1.5°C.

a The carbon budgets approach does not apply to other greenhouse gases, whose effects are factored into the calculation of carbon budgets in the form of assumptions about their future emissions.
b CCS has not been successfully deployed at scale despite major efforts, and there are doubts as to whether it will ever be affordable or environmentally safe.

WHEN YOU'RE IN A HOLE, STOP DIGGING

Traditional climate policy has largely focused on regulating at the point of emissions, while leaving the supply of fossil fuels to the market. If it ever was, that approach is no longer supportable. Increased extraction leads directly to higher emissions, through lower prices, infrastructure lock-in, and perverse political incentives. Our analysis indicates a hard limit to how much fossil fuel can be extracted, which can be implemented only by governments:

- No new fossil fuel extraction or transportation infrastructure should be built, and governments should grant no new permits for them.[c]

Continued construction would either commit the world to exceeding 2°C of warming, and/or require an abrupt end to fossil fuel production and use at a later date (with increasing severity depending on the delay). Yet right now, projected investment in new fields, mines, and transportation infrastructure over the next twenty years is $14 trillion – either a vast waste of money or a lethal capital injection. The logic is simple: whether through climate change or stranded assets, a failure to begin a managed decline now would inevitably entail major economic and social costs.

The good news is that there is already progress toward stopping new fossil fuel development. China and Indonesia have declared moratoria on new coal mine development, and the United States has done so on federal lands. These three countries account for roughly two-thirds of the world's current coal production. In 2015, U.S. President Barack Obama rejected the proposed Keystone XL tar sands pipeline by noting that some fossil fuels should be left in the ground, and there is growing recognition of the importance of a climate test in decisions regarding new fossil fuel infrastructure.[d] There is an urgent need to make the coal moratoria permanent and worldwide, and to stop new oil and gas development as well.

Ending new fossil fuel construction would bring us much closer to staying within our carbon budgets, but it is still not enough to achieve the Paris goals. To meet them, some early closure of existing operations will be required. Every country should do its fair share, determined by its capacity to act, along with its historic responsibility for causing climate change. With just 18% of the world's population, industrialized countries have accounted for over 60% of emissions to date, and possess far greater financial resources to address the climate problem.

Most early closures should therefore take place in industrialized countries, beginning with (but not limited to) coal. While politically pragmatic, the approach of stopping new construction tends to favor countries with mature fossil fuel industries; therefore, part of their fair share should include supporting other countries on the path of development without fossil fuels, especially in providing universal access to energy. Therefore:

- Some fields and mines – primarily in rich countries – should be closed before fully exploiting their reserves, and financial support should be provided for non-carbon development in poorer countries.

Additionally, production should be discontinued wherever it violates the rights of local people – including indigenous peoples – or where it seriously damages biodiversity.

c This does not mean stopping all capital investment in existing field and mines, only stopping the development of new ones (including new project phases).
d http://ClimateTest.org

A MANAGED DECLINE AND A JUST TRANSITION

Stopping new construction does not mean turning off the taps overnight. Existing fields and mines contain a finite stock of extractable fossil fuels. Depleting these stocks, even including some early closures, would entail a gradual transition in which extraction rates would decline over a few decades. This is consistent with a rate of expansion of clean energy that is both technically and economically possible.

We consider a simple modelling of world energy sources under two scenarios: 50% renewable energy by 2035 and 80% by 2045, both with a complete phase-out of coal usage, except in steel production. It is compared with the projected oil and gas extraction from existing fields alone.

We conclude that:

- While existing fields and mines are depleted over the coming decades, clean energy can be scaled up at a corresponding pace.

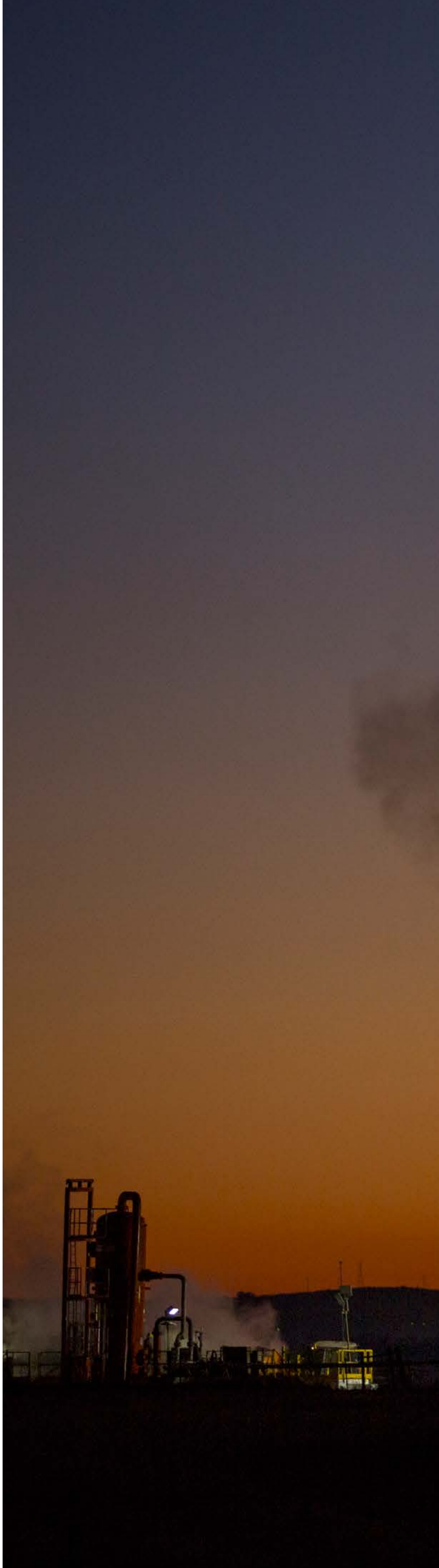
While this pace of renewable energy expansion will require policy support, it continues existing trends. In many countries – large and small, rich and poor – clean energy is already being deployed at scale today. Denmark now generates more than 40% of its electricity from renewable sources, Germany more than 30%, and Nicaragua 36%. China is now the largest absolute generator of renewable electricity, and expanding renewable generation quickly. In most contexts, the costs of wind and solar power are now close to those of gas and coal; in some countries renewable costs are already lower. The expansion of renewable energy will be harder where there are weak grids in developing countries, hence the importance of climate finance in supporting a non-carbon transition.

As for transportation, electric vehicles are now entering the mainstream and are on course to soon be cheaper than gasoline or diesel cars. With sufficient policy support and investment, the growth in clean energy can match the needed decline in fossil fuel extraction and use.

While there are clear advantages to clean energy – lower costs, greater employment, reduced local pollution, and ultimately greater financial returns – the transition will not be painless. Energy workers' skills and locations may not be well matched to the new energy economy. Whole communities still depend on fossil fuel industries. There is a vital need for a careful, just transition to maximize the benefits of climate action while minimizing its negative impacts.

Governments should provide training and social protection for affected energy workers and communities. Where appropriate, they should require energy companies to offer viable careers to their workers in non-carbon areas of their business. Governments should also consult with communities to kick-start investments that will enable carbon-dependent regions to find a new economic life. Waiting is not an option; planning and implementation must begin now:

- Governments and companies should conduct a proactively managed decline of the fossil fuel industry and ensure a just transition for the workers and communities that depend on it.



A flare burns near a hydraulic fracturing drilling tower in rural Weld County in northern Colorado, the most intensively fracked area in the United States.

Aerial view of seismic lines and a tar sands mine in the Boreal forest north of Fort McMurray, northern Alberta.

1. CLIMATE SCIENCE AND CARBON BUDGETS

Burning of fossil fuels – oil, gas and coal – is driving one of the biggest challenges facing the world today: climate change. Extreme weather events, rising oceans, and record setting temperatures are already wreaking havoc on hundreds of millions of lives and livelihoods around the world. In the absence of strong action to reduce emissions, these impacts will get significantly worse throughout the course of the twenty-first Century:[1]

- A large proportion of the earth's species faces increased risk of extinction, as many cannot adapt or migrate as fast as the climate changes. Lost species will never return.
- Crop yields will be severely reduced, potentially causing hunger on a mass scale. The Intergovernmental Panel on Climate Change (IPCC) reports a one-in-five chance (in terms of proportion of model projections) that yields of wheat, corn, rice and soy will decrease by more than 50% by 2100, and a further one-in-five chance that they will decrease by between 25% and 50%: in either case the consequences would be catastrophic.
- Water supplies too will become stressed, especially in dry and tropical regions.
- Cities will increasingly be hit by storms and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea level rise and storm surges.

This report sets out the decisions and actions that can be taken now to avoid the worst of these impacts on lives and livelihoods, on economies and ecosystems.

WELL BELOW 2°C, AND AIMING FOR 1.5°C

During the first decade of the twenty-first century, 2°C of warming above pre-industrial levels was often seen as a "guardrail" of a safe climate. Since then, new findings have indicated that view to be too optimistic. Runaway climate change – in which feedback loops drive ever-worsening climate change, regardless of human activities[e] – are now seen as a risk even at 2°C of warming.[2]

A two-year review within the United Nations Framework Convention on Climate Change (UNFCCC), based on inputs from scientists and other experts, summarized the evolving understanding: "The 'guardrail' concept, in which up to 2°C of warming is considered safe, is inadequate and would therefore be better seen as an upper limit, a defense line that needs to be stringently defended, while less warming would be preferable."[3]

There has been limited study of specific climate impacts at 1.5°C, but some initial findings suggest significantly lower risks than at 2°C. Bruce Campbell of the Consultative Group for International Agricultural Research (CGIAR) estimates that 2°C of warming could reduce African maize yields by 50% compared to 1.5°C of warming,[4] while a recent assessment by Carl-Friedrich Schleussner and others identified several differential impacts between 1.5°C and 2°C of warming:[5]

- Heat extremes would become both more frequent and of longer duration at 2°C than at 1.5°C.
- Reductions in water availability for the Mediterranean region would nearly double from 9% to 17% between 1.5°C and 2°C, and the projected lengthening of regional dry spells would increase from 7% to 11%.
- Wheat yields would be reduced by 15% at 2°C compared to 9% at 1.5°C in a best estimate; the reduction could be as bad as 42% at 2˚C versus 25% at 1.5°C.
- The difference between 1.5°C and 2°C is likely to be decisive for the survival of tropical coral reefs.

For these reasons – and due to the moral call from small island states and other vulnerable nations – governments meeting in Paris set more ambitious goals than at previous UNFCCC meetings. The Paris Agreement established the goal of "holding the increase in global average temperature to well below 2°C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5°C above preindustrial levels."[6]

Still, the specific commitments that governments made in Paris were not sufficient to deliver these long-term goals. The Climate Action Tracker estimates that current global commitments (as stated in countries' Intended Nationally Determined Contributions to the UNFCCC) would result in 2.7°C of warming by the end of the century.[7] In this report we explore what is necessary to actually meet the Paris goals.

e Examples include release of methane due to melting permafrost or accelerated dieback of Amazon rainforest.

CARBON BUDGETS

Many existing analyses of the energy transition start from the current energy system, and attempt to plot what they consider pragmatic rates of change from the status quo. In some cases, such an approach fails to deliver the emissions reductions needed. In that vein, oil companies have often used their energy forecasts to claim that preventing dangerous climate change is simply impossible:

- BP: "Emissions [will] remain well above the path recommended by scientists."[8]
- Shell: "We also do not see governments taking the steps now that are consistent with the 2°C scenario."[9]
- ExxonMobil: "It is difficult to envision governments choosing this [low carbon] path."[10]

In this report we take the opposite approach: we start from climate limits and translate into what needs to happen to the energy system in order to achieve them. We find that what is necessary is also achievable.

We know from atmospheric physics that the key factor determining the extent of global warming is the cumulative amount of carbon dioxide (CO_2) emissions over time.[11] Because CO_2 stays in the atmosphere for centuries, it has been accumulating for many decades and continues to do so.[12] To keep warming within any particular limit – all else being equal – there is a maximum cumulative amount of CO_2 that may be emitted. (Non-CO_2 greenhouse gases are treated differently – see Box 1)

In the same way that an individual, business, or government has a budget corresponding to the resources they have, how long they need them to last, and the consequences of debt or deficit, a carbon budget does the same for greenhouse gas pollution. This is an important and helpful way to understand what we can afford to burn when it comes to fossil fuels (and other sources of emissions), and to drive conversations about the most effective and fairest ways to divide the budget between regions and types of fossil fuels.

In this report we analyze the carbon budgets calculated by the IPCC, to examine their implications for the energy system. We consider two climate limits: a likely chance (66%) of limiting global warming to below 2°C, and a medium chance (50%) of limiting it to below 1.5°C. These budgets are shown in Table 1, deducting emissions that have occurred since the IPCC compiled them.

Some scenarios and analyses, such as the International Energy Agency's 450 Scenario, are based on a 50% chance of staying below 2°C of warming.[13] Since 2°C is considered an absolute limit beyond which severe dangers occur, these 50% odds may be considered imprudent; hence other analyses such as United Nations Environment Programme's annual Emissions Gap report use the budget for delivering a 66% chance of avoiding those dangers, as do we in this report.[f] However, we use a 50% chance of reaching 1.5°C because it has been set as an aspirational goal in the Paris Agreement, rather than an absolute maximum.

Table 1: Global Carbon Budgets for Likely Chance of 2°C and Medium Chance of 1.5°C

($GtCO_2$)	2°C	1.5°C
Post-2011 Budget (from IPCC)[14]	1,000	550
Emissions 2012 to 2015[15]	157	157
Post-2015 Budget	843	393

Sources: IPCC, Global Carbon Project

Box 1: Carbon Budgets and Other Greenhouse Gases

The carbon budgets concept applies to CO_2, because of the way it accumulates in the atmosphere over many decades. The budgets concept cannot be used in the same way to account for other greenhouse gases, which have a more complex warming effect because they do not last for as long in the atmosphere. Methane is the most important of these other gases.

In the short term, methane is a much more potent greenhouse gas than CO_2. However, because methane molecules break down after an average of twelve years, their direct warming effect occurs only during those years after they are emitted, while they are still present in the atmosphere. Methane also has indirect effects lasting beyond twelve years, due to feedback loops in the climate system.[g] Because these loops do not follow a linear relationship with cumulative emissions, they cannot be described using carbon budgets.

For these reasons, carbon budgets as discussed in this report relate only to CO_2. However, other greenhouse gases are factored in when the sizes of CO_2 budgets are calculated. Assumptions are made about what other gases' future emissions will be, and so if those assumptions change, then the sizes of carbon budgets change. Recent studies have indicated that methane leakage rates from natural gas facilities in the United States are much higher than previously thought, especially as a result of hydraulic fracturing, or "fracking."[16] Such changed assumptions may require CO_2 budgets to be revised downward, which would allow for less CO_2 to be emitted.

f There is an argument on that basis that we should require a better than 66% of staying below 2°C – a 33% chance of failure is frightening, given the severity of what failure actually means. The IPCC provides budgets only for 33%, 50%, and 66%, partly as a relic of earlier decisions on how to quantify English-language terms such as "likely" and "unlikely." While some scientists have calculated carbon budgets that would give 80% or 90% probabilities, in this report we use the IPCC budgets, as they are the most-reviewed and most-authoritative options. However, we do so with the following proviso: to be more confident of staying below 2°C, budgets would be smaller and require more dramatic action than outlined here.

g For example, short-term warming caused by methane's direct greenhouse effect may cause ice to melt, reducing the extent to which solar radiation is reflected, and hence leading to greater absorption of heat, even beyond the methane's atmospheric lifetime.

URGENT EMISSIONS CUTS

To put the carbon budget numbers in context, we can compare them with current rates of emissions.

We see from Table 2 that reducing emissions is urgent: at current rates of emissions, the carbon budget for a likely chance of limiting warming to 2°C will be fully exhausted by 2037, and by 2025 for a medium chance at 1.5°C.

For the world to stay within either of these temperature limits, rapid emissions cuts are required. Figure 1 shows a range of scenarios for emissions pathways that would lead to achieving the likely chance of 2°C or medium chance of 1.5°C outcomes. For 2°C, emissions need to reach net zero by around 2070, and for 1.5°C they must do so by 2050 – and in both cases they must fall steeply, starting immediately.

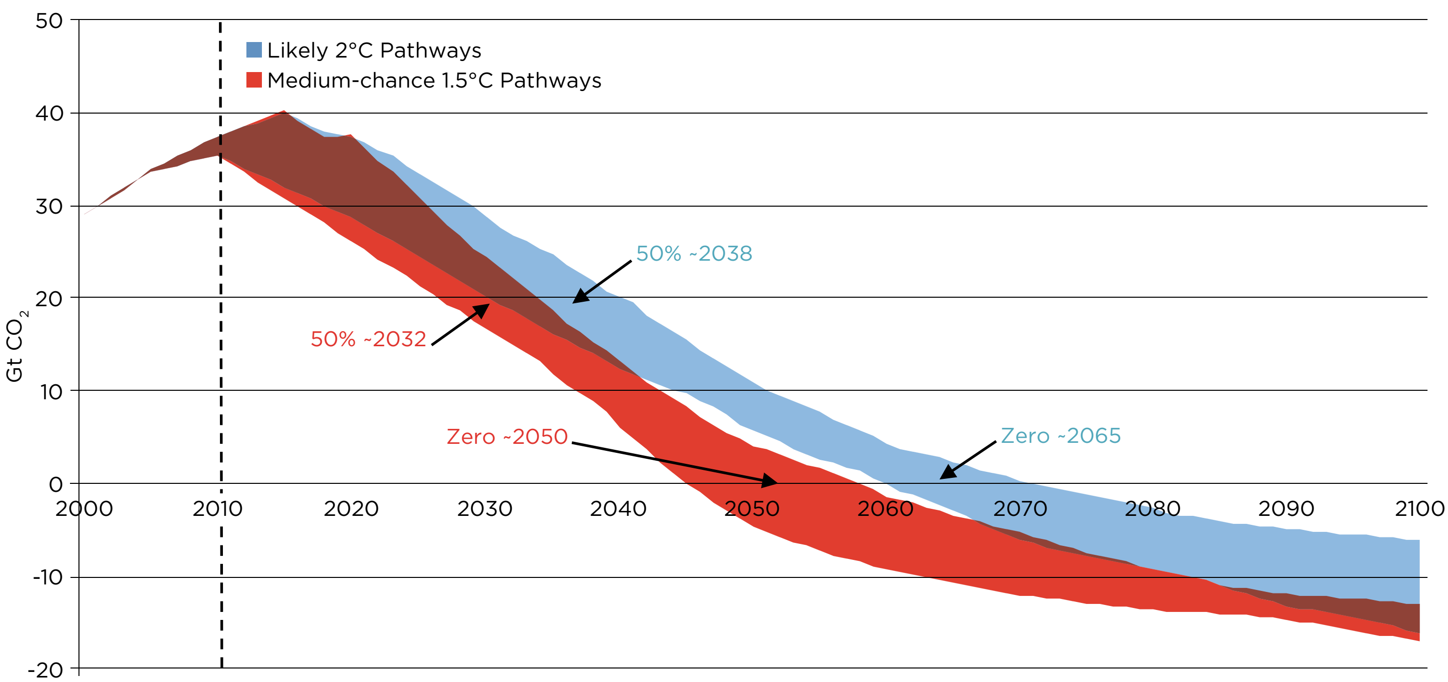
Note that these scenarios assume that "negative emissions" technology will occur in the second half of the century, through approaches such as bioenergy with carbon capture and storage or direct air capture. If we want to avoid depending on unproven technology becoming available, emissions would need to be reduced even more rapidly.

Table 2: Global Carbon Budgets for Likely Chance of 2°C and Medium Chance of 1.5°C, in context

	2°C	1.5°C
Post-2015 Budget ($GtCO_2$)	843	393
Current Global Emissions ($GtCO_2$)[17]	39.2	39.2
Years Remaining at Current Rate	21.5	10.0
Year Exhausted at Current Rates	2037	2025

Sources: IPCC, Global Carbon Project

Figure 1: Range of Global Emissions Pathways in Scenarios Consistent with Likely Chance of 2°C or Medium Chance of 1.5°C[18]



Sources: Joeri Rogelj et al

BOX 2: A History of Carbon Budget Analyses

This report continues a tradition of work by scientists and campaigners showing how global carbon budgets limit the amount of fossil fuels that can safely be extracted and burned.

It has been known for more than 20 years that cumulative emissions of CO_2 are a key determinant of how much the planet warms. The IPCC's Second Assessment Report in 1995 observed that in climate models all pathways leading to a particular temperature outcome had similar cumulative emissions.[19] Indeed, the notion of carbon budgets goes back at least to the early 1990s.[20] Further scientific study has developed our understanding of how this works in relation to the carbon cycle, forming a major theme in the IPCC's Fifth Assessment Report in 2013-14.

The pioneering step was taken by Bill Hare, then Climate Policy Director of Greenpeace, in what he called the 'carbon logic'. His 1997 paper, "Fossil Fuels and Climate Protection" showed that if burned, the fossil fuel reserves that were known at that time would release at least four times as much CO_2 as could be afforded while keeping warming below 1°C, or twice as much as the budget to keep below 2°C.[21] Several campaign groups (including Greenpeace, Oilwatch, Rainforest Action Network, Project Underground, and Amazon Watch) used the analysis to argue that exploration for new reserves should be stopped, but it was many more years before such calls started to gain traction.

In 2009, an influential paper was published in the journal Nature by Malte Meinshausen and seven co-authors (including Hare, who by then worked with Meinshausen at the Potsdam Institute for Climate Impact Research). They found that only 43% of the world's fossil fuels could be burned before 2050 if the world was to have a 50% chance of keeping warming below 2°C, or 27% of reserves for a 75% chance.[22]

Based on Meinshausen's research, in 2011 the Carbon Tracker Initiative published a report coining the term 'unburnable carbon' and describing its potential consequences for financial markets.[23] Carbon Tracker continues to examine the implications of stranded assets, which are long-term fossil fuel investments that will fail to generate returns because they were made assuming the world will not sufficiently act to address climate change.

Bill McKibben brought this analysis to a wider audience in 2012 in an article in Rolling Stone entitled "Global Warming's Terrifying New Math." In it, he argued that three simple numbers – the 2°C limit, the 565 Gt CO_2 budget for an 80% chance of staying within the limit, and the 2,795 Gt CO_2 of fossil fuel reserves – added up to global catastrophe.[24] The following year, Mike Berners-Lee and Duncan Clark published an analysis of reserves versus carbon budgets in a book, "The Burning Question".

In 2015, Christophe McGlade and Paul Ekins assessed which reserves might be left unburned if emissions were constrained within carbon budgets through an escalating carbon price. Their paper in Nature concluded that 88% of global coal reserves should remain unburned for a 50% chance of staying below 2°C. Even after assuming significant development of CCS, this proportion dropped to just 82% of global coal reserves. 75% of Canada's tar sands would have to remain unburned, or 74% with CCS.[25]

This report is inspired by that history of earlier work, and aims to build on it by turning the focus to reserves in fields and mines that are already operating.

FOSSIL FUEL RESERVES

After a company finds and then develops a deposit of oil, gas, or coal, it will generally extract the deposit over a period of several decades (see Figure 4 on page 20). *Reserves* are the quantity of known oil, gas, or coal that can be extracted in the coming years, with current technology and in current economic conditions.[h]

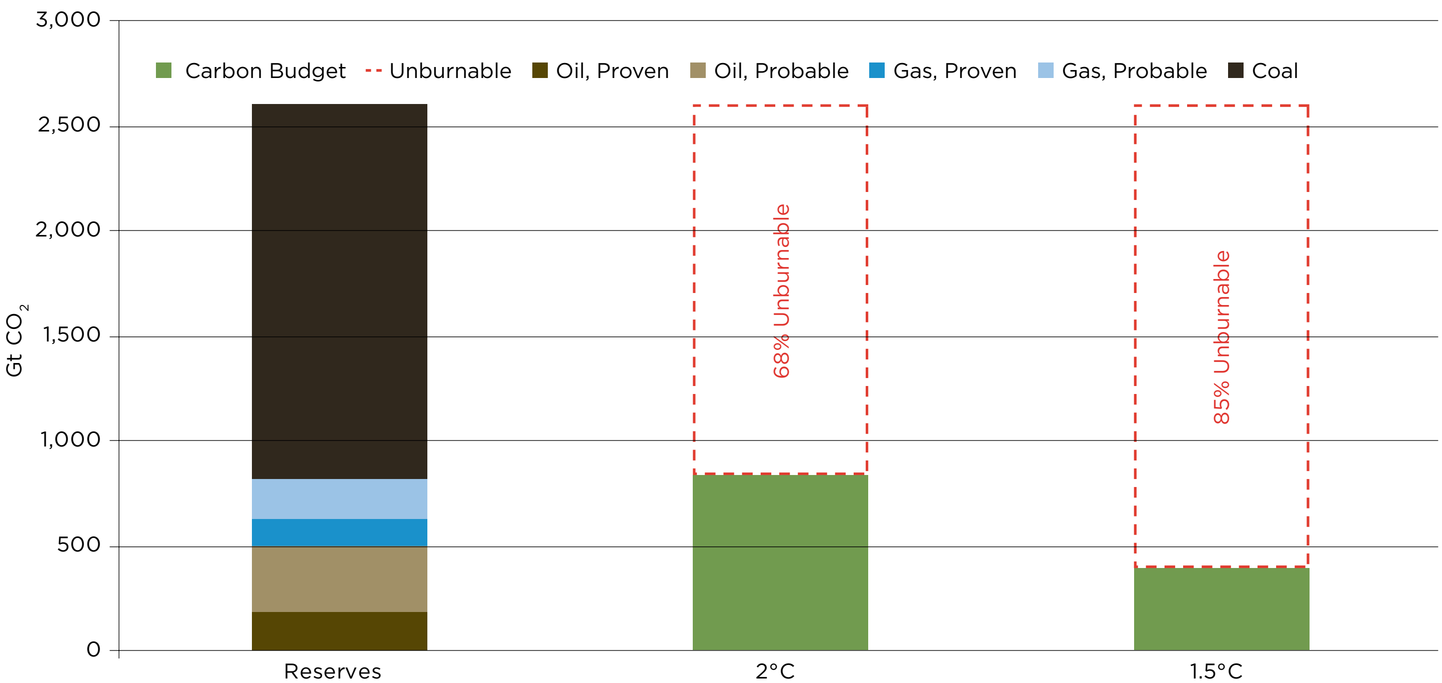
In Figure 2 we compare carbon budgets with fossil fuel reserves, echoing earlier work to translate climate limits into energy limits (see Box 2). For oil and gas, both proven and probable reserves are shown, while for coal only proven reserves are shown (see Appendix 1).[i]

We see that for a likely chance of keeping warming below 2°C, 68% of reserves must remain in the ground. For a medium chance of limiting warming to 1.5°C, 85% of reserves must remain underground.

This conclusion is based on an assumption that carbon capture and storage (CCS) is not widely deployed. CCS is a process in which some of the CO_2 released from burning fossil fuels is captured, compressed, and stored underground in deep geological reservoirs – thus enabling fossil fuels to be burned without releasing all of their carbon into the atmosphere. The problem is that the technology needed is far from proven: it has been deployed only in a few pilot settings, and without significant success (see Appendix 3); meanwhile, there are reasons to believe its costs may remain prohibitive, and questions about its environmental safety.

If CCS is eventually proven and deployed, it might provide a welcome means of further lowering emissions. However, we take the view that it would not be prudent to be dependent on an uncertain technology to avoid dangerous climate change; a much safer approach is to ensure that emissions are reduced in the first place by reducing fossil fuel use and moving the economy to clean energy. Therefore, we apply that assumption throughout this report.[j]

Figure 2: Global Fossil Fuel Reserves Compared to Carbon Budgets for Likely Chance of 2°C and Medium Chance of 1.5°C[28]



Sources: Rystad Energy, World Energy Council, IPCC

h Reserves are a subset of resources, which are an estimate of all the oil, gas, or coal that might one day be extracted. There are two criteria that define reserves:
(i) They have been identified – they have a specified location and grade/type (whereas resources also include those that are expected or postulated to exist, based on geological understanding)
(ii) They can be extracted with currently available technology and under current economic conditions (whereas resources also include those that rely on speculative future technologies or commodity prices)[26]

i An overview of government-reported data for nine countries that together account for 60% of proven coal reserves suggests additional probable reserves of around 350 Gt of coal in those countries, equivalent to 885 Gt of CO_2. However, coal data is plagued by unreliability and inconsistent definitions, so this estimate should be taken with caution.[27]

j As noted, we are taking a different approach from the IEA's 450 Scenario, which assumes large-scale CCS will become available, hence requiring only modest reductions in fossil fuel usage while having a 50% chance of staying within 2°C.

Excavators pile up coal on a quay at the Port of Lianyungang in Lianyungang city, east China's Jiangsu province, 10 November 2013.

© Associated Press, Wang Chun.

2. ENOUGH OIL, GAS, AND COAL ALREADY IN PRODUCTION

We have seen that existing fossil fuel reserves considerably exceed both the 2°C and 1.5°C carbon budgets. It follows that exploration for new fossil fuel reserves is at best a waste of money and at worst very dangerous. However, ceasing exploration is not enough, as that still leaves much more fossil fuel than can safely be burned.

DEVELOPED RESERVES

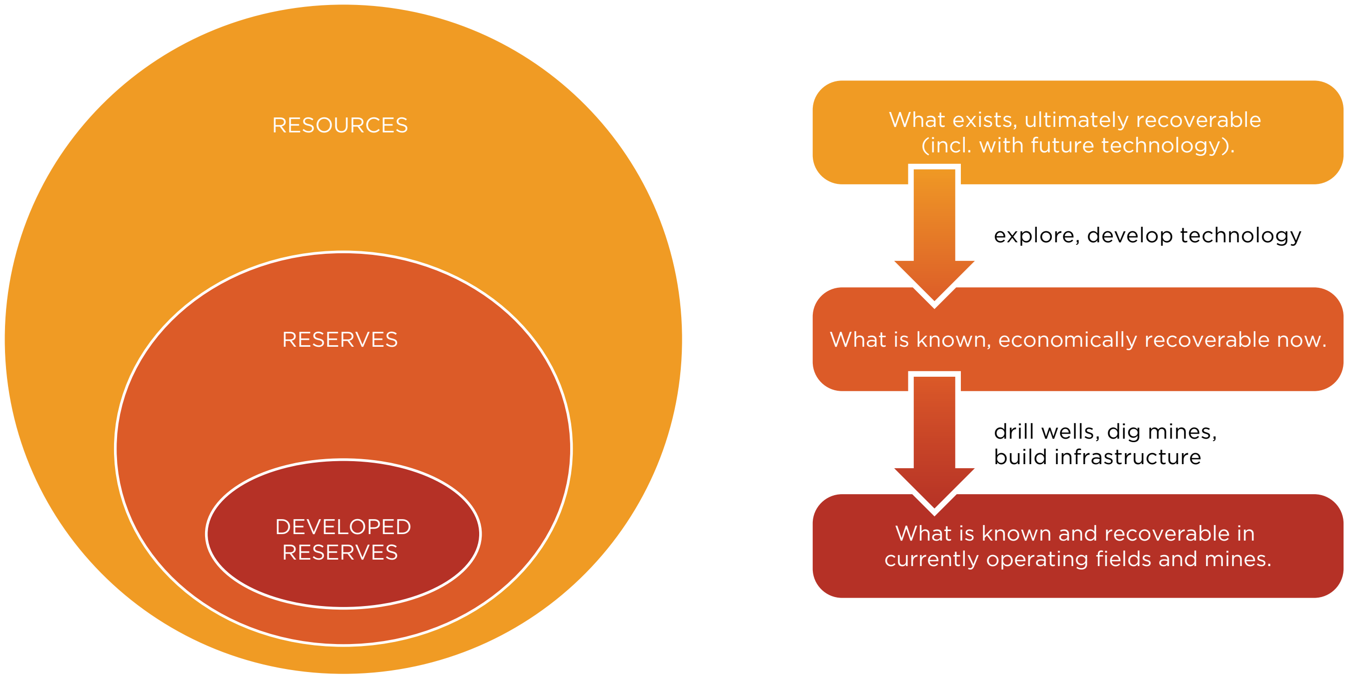
We now turn to the question of how much room exists within the carbon budgets for development of new oil fields, gas fields, and coal mines.

Figure 3 explains three categories of fossil fuels in the ground:

- **Resources** that might one day be extracted, some of which are geologically "expected" but yet to be actually found.
- **Reserves** that are known and extractable using today's technologies and in today's economic conditions.
- **Developed Reserves** that can currently be extracted from oil fields, gas fields and coal mines that are already operating – for which the wells have been drilled and the pits dug, and where the pipelines, processing facilities, railways, and export terminals have been constructed.

We focus on the smallest of these three measures: 'developed reserves'. If no new fields or mines are developed, production of each fossil fuel will decline over time as existing fields and mines are depleted, eventually reaching zero. A finite amount of cumulative production would thus occur with no new development, which we have estimated in Table 3.

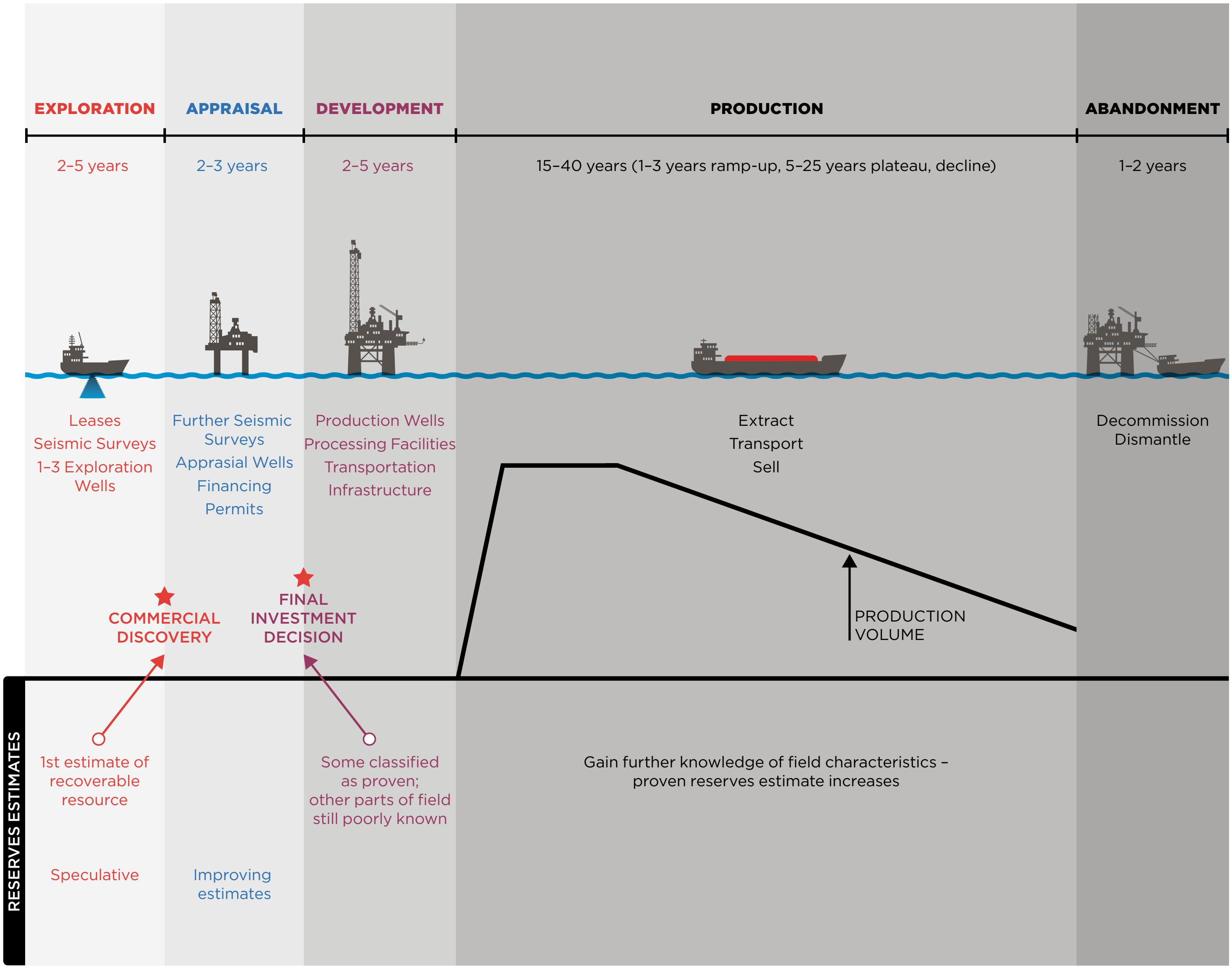
Figure 3: Three Measures of Available Fossil Fuels



Source: Oil Change International. Not to scale.

Figure 4: Lifecycle of an Oil or Gas Field

Source: Oil Change International



For oil and gas fields, we use data from Rystad Energy's UCube, a database of upstream oil and gas projects.[29] Rystad creates this data using a combination of company reports, regulatory information, and modeling. We have included fields that are currently being developed – for which shovels are in the ground – as well as those already producing, as the under-construction ones are "committed" in a similar sense. Because the estimates of reserves in existing fields are sensitive to oil and gas prices, we have used Rystad's base case, which projects the prices Rystad considers most likely over coming years.

Rystad provides data at the level of an "asset", which roughly divides the oil and gas universe into units for which a separate investment decision is made, based on its assessed profitability. For this reason, we do not count the reserves that would be unlocked in future development phases of a producing field as "developed." For example, we count the 3.6 billion barrels of oil that can be extracted with existing infrastructure on BP's Mad Dog field in the Gulf of Mexico as developed, but not the further 10.7 billion barrels that would be unlocked by its planned Mad Dog Phase 2 development, which would involve additional infrastructure investments.

For coal mines, we use estimates from the International Energy Agency (IEA), which are comprised of data from various sources combined with the IEA's own analysis.[30] It should be noted that available data for coal is generally of poorer quality than for oil and gas (see Appendix 1). Data is not available for coal mines under construction.

Table 3: Developed Reserves and CO_2 Emissions, from Existing and Under-Construction Global Oil and Gas Fields, and Existing Coal Mines[31]

	Reserves	Emissions
Oil, Proven	413 bn bbl	175 Gt CO_2
Oil, Probable	400 bn bbl	169 Gt CO_2
Gas, Proven	1,761 Tcf	105 Gt CO_2
Gas, Probable	1,130 Tcf	68 Gt CO_2
Coal, Proven	174 Gtce	425 Gt CO_2
TOTAL		942 Gt CO_2

Sources: Rystad Energy, IEA

DEVELOPED RESERVES COMPARED TO CARBON BUDGETS

Figure 5 compares developed reserves with the carbon budgets. In addition to emissions from energy (the burning of the three fossil fuels), we must also consider two other sources of emissions:

- Land use, especially changes in forest cover and agricultural uses;
- Cement manufacture, where aside from any energy usage, CO_2 is released in the calcination reaction that is fundamental to cement production.[k]

In both cases, we use relatively optimistic projections of emissions this century, assuming climate action, while noting that these sit within a wide range of projections, from those assuming business-as-usual to those involving speculative new technologies. This range is shown in Table 4 (more details in Appendix 2). There is considerable variation in modelled land use emissions.[l] If emissions from these two sources are not reduced to zero by the end of this century, they could occupy a larger share of the remaining carbon budgets, leaving less for fossil fuel emissions.

It can be seen from Figure 5 that (in the absence of CCS):

- The emissions from existing fossil fuel fields and mines exceed the 2°C carbon budget.

A recent study by Alex Pfeiffer and colleagues at Oxford University found that the "2°C capital stock" of power plants will be reached in 2017, by projecting the emissions from power plants over their full 40-year lifespans. In other words, if any more gas or coal plants are built after next year, others will have to be retired before the end of their design lives, in order for the world to have a 50% chance of staying below the 2°C limit (for a 66% chance of 2°C, that capital stock was reached in 2009, meaning early retirements are already required).[32] We have reached a similar conclusion for the capital stock in fossil fuel extraction.

NO MORE FOSSIL FUELS

In 2015, President of Kiribati Anote Tong wrote to other national leaders urging an end to the development of new coal mines, "as an essential initial step in our collective global action against climate change".[33] As a low-lying island in the Pacific, Kiribati is a nation whose very existence is threatened. Our analysis in this report supports his call, and extends it further.

If we are to stay within the agreed climate limits and avoid the dangers that more severe warming would cause, the fossil fuels in fields that have already been developed exceed our global carbon budget. Therefore, we conclude that:

- No new oil fields, gas fields, or coal mines should be developed anywhere in the world, beyond those that are already in use or under construction.[m]
- Similarly, no new transportation infrastructure – such as pipelines, export terminals, and rail facilities – should be built to facilitate new field and mine development (this does not preclude replacing existing infrastructure such as an old, leaky pipeline).[34]

Governments and companies might argue that early closure of coal could make space for new development of oil and gas. This substitution argument might have worked if the total developed reserves were equivalent to well below 2°C or 1.5°C. But instead, Figure 5 shows that developed reserves exceed the 2°C carbon budget and significantly exceed the 1.5°C budget. Furthermore:

- Oil and gas emissions alone exceed the 1.5°C budget.

If governments are serious about keeping warming well below 2°C and aiming for 1.5°C, no new oil or gas development would be permitted, even if coal, cement, and deforestation were stopped overnight.

LEAST-COST APPROACHES

Many analyses of emissions pathways and climate solutions assess the "least-cost" routes to achieving climate targets.[n] Such an analysis – with the same targets we have used in this report – might not lead to the conclusion that no new fields or mines should be developed. Although developed reserves will often be cheaper to extract than new reserves because capital has already been spent, that is not always the case. A new Saudi oil field may cost less to develop and operate than simply maintaining production from an existing Venezuelan heavy oil field, for example. In optimizing the global economics, a least-cost approach might suggest that rather than precluding new development, we should instead close the Venezuelan field early and open the Saudi one. In this report we take a different approach.

There are two rationales for using least-cost models to assess the best way of achieving a given climate target: predictively, assuming a markets-based mechanism for delivering change; or normatively, on grounds that the least total cost implies the greatest net benefit to humanity.

As it relates to this report, the predictive role will hold only if we expect that sufficiently strict market-based policies will be put in place to achieve climate goals. In the absence of these policies, the predictive role is lost. Those policies do not currently exist; and in fact, in Section 4 we will argue that market-based, demand-side policies alone may not be enough to transform the energy system to the extent climate limits require.

k Calcium carbonate (limestone) is heated to break it into carbon dioxide and calcium oxide, the largest ingredient used to make cement clinker: $CaCO_3 \rightarrow CaO + CO_2$. The heat may come from coal or gas, but those emissions are counted within the energy total: the additional component here is the CO_2 from the calcination reaction.

l Many scenarios include significant negative emissions, from bioenergy with CCS (BECCS), biochar, and afforestation. In this report, we have based our conclusions on an assumption that CCS is not deployed at scale, based on unpromising experience to date (see Appendix 3). Extending this precautionary assumption could potentially increase the assumed land use emissions, and reduce the share of carbon budgets available for fossil fuels.

m It should be noted that we have not included probable reserves of coal, due to lack of data and for the other reasons listed in Appendix 1. So more precisely, our conclusion is that coal mines should not continue producing beyond their proven reserves. Similarly, if new technology enabled greater recovery from existing oil and gas fields, further restraint would be needed.

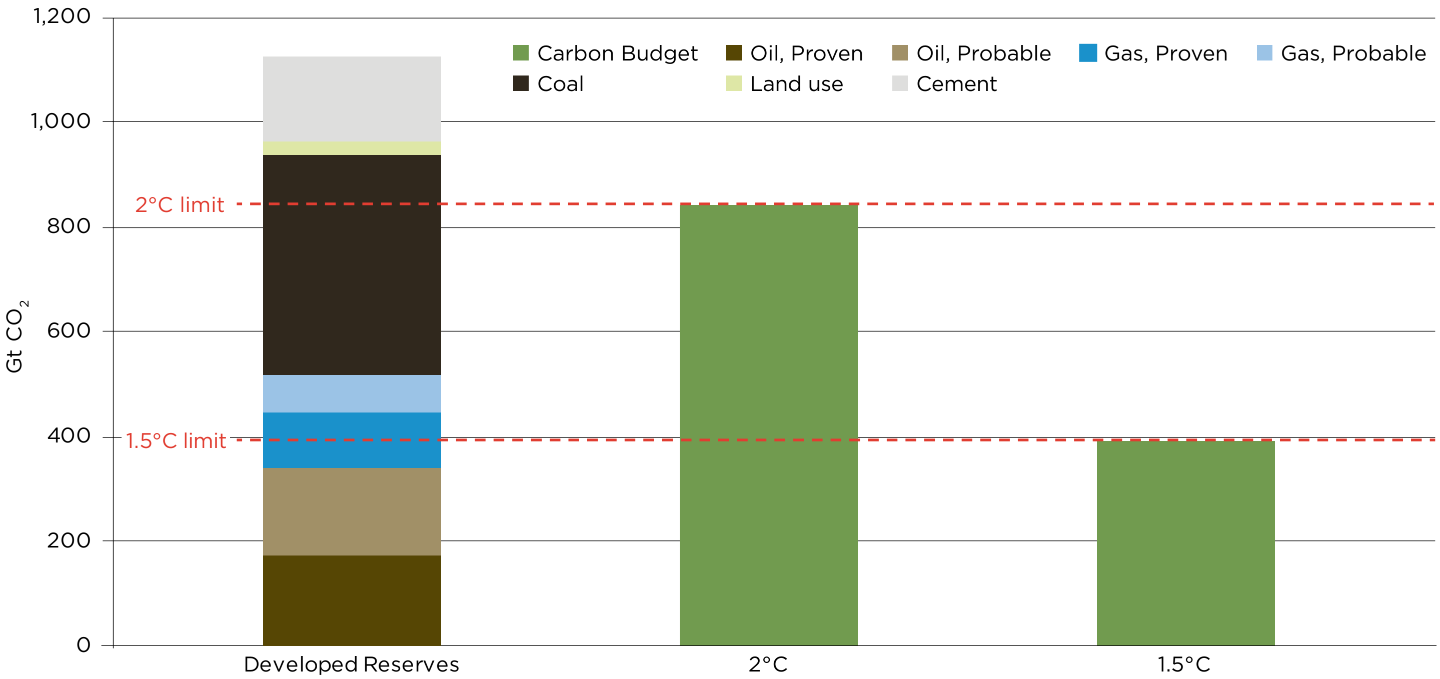
n They commonly do so using an integrated assessment model, which combines both physical effects of emissions in the climate system, and economic effects of energy in the economy. Such models are used to generate the emissions scenarios featured in IPCC reports, such as those shown in Figure 1.

Table 4: Assumed 2015 to 2100 Emissions from Land Use and Non-Energy Emissions from Cement Manufacture (see Appendix 2 for details)

Gt CO_2	Assumed Base Case	Range
Land Use	21	-206 to 57
Cement Manufacture	162	150 to 241

Sources: IPCC Scenarios Database, IEA

Figure 5: Emissions from Developed Reserves, Compared to Carbon Budgets for Likely Chance of 2°C and Medium Chance of 1.5°C



Sources: Rystad Energy, IEA, World Energy Council, IPCC

Examining the normative rationale, we run into the important question of how the climate goal is to be achieved. It is a sad reflection on climate politics that leaders find it easy to make principled or pragmatic arguments for why others should take action, but much harder to see arguments for why they should do so themselves. No government seems to need much excuse to carry on extracting or burning fossil fuels: the logic leaps quickly from "someone can extract if conditions ABC are met" to "I can extract as much as I like." This is one reason why we focus on overall global limits.

Since political action is required, we should look for solutions that are not just economically optimized, but politically optimized. Politically, it is much more difficult to demand the loss of physical capital – on which dollars have been spent, and steel and concrete installed – than to relinquish the future hope of benefits from untapped reserves. Shutting an existing asset leads to an investor losing money, and if a government shuts it by decree the investor will demand compensation. That lost money is a powerful disincentive for all parties involved. In contrast, stopping plans for the construction of unbuilt facilities mostly involves the loss of potential future income, since the amount spent on exploration is relatively small.

Similarly, existing jobs held by specific people generally carry more political weight than the promise of future jobs. This can even be the case when policy decisions may lead to more jobs than the present ones that would be lost. We will examine this in more detail in Section 4 and 5.

Mountaintop removal coal mining on Cherry Pond and Kayford mountains in West Virginia 2012.

THE FRONT LINES OF EXPANSION

The consequence of our analysis is that no new extractive or facilitating infrastructure should be built anywhere in the world. We identify here the countries where the most expansion is proposed. If these expansions go ahead, they could be the worst culprits in tipping the world over the edge.

(i) Coal

The world's largest and fifth-largest coal producers, China and Indonesia, have declared moratoria on new coal mine development. The second-largest producer, the United States, has implemented a limited moratorium on new coal mines on public lands. These three countries account for roughly two-thirds of the world's coal production (or 60%, if US production on non-federal lands is excluded).[35] The first priority must be to make these moratoria permanent, and to extend the U.S. moratorium to all coal mining in the country.

The two countries that are currently proceeding with major coal mining development are Australia and India:

- **Australia:** Nine coal mines are proposed in the Galilee Basin in Queensland. They would have combined peak production of 330 Mt of coal per year, amounting to 705 Mt CO_2 of emissions per year – if this were a country, it would be the world's 7th largest emitter.[36] Table 5 shows the six mines that have filed applications for regulatory approval, with estimated recovery of 9.6 billion metric tons of coal over their lifetimes, leading to 24 Gt of CO_2 emissions. This would total 6% of the global carbon budget for 1.5°C. Three further mines – Watarah's Alpha North, GVK/Hancock's Alpha West, and Vale's Degulla – have not yet started the approvals process.

- **India:** In 2015, the government of India set a target of tripling national coal extraction to 1.5 billion metric tons per year by 2020, with majority-state-owned Coal India Limited increasing its extraction to 1 billion metric tons per year, and other companies increasing from 120 Mt per year to 500 Mt per year.[38] Most commentators expect production growth to fall well short of these goals; the IEA's projection of production from existing and new mines is shown in Figure 6. Data are not available on the reserves in new mines.

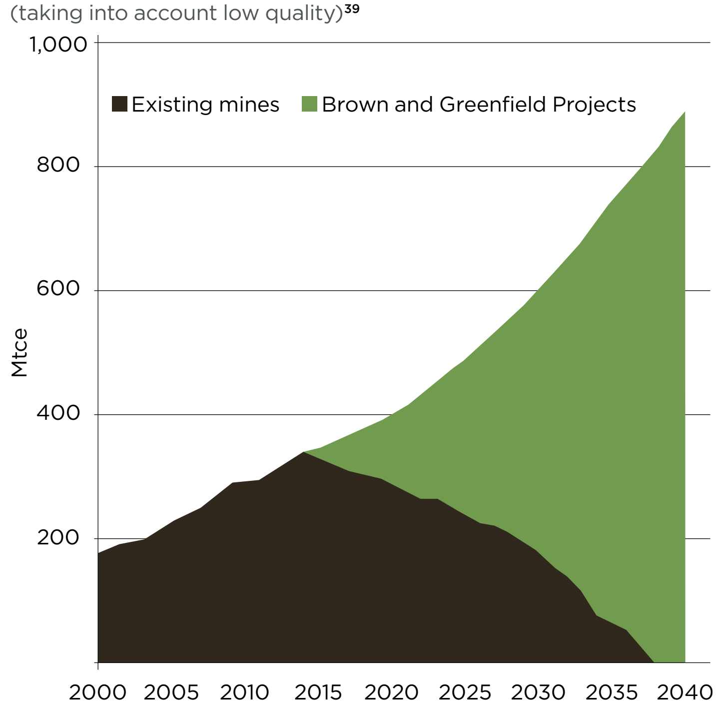
It should be noted that India has done less than most countries to cause the climate problem: despite having 18% of the world's population, it has accounted for just 3% of historical global CO_2 emissions.[40] And with per capita GDP of just $1,600, the country has an urgent need for economic development. Therefore, many argue with good justification that it is unreasonable to expect a country like India to bear an equal burden of addressing climate change to those with far greater historic responsibility. At the same time, it is difficult to see how the world can avoid dangerous climate change if this coal expansion goes ahead. The solution could be a generous support package, primarily provided by the wealthy countries that are most responsible for climate change, including climate finance and technology transfer, to help India pursue a low-carbon development path.

Table 5: Proposed Coal Mines in Australia's Galilee Basin[37]

Mine	Company	Expected recovery / Mt coal
Carmichael	Adani	5,000
China Stone	MacMines	1,800
China First	Watarah Coal	1,000
Alpha	GVK / Hancock	840
Kevin's Corner	GVK	470
South Galilee	Bandanna/AMCI	450
TOTAL		9,560

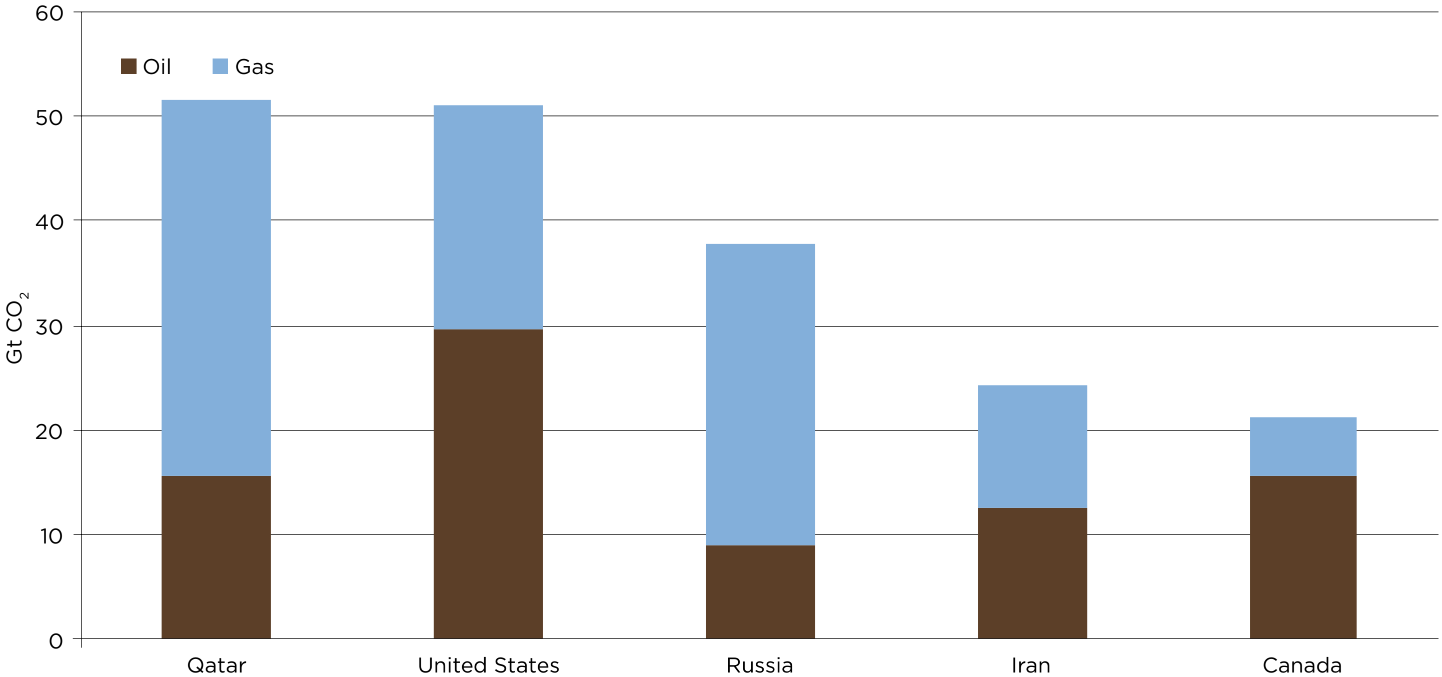
Sources: Individual Project Environmental Impact Statements

Figure 6: Projected Indian Coal Production from Existing and Proposed Mines, in Million Metric Tons of Coal Equivalent (taking into account low quality)[39]



Source: International Energy Agency

Figure 7: CO_2 Emissions from Largest Proposed New Oil and Gas Developments



Source: Rystad Energy

(ii) Oil and Gas

The largest proposed oil and gas developments, as projected by Rystad, are shown in Figure 7.

They comprise:

- **Qatar:** Along with partner ExxonMobil, state-owned Qatar Petroleum plans to expand gas and oil production on the massive North field in several new phases, although this is not expected until prices increase. The projected 52 Gt of lifetime CO_2 emissions would on their own exhaust 13% of the 1.5°C budget.

- **United States:** Major ongoing fracking developments, particularly for oil in North Dakota's Bakken, and Texas' Permian and Eagle Ford shales, and for gas in the Appalachian Basin's Marcellus-Utica shale. These are all proceeding in spite of low prices, and would add another 51 Gt of CO_2 emissions.

- **Russia:** Gazprom proposes several major gas and oil developments in the Yamal Peninsula in Arctic northwest Siberia, though this is not expected until prices increase. They would add 38 Gt of CO_2 emissions.

- **Iran:** The Iranian government is currently preparing an auction of several fields and exploration blocks to foreign companies, with initial offerings expected in late 2016 or early 2017. The emissions would amount to 24 Gt CO_2.

- **Canada:** Proposed expansion of tar sands extraction in Alberta depends on the construction of new pipelines, which have been stalled due to public opposition. Two major new pipelines are currently proposed, one by Kinder Morgan to the west coast and another by TransCanada to the east coast. Projected emissions are 21 Gt CO_2.

It can be seen from the chart that new gas development is as much of a threat as new oil development.

Proceeding with any of the above oil, gas, or coal expansions – the world's largest new sources of new carbon proposed for development – could commit us to far more than 2°C warming.

3. TRIMMING THE EXCESS

We saw in the previous section that stopping new fossil fuel construction can get the world closer to staying below 2°C of warming, but still is not enough (see Figure 5). Some closure of existing operations will be required to limit warming to 2°C. To have a chance of staying below 1.5°C, significant closures will be needed.

We have noted that closing existing facilities is more politically difficult than not building new ones. Stopping new fossil fuel construction minimizes the number of existing operations that need to be closed early. In this section we will consider where the necessary early shut-downs could or should take place.

Environmental justice is a priority principle for considering where to stop fossil fuel extraction. Extraction should not continue where it violates the rights of local people – including indigenous peoples – nor should it continue where resulting pollution would cause intolerable health impacts or seriously damage biodiversity. Fossil fuels have a long and violent history of being associated with such violations, stopping which is important in its own right.

COAL MINES

An obvious candidate for early closure is the coal sector. Coal accounts for the largest share of resources, the largest CO_2 emissions intensity, and the largest emissions per unit of power generated. Furthermore, coal's use in power generation is readily substitutable by renewable energy,[o] at least in countries and regions with mature electrical grids. Coal mining is also less capital-intensive than oil or gas extraction, so it is less costly to retire a coal asset early (although coal mining is also more labor-intensive, raising issues of its closure's impact on workers – see Section 5).

This does not mean that all coal should be phased out before any action to restrict existing oil and gas extraction. Poorer countries rely disproportionately on coal for their energy, compared to oil and gas: coal accounts for 19% of primary energy in industrialized countries in the Organisation for Economic Co-operation and Development (OECD), but 37% of primary energy in non-OECD countries.[42] There is danger that placing too much emphasis on coal may put an unfair share of the burden on the very countries who did least to cause the climate problem and who have the least financial and technological capacity to transform their economies. We will examine these issues in more detail shortly.

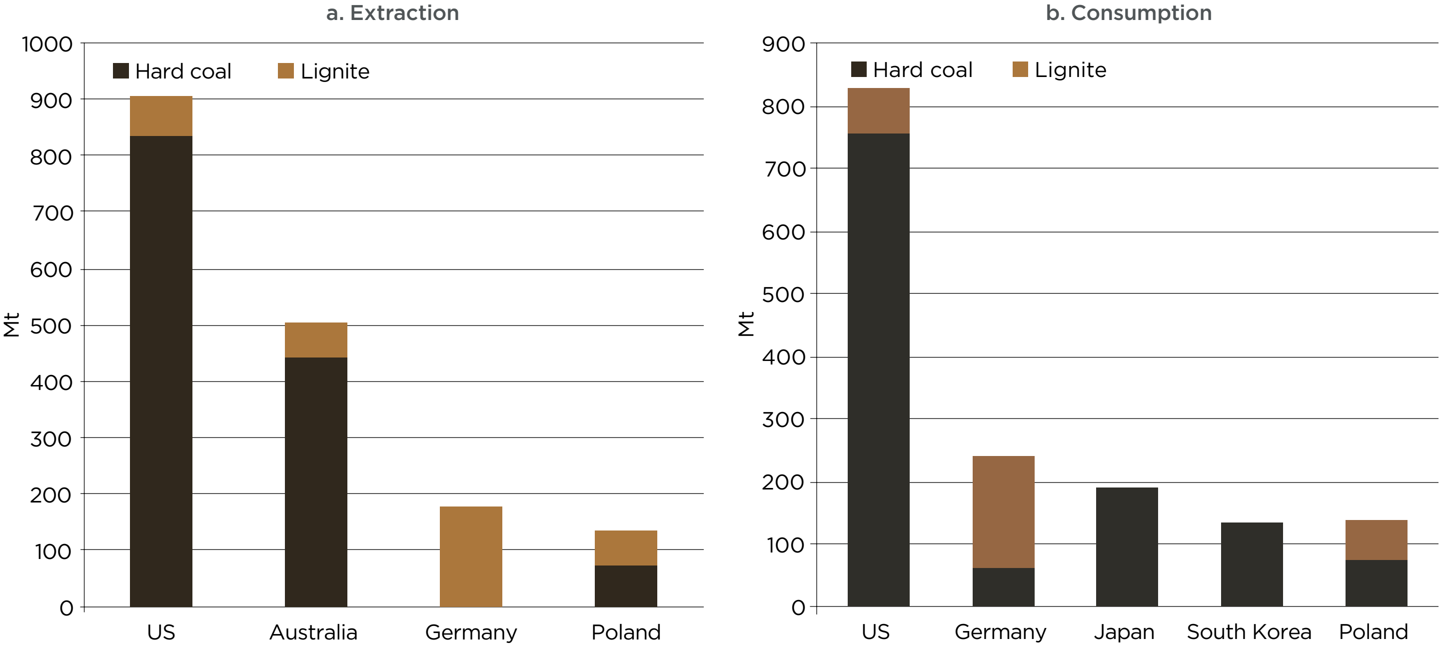
As a starting point, there is little justification for continued mining or burning of thermal coal in industrialized countries. Figure 8 shows that the OECD countries extracting the most coal are the United States, Australia, Germany, and Poland.

China has already adopted a policy of closing some existing coal mines, which will cut its annual production capacity by between one to two billion metric tons of coal, depending on implementation. For comparison, China currently extracts 3.7 billion metric tons, (though these capacity reductions will not translate to a 25% to 50% cut in output because of current overcapacity, but they will reduce China's developed reserves.)[43]

o Around 17% of coal demand is used in steel production. Research and development is under way to seek to make steel without coal; some projects have instead used forestry-derived charcoal, and earlier-stage technologies include polymers or natural gas. Steel is also highly recyclable, boosting recycling levels from the current 30% could help reduce the level of demand.[41]

The Shengli open-cast coal mine in Xilinhot, Inner Mongolia, China, 2012.

Figure 8: Partying Like it's 1899:[44] OECD Countries (a) Extracting and (b) Burning the Most Coal (2014 data)



Source: German Federal Institute for Geosciences & Natural Resources (BGR)

EQUITY: ALLOCATING FAIR SHARES

Some poorer countries see extraction and use of fossil fuels as a means to achieve economic empowerment, by providing either domestic energy or revenue from exports. At the same time, the greatest impacts of climate change will fall on poorer countries which have done the least to cause the climate problem. A study commissioned by the Climate Vulnerable Forum estimates that climate change already causes 400,000 deaths per year, 98% of which occur in developing countries as a result of increases in hunger and in communicable diseases. The current estimated 1.7% reduction in global gross domestic product (GDP) due to climate change is disproportionately felt by the world's poorest nations, the Least Developed Countries, whose GDP is being reduced by 7%.[45]

In contrast to the least-cost approaches discussed in the previous section, the appropriate question is not only which solution incurs the least cost to humanity as a whole: we must also consider a just distribution of who incurs the cost, such that each country contributes its fair share to address the global problem of climate change.

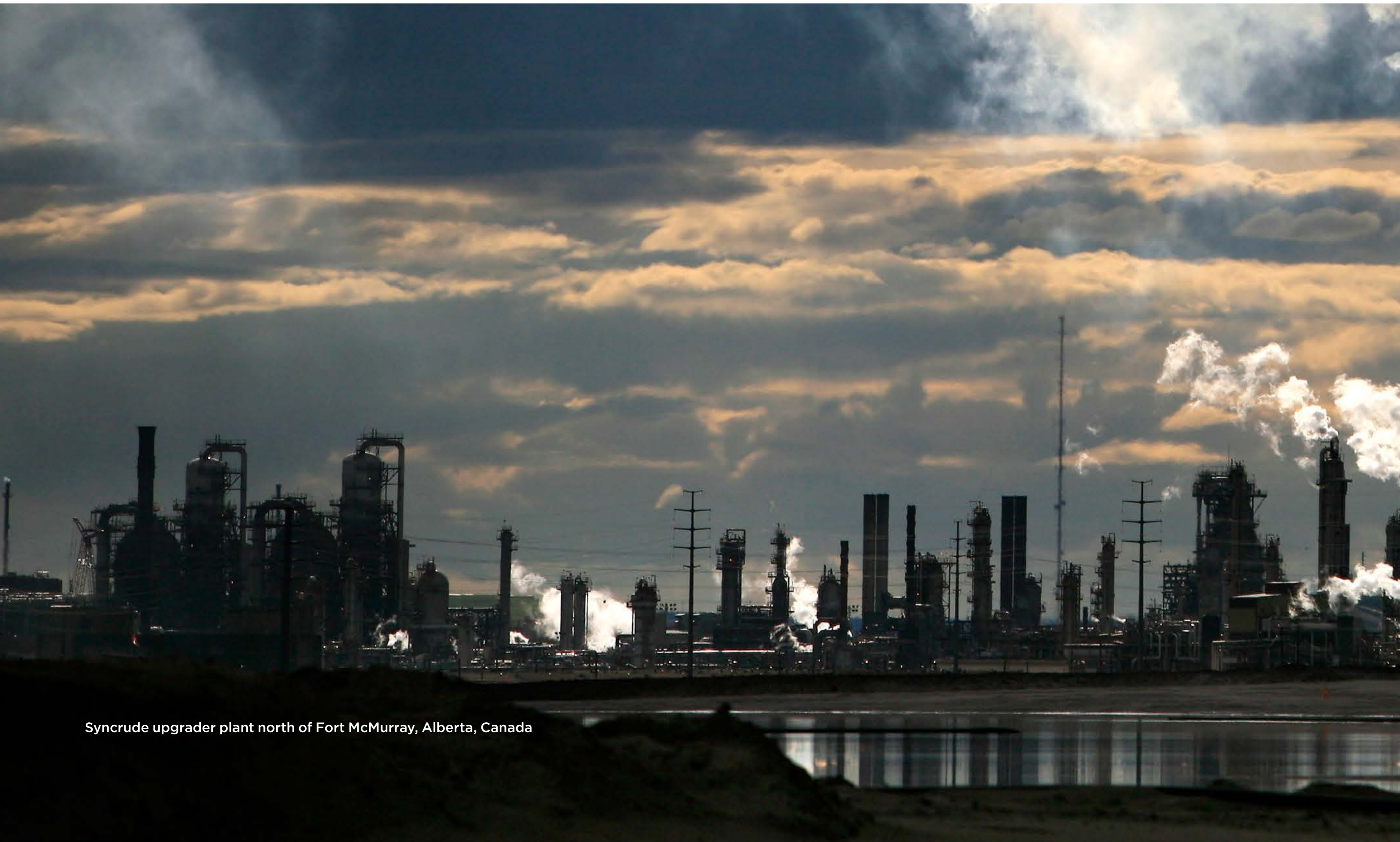
We have argued that ending the construction of new fossil fuel infrastructure is a politically pragmatic approach to avoiding dangerous climate change. The problem is that much of current fossil fuel extraction is located where it may not be most needed or justified in terms of fairness; examples include oil, gas, and coal in the United States and Russia, oil in Canada, oil in Saudi Arabia, and coal in Australia.

A forthcoming paper by Sivan Kartha and colleagues at the Stockholm Environment Institute argues that climate politics contain an unresolved tension between two different views of fossil fuel extraction: one of "extraction as pollution," and another of "extraction as [economic] development."[46] The authors point out that this tension goes right back to the 1992 UNFCCC treaty, whose preamble says: "States have [...] the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."

At the level of emissions, where most climate policy has historically focused, this tension has been addressed through the principles of equity. Most importantly, the duty to cut emissions rests more with countries that carry greater responsibility for causing the problem (those with greater historic emissions), and with those that have most capacity to act (the wealthiest countries).[47] Industrialized countries, which account for just 18% of the world's population, are responsible for 60% of all historical CO_2 emissions.[48]

Already, important questions arise. How do these principles of responsibility and capacity translate to the fossil fuel supply side? How does the "resource curse" – the paradox that those countries with the most natural resources sometimes have less economic development success – diminish the developmental value of fossil fuels, or the historic responsibility for their extraction? How do demand-side equity and supply-side equity interrelate?

Oil Change International is working with the Stockholm Environment Institute on a paper that more fully explores these questions and makes concrete proposals for an equity framework on fossil fuel



Syncrude upgrader plant north of Fort McMurray, Alberta, Canada supply. For now, it is clear that whatever the details, the onus of climate action remains on wealthier countries both to take action themselves, and to help finance and facilitate further action in countries that do not have the resources to do so themselves.

Countries with low levels of fossil fuel infrastructure have an opportunity to seek sustainable development along a low-carbon pathway, leapfrogging to clean energy without the risk and cost of investing in assets that may become stranded when climate action makes them obsolete. In this regard, it should be noted that some of the greatest ambition for energy transition comes from small, poor, and vulnerable countries, such as Costa Rica, Nicaragua, Djibouti, and Vanuatu (see Box 3 in Section 5).

However, in return such countries can and should rightly demand financial support from industrialized countries, given the advantages these nations have drawn from fossil fuels, and conversely the challenges for poorer countries of integrating variable renewables in weaker grids. This may include investment and transfer of technologies in renewable energy, as well as in other industries that can provide alternatives to revenue from fossil fuel extraction.

Other developing countries that have relied more on fossil fuel extraction or combustion will similarly require finance to facilitate a transition, in a manner that protects the livelihoods of those working in the energy industry and diversifies their revenue bases and broader economies. Some fossil fuel exporters have grappled with the challenge of how to lift their people out of poverty while addressing climate change. Ecuador, for instance, has proposed charging a tax on oil exports to wealthy countries, to increase revenue while also incentivizing lower oil use.

We conclude:

- To achieve the Paris goals, no new fossil fuel extraction infrastructure should be built in any country, rich or poor, except in extreme cases where there is clearly no other viable option for providing energy access.

- Since rich countries have a greater responsibility to act, they should provide finance to poorer countries to help expand non-carbon energy and drive economic development, as part of their fair share of global action. Particularly important will be financial support to meet the urgent priority of providing universal access to energy. Around the world, over a billion people have no electricity in their home. Nearly three billion rely on wood or other biomass for cooking or heating. Lack of access to energy in households and communities threatens the achievement of nearly every one of the Sustainable Development Goals that the international community has set to fight poverty, hunger, and disease.

- To stay within our carbon budgets, we must go further than stopping new construction: some fossil fuel extraction assets must be closed before they are exploited fully. These early shut-downs should occur predominantly in rich countries.

- Extraction should not continue where it violates the rights of local people – including indigenous peoples – nor should it continue where resulting pollution would cause intolerable health impacts or seriously damage biodiversity.

©Jiri Rezac/Greenpeace

Oil workers at the Rumaila oil refinery, near the city of Basra, Iraq. 2013

©AP Photo/Nabil al-Jurani

4. WHY FOSSIL FUEL SUPPLY MATTERS

Over the last three decades, climate policy has focused almost exclusively on limiting the combustion rather than the extraction of fossil fuels. While there is a certain intuitive sense to that, because it is combustion that physically releases CO_2 into the atmosphere, this is far from the only way to address the problem. By contrast, ozone protection was achieved by regulating the production of chlorofluorocarbons (CFCs) and other chemicals, rather than trying to influence their usage and release (for example by a deodorant tax or quota).

Around 95% of the carbon extracted in oil, gas, or coal is subsequently burned and released into the atmosphere as CO_2. As such, the amount of carbon extracted is roughly equal to the amount that will be emitted.

There are two routes by which extracted carbon may not end up in the atmosphere:

- Small amounts of oil and gas are used in industrial manufacturing of plastics, chemicals, fertilizer, and other products. In 2011, non-combustion uses accounted for 14% of U.S. oil consumption, 2% of gas consumption, and 0.1% of coal consumption – combined, these total just 6% of the carbon in U.S. fossil fuel consumption.[49] Even in some of these cases, the carbon still ends up in the atmosphere as the finished products decompose.

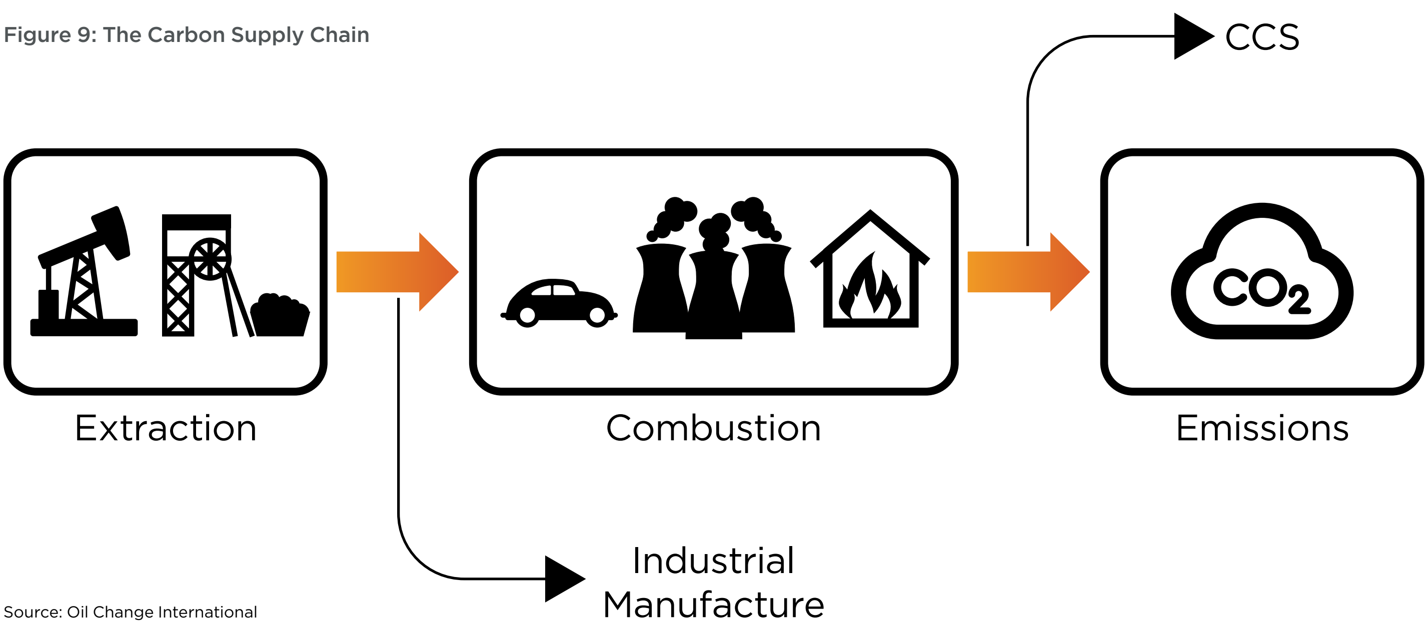
- In theory, CO_2 emissions could be captured. However, CCS has barely been deployed to date, despite strong advocacy since the 1990s by the fossil fuel industry. Due to slow development of the technology, even if CCS were developed at scale – and it is questionable whether it could be at affordable cost – the carbon budget would only be extended by an estimated 12-14% by 2050 (see Appendix 3).[50]

Apart from these exceptions – one of them minor, and the other currently tiny with uncertain prospects – any carbon that is extracted in fossil fuels ends up in the atmosphere as CO_2, as shown in Figure 9.

THREE POSSIBLE FUTURES

We have seen that the reserves in developed fields and mines exceed the carbon budget for a likely chance of staying below 2°C. As a result of this arithmetic, adding any new resource can logically do only one of two things (in the absence of CCS): either add to the excess of emissions above 2°C, or cause an asset to be stranded elsewhere.

Figure 9: The Carbon Supply Chain



Source: Oil Change International

To illustrate what this means, we extend this basic logic to all new sources of fossil fuel. There are three scenarios:

- **Managed Decline:** No further extraction infrastructure is developed, existing fields and mines are depleted over time, and declining fossil fuel supplies are replaced with clean alternatives to which energy workers are redeployed, thus preventing dangerous climate change.
- **Stranded Assets:** Companies continue to develop new fields and mines, governments are eventually successful in restricting emissions, and the resulting reduction in demand causes many extraction assets to become uneconomic and shut down, causing destruction of capital and large job losses.
- **Climate Chaos:** Companies continue to develop new fields and mines, none are stranded, and the resulting emissions take us well beyond 2°C of warming, with resulting economic and human catastrophe.

In reality, the scenarios are not mutually exclusive – the future will be some combination of all three. However, we know that each new field or mine must contribute to one of the following outcomes; if developed it will either cause stranded assets and/or dangerous climate change. Figure 10 illustrates the situation: the aggregate effect of many such decisions will be to cause considerable warming above 2°C, and/or considerable stranding of assets.

The "managed decline" scenario is explored in more detail in Section 5. This scenario requires deliberate policy decisions to cease development of new fields, mines, and infrastructure.

If that decision is not made, economic and political factors will determine the ratio of "climate chaos" (see Section 1) to "stranded assets," which we outline below. We will then consider how fossil fuel supply relates to emissions, in order to better identify the economic and political factors that arbitrate between the two scenarios.

STRANDED ASSETS

The concept of stranded assets has entered the climate debate in the last few years, especially through the work of Carbon Tracker Initiative.[51] It has been taken up by many in the financial sector, including banks such as HSBC[52] and Citi,[53] and Bank of England Governor Mark Carney.[54]

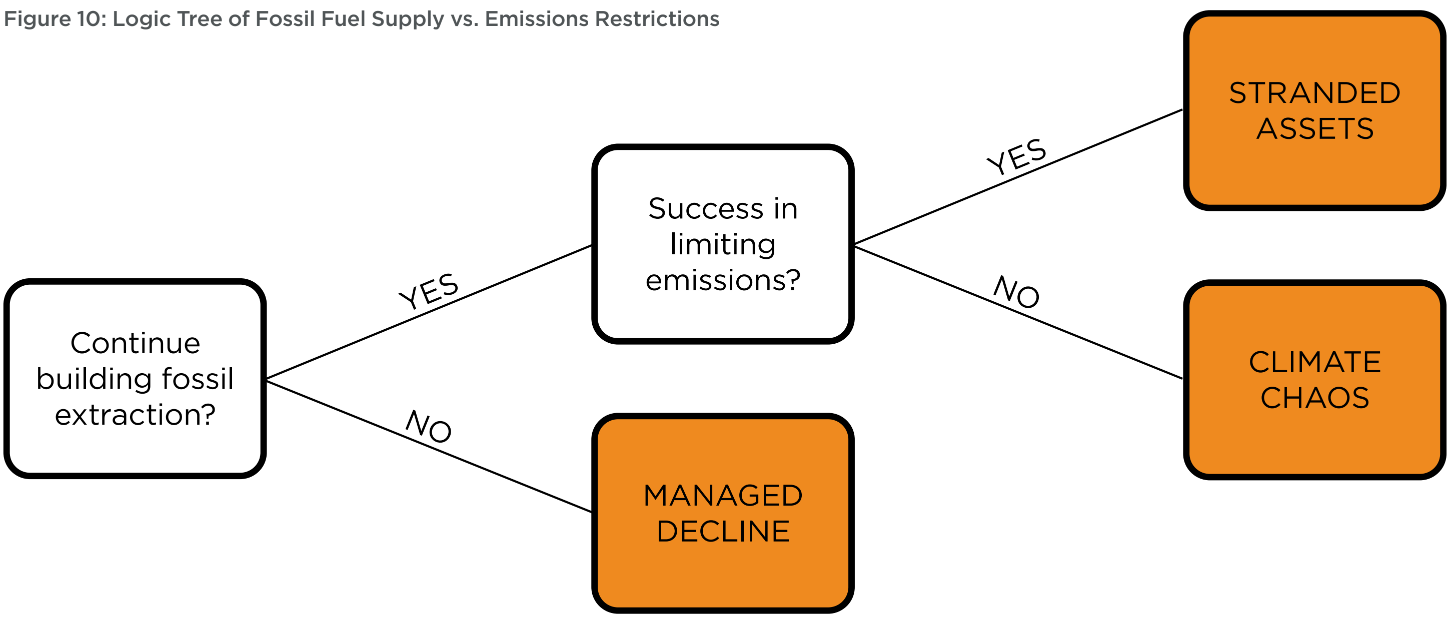
If we assume that a combination of government policy and technological change is successful in limiting warming to below 2°C or to 1.5°C (and that CCS prospects do not radically improve), demand for fossil fuels will fall rapidly, resulting in a significant decrease in fossil fuel commodity prices. This in turn will make many extraction projects unprofitable, leading to significant losses for investors.

To estimate the scale of stranding, Table 6 gives estimates of projected capital expenditure over the next 20 years that will potentially be wasted: over $10 trillion in new oil fields, gas fields, and coal mines, and up to $4 trillion in transportation infrastructure such as pipelines, railways, and port terminals. (For comparison, projected ongoing and maintenance capital expenditure on existing fields and mines is just over $6 trillion).[p]

On top of this, there would be stranding of downstream assets such as power plants and refineries, the estimation of which is beyond the scope of this report.

The "stranded assets" scenario is not something we can regard as a problem only for financial institutions. It would be bad news for pension-holders, for those employed by the fossil fuel industry, and for

Figure 10: Logic Tree of Fossil Fuel Supply vs. Emissions Restrictions



Source: Oil Change International

p Comprising $4.4 trillion on oil, $1.5 trillion on gas and $0.35 trillion on coal

Table 6: Potential for Asset Stranding: Projected (Public and Private) Capital Expenditures on New Fields and Mines, 2014-35 (2012 Dollars)

	Extraction Projects[55]	Transportation Projects[56]
Oil	$6,270 bn	$990 bn
Gas	$3,990 bn	$2,630 bn
Coal	$380 bn	$300 bn
TOTAL	$10,640 bn	$3,920 bn

Sources: International Energy Agency, Rystad UCube

the wider population dependent on a stable economy. Inevitably, if fossil fuel extraction is maintained or increased, then staying within climate limits would require a much faster pace of reductions than if a managed decline begins now. This means much more disruption, more expenditure on faster development of alternative infrastructure, and the loss of more jobs at a quicker rate.

"Stranded assets" is not the only scenario that causes economic loss. On top of the severe human costs of greater disease, starvation, and lost homes, the economic costs of climate change are vast, encompassing infrastructure damage and the decline of sectors such as agriculture and insurance. Estimates since the Stern Review of 2006 have commonly put the impact at several percent of global GDP by the late twenty-first century, and a more recent study of historic correlations between temperature and economic activity suggested that unmitigated climate change could cause as much as a 20% reduction in 2100 output.[57] Another study on the impact on financial investments estimated that $2.5 trillion of financial assets could be at risk.[58] The economic disruption of climate change would also cause major job losses across numerous sectors, and would do so in a chaotic way that would make transitional support even more difficult.

In contrast to the combination of these two costly scenarios, managed decline of fossil fuel extraction offers a more reasonable path forward.

SUPPLY AND DEMAND

In recent years, many governments have adopted the apparently contradictory goals of reducing emissions while encouraging increased fossil fuel extraction. In the absence of CCS, these two goals cannot both be achieved at a global level: if emissions are to be reduced, total fossil fuel consumption must be reduced, which in turn means that total fossil fuel extraction must be reduced as well.

When pressed, governments and companies tend to square the circle by assuming that it is someone else's production that will get constrained and some other investor's bet that will go sour. However, they never specify which other country or company's production they anticipate will be stopped, or why, or how.

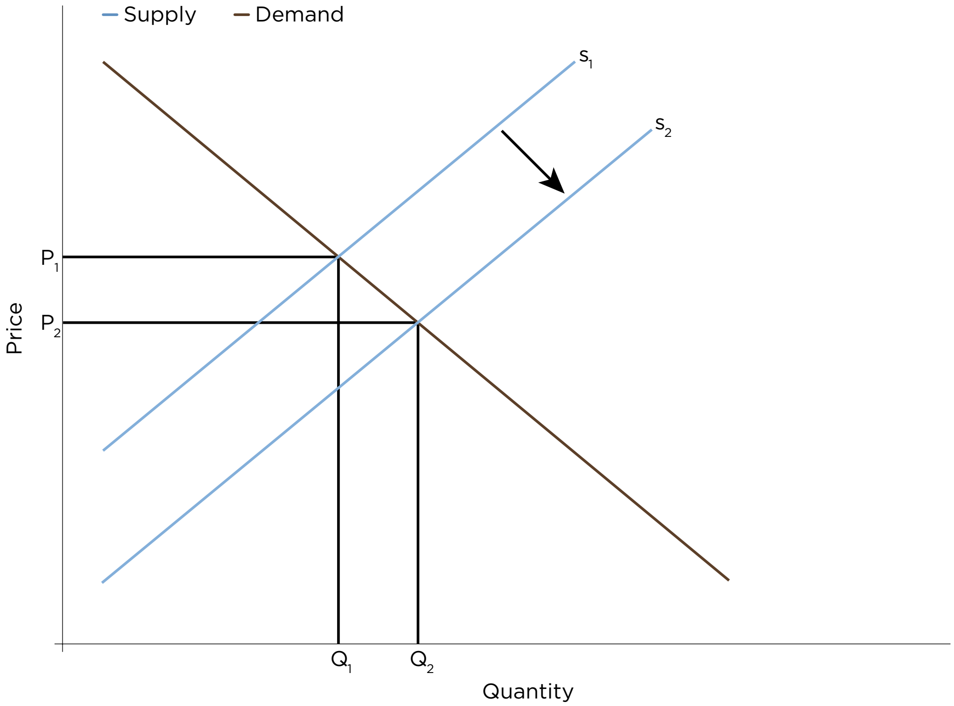
Some commentators insist that climate change should only be addressed on the demand side.[59] But the trouble with this view is that the act of increasing supply makes it harder to cut emissions.

(i) More Supply = Lower Price = Higher Demand

While climate policy has addressed fossil fuels almost entirely on the demand side, there has been an implicit assumption that markets will then simply allocate the aggregate demand between suppliers. However, this is not how energy markets work.[60]

Over the history of the modern energy industry, there have been times when demand has led events, and times when supply has done so. For an illustration of supply leading the way, consider the present-day situation. U.S. oil extraction expanded from 6.8 million barrels per day (mbd) in 2010 to 11.7 mbd in 2014,[61] stimulating a fall in price, which was exacerbated when the Organization of the Petroleum Exporting Countries (OPEC) decided in November 2014 not to cut its production to compensate. The resulting low oil prices led to global oil demand growing at the fastest pace in five years,[62] and to the fastest increase in U.S. gasoline consumption since 1978.[63]

Figure 11: Impact of Policy to Encourage Supply on Supply / Demand Equilibrium



This should not be surprising, as it is what basic economic theory tells us: supply does not simply passively match demand, but interacts with it in dynamic equilibrium.[q] Figure 11 shows how supply and demand interact: the actual quantity consumed and produced is determined by the point where the two lines cross. A policy designed to increase extraction or lower its costs – in this example, weak environmental regulation of hydraulic fracturing in the United States – will move the supply curve to the right and/or downward. The resulting new equilibrium has a lower price and a higher quantity. In short, the increase of supply has also increased consumption, and thereby emissions.

(ii) Lock-In of Production

Once a field or mine has been developed, it will generally keep producing. In other words, the act of developing it locks in future production. This is because once capital has been expended, an investor has strong incentives to avoid letting the asset become stranded. This is illustrated in Figure 12, where cash flow is negative in the early phase as capital is invested. The project only receives income once oil production begins, after three years. In the higher-price scenario, it takes a further nine years to pay back the invested capital, and the project finally begins making a profit around Year Twelve. In the lower-price scenario, the project never breaks even.

If the company knew beforehand – in Year Zero – that the price would follow the lower path, it would not move ahead with the project. But once the project has been developed, the economic incentives push for continued production even if it means a long-term loss on the capital invested, since closing down would lead to an even greater loss. As long as the red curve is rising in Figure 12, continued production reduces the ultimate loss. It is only if the price received is less than the marginal operating cost (the curve bends downward) that it is better to stop before losses increase.

In sum, a company will not proceed with a new project if commodity prices are less than the total operating and capital costs, but will close down an-already developed project only if prices hit the much lower threshold of marginal operating costs. In other words, any given action to reduce demand becomes less effective as soon as extraction projects have been developed and operation is ongoing.

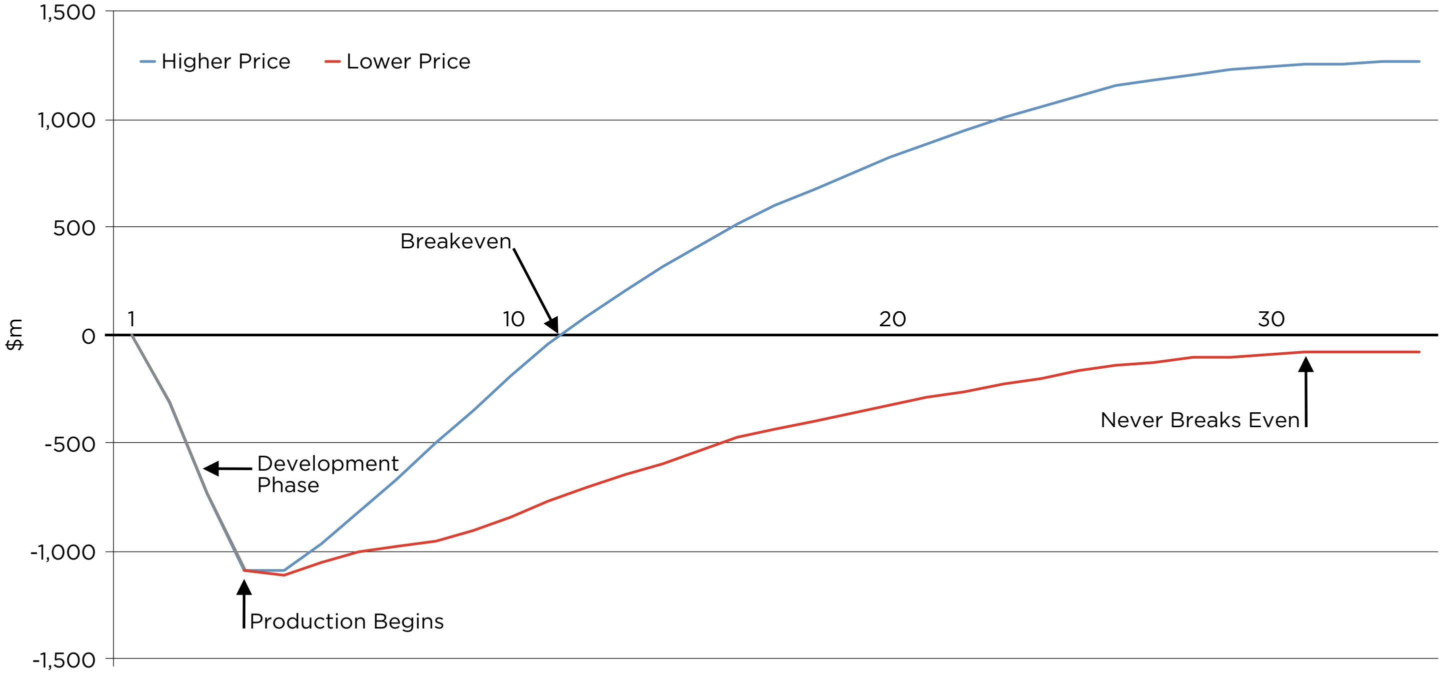
(iii) Perverse Political Effects

As well as the perverse economic impacts of increasing fossil fuel supply, there are also perverse political impacts. Governments tend to act more strongly to protect existing industries than to stimulate future ones, because of the political clout of real jobs held by identifiable people (as opposed to abstract numbers), and because of the lobbying power of dominant industries.

When fossil fuel prices are low, governments often feel political pressure to reduce taxes on fossil fuel production or provide other subsidies to keep companies producing. For example, the United Kingdom cut the highest tax rate on North Sea oil production from 80% to 68% in 2015 and again to 40% in 2016.[64] Noting declining profitability since 2011 (when coal prices began their slide), the Indonesian Coal Mining Association is calling for the government to guarantee cost-based prices in order to enable continued expansion.[65] The effect of subsidies expanding or maintaining supply translates through the price mechanism again into increasing demand and increased emissions.

q This mechanism breaks down if there is a perfect swing producer, which adjusts its own supply to maintain equilibrium at a certain level. Even before 2014, OPEC's ability to act was in reality limited by physical, political and economic factors (if it had been a perfect swing producer, the price would not have fluctuated). Now that Saudi Arabia and OPEC have decided not to fulfil that role even partially, and instead to maximize their production, the market reflects this model.

Figure 12: Cumulative Discounted Cash Flow for a Typical Fossil Fuel Project[r]



Source: Oil Change International

r Cash flow is the total income minus total (undepreciated) expenditure in any year. Discounting adjusts this to account for the time value of money, reflecting both the cost of capital and the opportunity cost of not investing it elsewhere.

5. MAKING AN ENERGY TRANSITION HAPPEN

Twenty-five years of climate politics has thoroughly embedded the notion that climate change should be addressed at the point of emissions, while the supply of fossil fuels should be left to the market. That view is now no longer supportable (if in fact it ever was). Our analysis indicates a hard limit on the amount of fossil fuels that can be extracted, pointing to an intervention that can only be implemented by governments. We conclude that:

- Governments should issue no further leases or permits for new oil, gas, or coal extraction projects or transportation infrastructure.

While this would mark a significant change in the direction of climate policy, it is also the least disruptive and least painful option. As we saw in the previous section, in the absence of a dramatic turnaround for CCS, further building of fossil fuel extraction infrastructure will lead us only to two possible futures, both of which entail vast economic and social costs.

What we propose in this report is the easiest global approach to restraint: when in a hole, stop digging.

A GRADUAL TRANSITION

Existing fields and mines contain a large amount of oil, gas, and coal, which will be extracted over time. Rates of extraction will decline without development of new resources and infrastructure, but the decline is far from precipitous. The fastest decline will be in fracked shale, where wells produce for only a few years. Other fields often last much longer.

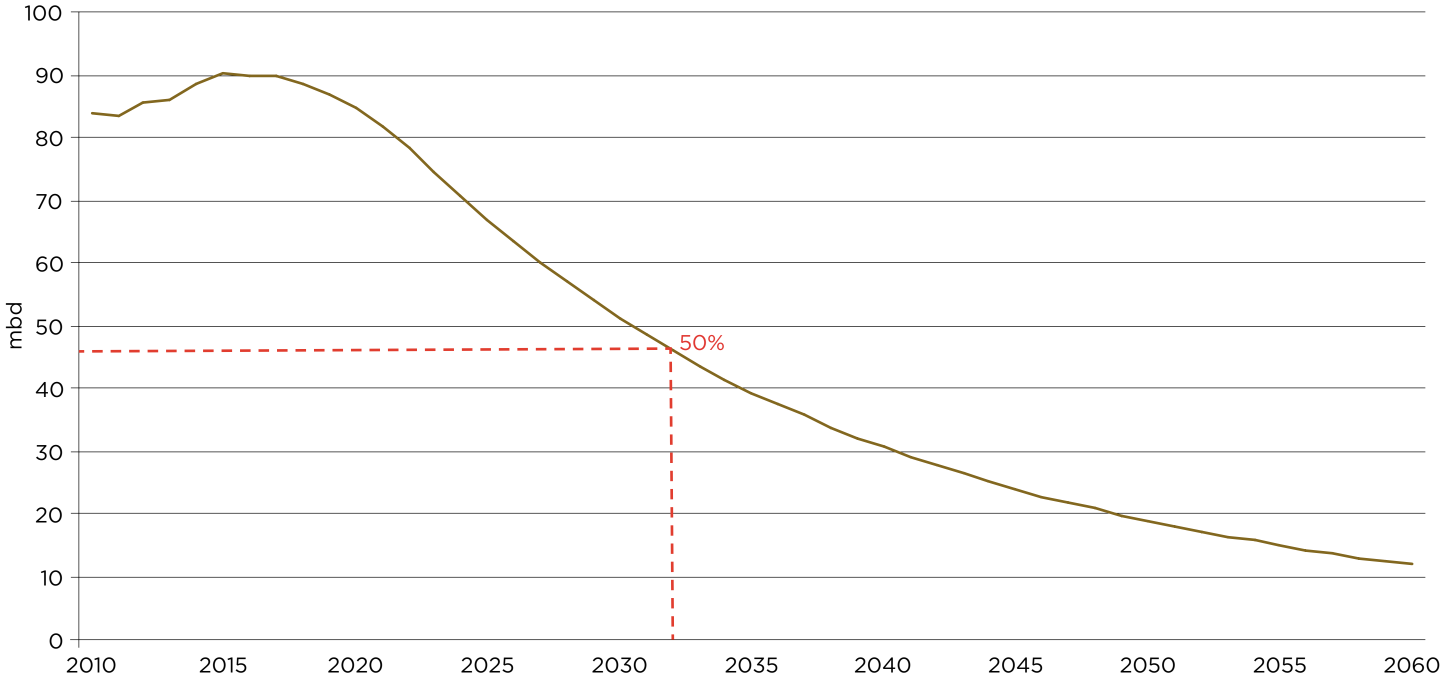
Figures 13 and 14 show Rystad's projection of oil and gas extraction from existing fields and those under construction, in its oil price base case[s]: extraction (and hence global supply) would fall by 50% by the early 2030s. Data is not available for coal.

This projection should not be alarming. Remember that emissions must decline rapidly, to net zero by 2070, for a likely chance of staying below 2°C, or by 2050 for a medium chance of staying below 1.5°C (see Figure 1 on page 13). For emissions to decline, fossil fuel use (and consequently extraction) must decline at the same overall rate.

Simply restricting supply alone would lead to increased prices, potentially making marginal production in existing fields and mines viable. The amount ultimately extracted and emitted would still be lower (see Figure 11 on page 34), but may not be as low as carbon budgets allow. A more powerful policy approach would be to pursue reductions in supply and demand simultaneously. As long as the two remain roughly in sync, prices will remain more stable, and "leakage" – where reductions in one country's extraction are offset by increased extraction in another country – will be minimized. The two policy approaches can also be mutually reinforcing, as declining supply of fossil fuels stimulates more private investment in alternatives, and vice versa.

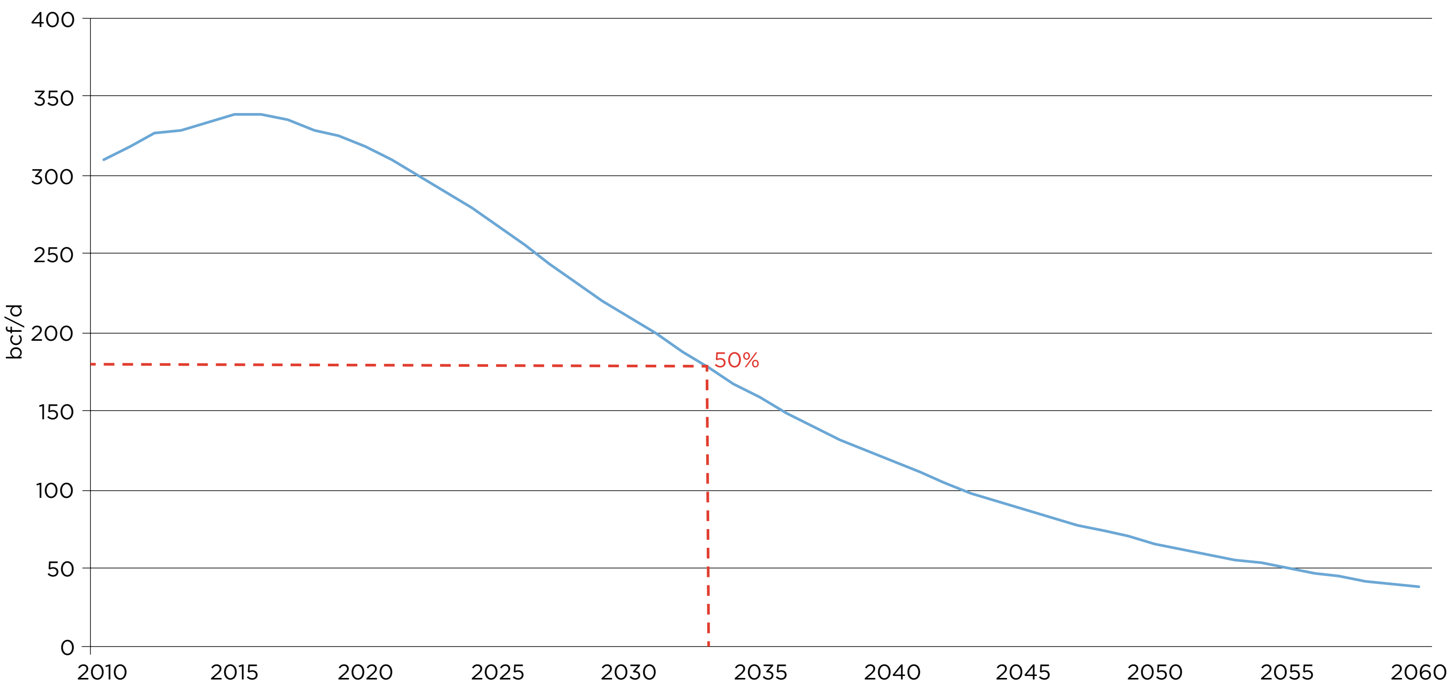
s A higher price would lead to slower decline, as companies would invest more capital expenditures even in existing fields. Conversely, a lower price would lead to faster decline.

Figure 13: Projected Global Oil Production from Existing and Under-Construction Fields[66]



Source: Rystad Energy

Figure 14: Projected Global Gas Production from Existing and Under-Construction Fields[67]



Source: Rystad Energy

BOX 3: The Remarkable Growth in Renewable Energy

Renewable power generation is growing exponentially: wind at around 20% per year globally, and solar at around 35% per year.[68] Wind generation has more than doubled since 2010, while solar has doubled nearly three times in that period. Compounded over many years, these growth rates add up rapidly: if wind and solar sustained their current global growth rates, they would exceed current coal and gas power generation in 2029.[69] At some point, growth rates will slow down, but there is no indication that it is happening yet.

Denmark, a relatively small country, generates 40% of its electricity from renewables (mainly wind), and is aiming for 100% renewable generation by 2035.[70] In 2015, Germany – the world's fourth largest economy – generated nearly one-third of its power from renewables, primarily wind and solar.[71]

Small and large developing countries are moving to renewables too. Costa Rica produces 99% of its electricity from renewable sources, including hydro, wind, and geothermal.[72] Neighbouring Nicaragua generates up to 20% of its electricity from wind, and 16% from geothermal.[73] Djibouti is aiming for 100% of its energy to be renewable by 2020, much of it off-grid solar.[74] Vanuatu currently generates 43% of its electricity from renewables, and aims for 65% by 2020 and 100% by 2030, with much of the growth coming from grid-connected wind and solar, and off-grid solar.[75] In absolute terms, China is set to overtake the United States in 2016 as the largest generator of wind and solar power.[76] China is also showing the fastest growth in wind and solar installations: 2015 was a record year in which its wind capacity grew by 33.5% and grid connected solar capacity by 73.7%.[77]

India has a target of a twenty-fold increase in solar power to 100 GW by 2022, which would take it to more than twice China's current level.[78]

In many countries, wind and solar are already cost-competitive with fossil fuel and nuclear power generation. A recent Deutsche Bank survey of sixty countries found that solar has reached grid parity in fully half of the countries already.[79] And costs are falling fast. The International Renewable Energy Agency reports that the levelized cost of electricity from utility-scale solar fell by 58% between 2010 and 2015, and could fall by a further 59% between 2015 and 2025.[80]

New transportation technologies, specifically electric vehicles (EVs), are also developing fast. Battery costs – a major element of the price of an EV – are falling quickly, as lithium-ion battery costs fell 65% from 2010 to 2015.[81] Further cost declines and performance improvements are widely expected, with some projecting a further 60% cost decline by 2020.[82] Financier UBS predicts that by the early 2020s, the purchase price of an EV will be only very slightly higher than a petroleum-fueled car, with only small a fraction of the fuel and maintenance costs.[83]

In 2016 and 2017, three different mass-market, long-range electric car models are being launched in the United States, with dozens more expected by 2020. China aims to have five million EVs on the road by 2020, while several European countries (including Norway, France and Germany) have recently announced that they to no longer allow sales of petroleum-fueled cars after either 2025 or 2030.[84]

An oil storage facility in Linden, New Jersey USA.

© AP Photo/Mark Lennihan

CLEAN ENERGY REPLACES FOSSIL FUELS

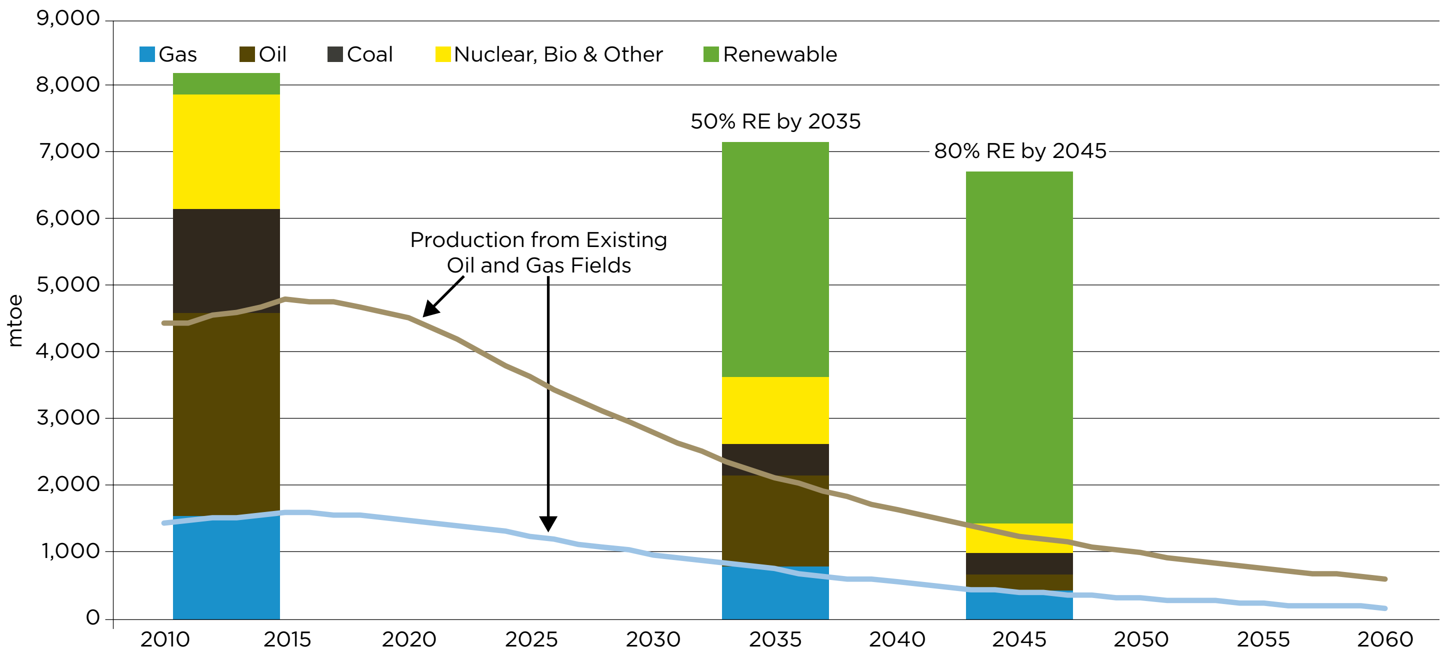
Renewable power technologies are not only possible; they are already in use at scale in many countries, growing rapidly, and often cost less than gas or coal generation (see Box 3). Electric vehicles are at an earlier stage of development than renewable power, but may be able to penetrate the market more rapidly: whereas a power plant has a typical lifetime of 40 years, cars generally last for around ten years.

A common objection to renewable energy relates to the challenges of intermittency. However, this problem is often overstated. For example, the chief executive officer of the northeast Germany electrical grid says the country can get up to 70% to 80% wind and solar even without "additional flexibility options" such as storage.[85] A 2012 report by the National Renewable Energy Laboratory found that with existing storage capacity, the U.S. grid can handle as much as 50% wind and solar penetration.[86] To go further, affordable storage solutions are now emerging, from lithium ion batteries to compressed air and others. Residential battery storage systems entered the mainstream market in the US and Australia in 2015, and the coming years are also expected to see increasing deployment of grid-scale storage.[87] The bigger challenges will be expanding renewable energy in weaker grids in developing countries, emphasizing again the importance of climate finance to facilitate the transition.

We now examine what is needed to replace depleting fossil fuel extraction, by comparing the residual oil and gas demand that will remain while aggressively moving to clean energy, with natural depletion of existing oil and gas fields (as shown in Figures 13 and 14, on page 37). Using a simple model of progressive electrification of energy-consuming sectors and progressive conversion of electricity generation to renewables, we convert the final energy consumption projected in the IEA's 450 Scenario in two scenarios: 50% renewable energy by 2035 and 80% by 2045. In both we assume a complete phase-out of
coal usage, except in steel production. The results are shown in Figure 15 (see detailed calculation and assumptions in Appendix 4).[88]

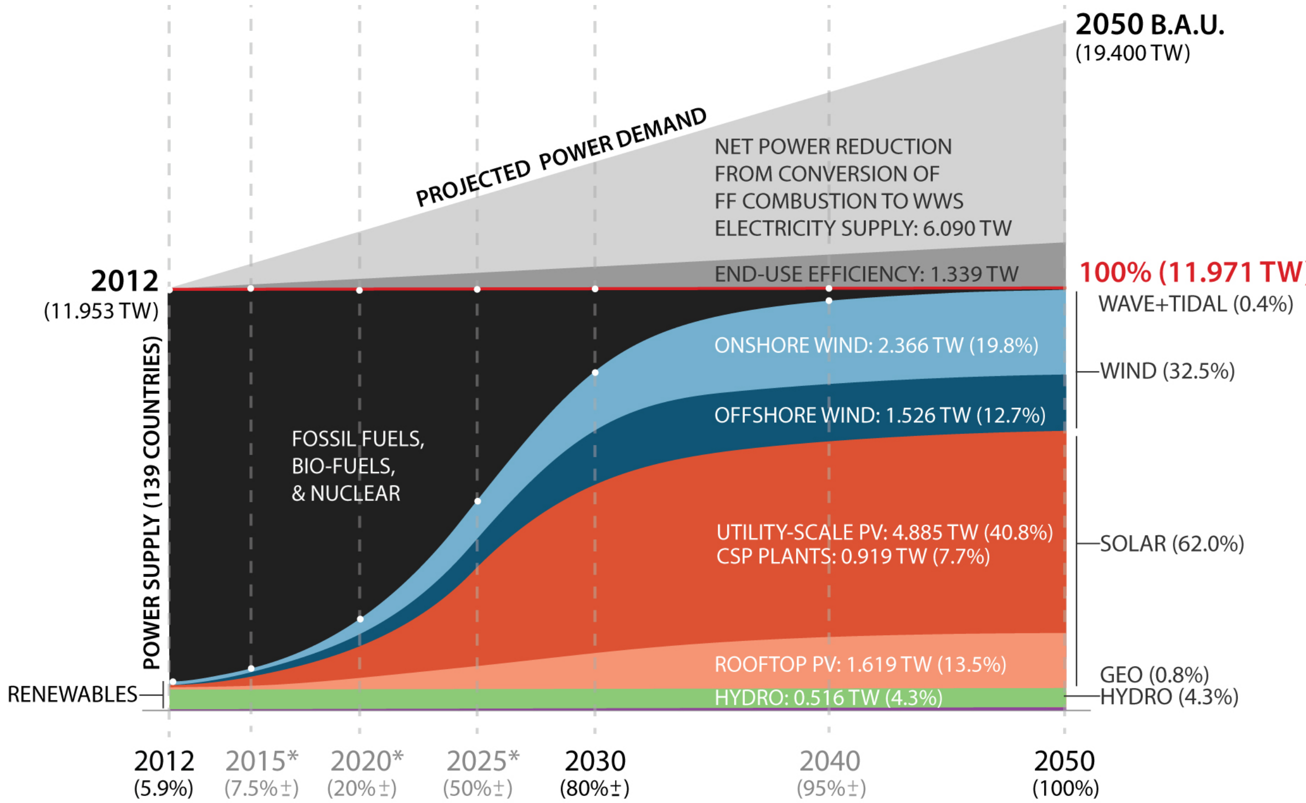
We see in the Figure that in 2035, expected oil and gas production from existing fields roughly matches the requirement with a 50% renewable energy penetration. Further depletion to 2045 leaves greater production than would be required while moving to 80% renewable energy.

Figure 15: Final Energy Consumption by Source With 50% Renewable Penetration in 2035 and 80% in 2045, Compared to Depletion of Existing Oil and Gas Fields (See Appendix 4)



Sources: IEA, Mark Jacobson et al, Rystad Energy, Oil Change International analysis

Figure 16: Projected Power Demand and Fuel Source, in Jacobson et al's Roadmap for 139 Countries



Source: Mark Jacobson et al

Mark Jacobson of Stanford University and colleagues have developed detailed roadmaps for how 139 countries could achieve 80% renewable energy by 2030, and 100% by 2050, as shown in Figure 16.[89] These are much faster rates of conversion than we have outlined above. For each country's projected energy demand – including electricity, transportation, heating/cooling, and industry – Jacobson's team considers what level of each renewable energy source would be required, using only technologies that are available today. They take into account the wind, solar and water resource, land area and infrastructure for each country, and allow for intermittency. A small proportion of transportation and industrial energy uses hydrogen as a fuel carrier.

What Jacobson and his colleagues have shown is the *technical* feasibility of obtaining 100% of energy from wind, water and solar by 2050, and 80% of it by 2030. The technology can deliver, and there is sufficient available resource, while taking up just 0.25% of the 139-country land area, mostly in deserts and barren land (plus a further 0.7% for spacing between wind turbines, which can be used at the same time for farmland, ranchland, grazing land, or open space). They have also shown that the transformation will create a major net addition to the number of energy jobs, compared to continuing with fossil fuels.

Jacobson's calculations are not just a theoretical possibility. In a global survey of 1,600 energy professionals by consultancy DNV GL, nearly half of respondents said they believed the electricity system they work in could achieve 70% renewable generation by 2030, if there were sufficient political will.[90]

How much does all this cost? Over recent years, estimates of clean energy costs have been consistently revised downward, while estimates of the cost of climate change have been revised upwards. In many parts of the world, wind and solar are cost-competitive with gas and coal power generation, and with fast-falling costs they soon will be elsewhere as well (see Box 3).

Bloomberg New Energy Finance (BNEF) estimates that by 2027, it will be as cheap to build a *new* wind or solar plant as to run an *existing* coal or gas plant. BNEF projects that to have a 50% chance of keeping warming to 2°C, $14 trillion of clean energy investments would be needed over the next 25 years; however, $9 trillion would occur even in the absence of policy intervention.[91] While in this report we focus on achieving a greater probability of staying below 2°C, and aiming for 1.5°C, which

Table 7: Case Studies of Rapid Energy Transitions

Country	Technology / Fuel	Market or Sector	Period of Transition	No. of Years from 1% to 25% Market Share	Population Affected (millions)
		End Use Energy Technology			
Sweden	Energy Efficient Ballasts	Commercial Buildings	1991-2000	7	2.3
China	Improved Cookstoves	Rural Households	1983-1998	8	592
Indonesia	Liquefied Petroleum Gas Stoves	Urban and Rural Households	2007-2010	3	216
Brazil	Flex-Fuel Vehicles	New Automobile Sales	2004-2009	1	2
United States	Air Conditioning	Urban and Rural Households	1947-1970	16	52.8
		Energy Supply			
Kuwait	Crude Oil and Electricity	National Energy Supply	1946-1955	2	0.28
Netherlands	Natural Gas	National Energy Supply	1959-1971	10	11.5
France	Nuclear Electricity	Electricity	1974-1982	11	72.8
Denmark	Combined Heat and Power	Electricity and Heating	1976-1981	3	5.1
Ontario, Canada	Coal	Electricity	2003-2014	11*	13

Source: Benjamin Sovacool

* The Ontario case study is the inverse, showing how quickly the province went from 25% coal supply to zero.

would require a greater proportion of clean energy, the BNEF estimate gives a useful ballpark figure. It should be compared with the projected $14 trillion in new fossil fuel extraction and transportation (Section 4), not to mention investment in power plants and refineries.

As a result of increasing cost-competitiveness, much new energy investment is now indeed going into clean energy. However, the rates of renewable penetration in Figure 15 – sufficient to replace fossil fuel decline – are greater than would occur due to market forces alone. The point is that policy intervention is needed to drive investment decisions solely into clean energy, to build sufficient institutional capacity to carry out the investments, and to stop expansion of fossil fuels. The cost competitiveness shows that the net cost of those interventions will be modest, or even negative. We would further note that one of the biggest barriers to the transition is the estimated $452 billion G20 countries currently provide in subsidies every year to fossil fuel extraction.[92]

Is such a large-scale transformation possible, at such a speed? Benjamin Sovacool of Aarhus University has pointed to several energy transformations at the national-level – in both end-use and supply technologies – that took place on these kind of timescales, shown in Table 7.[93] In several cases, a concerted and coordinated effort by government was vital to facilitating the transition, through subsidies, establishing pilot programs, retraining workers, and regulation. A worldwide transition away from fossil fuels is of course a larger and more complex undertaking than these examples, but as Sovacool notes, "previous transitions may have been accidental or circumstantial, whereas future transitions could become more planned and coordinated, or backed by aggressive social movements or progressive government targets."

We conclude that:

- Gradual decline of fossil fuel extraction by depleting existing oil and gas fields and phasing out coal is replaceable with existing clean energy technologies, without major extra cost.

JUST TRANSITION

The implications of limiting global warming to below either 2°C or 1.5°C are significant. It will require a fundamental transformation of the energy industry, beginning immediately and taking place over the next three to four decades. There are many advantages to this transition, even aside from its necessity to prevent dangerous climate change:

- Renewable energy sources generate power more cheaply than coal or gas in many parts of the world, and soon will do so nearly everywhere (see Box 3).
- Electric vehicles commonly offer higher performance than internal combustion engines, and are also expected to be cheaper within the next five years.
- Clean energy industries employ many more people per dollar invested and per GWh generated than fossil fuel industries. A study by the United Nations Industrial Development Organization found that $1 million creates twice as many jobs if invested in renewable energy and energy efficiency as it would if invested in fossil fuels.[94] Meanwhile, the United Kingdom Energy Research Centre finds that a GWh of electricity from wind and solar creates five times as many jobs on average as a GWh of electricity generated from gas and coal.[95]
- Reduced fossil fuel pollution will have massive benefits for health: coal burning alone is estimated to cause 366,000 deaths per year in China and 100,000 per year in India.[96]
- Some analysts argue that given diminishing returns from developing oil and gas at the frontiers, investors in oil companies would obtain higher returns from a phased wind-down of the companies than by their high-cost continuation.[97]

However, the process of transition will not necessarily be painless for individuals, companies, regions, and countries. It will affect fossil fuel energy workers, many of whom may not have the right skills or be in the right location to smoothly transition into clean energy jobs. It will also affect people working to service fossil-based utilities and worksites, whose positions are often more precarious than jobs directly in energy companies. Many energy jobs lie in construction rather than operations, and so in the short term, an end to fossil fuel construction may lead to a more rapid decline in job numbers than in volumes of fossil fuels. Communities may be hit by a loss of revenue or local economic activity, and cultural impacts in places where a community has been long associated with a particular employer or industry.

Action by governments is therefore needed to conduct the energy transition in a way that maximizes the benefits of climate action while minimizing hardships for workers and their communities. Trade unions and others have developed a framework for a just transition in relation to climate change, the importance of which is recognized in the preamble of the Paris Agreement.[98] In 2015 the International Labour Organization adopted guidelines on just transition.[99] Key elements of a just transition include:[100]

- **Sound investment**s in low-emission and job-rich sectors and technologies.
- **Social dialogue and democratic consultation** of social partners (trade unions and employers) and other stakeholders (such as communities).
- **Research and early assessmen**t of the social and employment impacts of climate policies.
- **Training and skills development** to support the deployment of new technologies and foster industrial change.
- **Social protectio**n alongside active labor markets policies.
- **Local economic diversificatio**n plans that support decent work and provide community stability in the transition.

As Jeremy Brecher of Labor Network for Sustainability points out, all of this is achievable and has several relevant precedents in the United States.[101] At the end of World War II, the G.I. Bill of Rights provided education and training, loan guarantees for homes, farms, and businesses, and unemployment pay for returning veterans. It was vital to their reintegration into American society and to the transition to peace. Another military example was the 2005 Base Realignment and Closing Commission (BRAC), which provided communities around closing bases with planning and economic assistance, environmental cleanup, community development grants, and funding for community services, as well as counselling and preferential hiring for affected workers.

In the energy sector, the current Obama Administration Power+ Plan, which offers support for communities previously dependent on coal, has many of the features of a just transition, including funding for job training, job creation, and economic diversification.

The job and skill profiles of workers who could potentially be affected vary widely, and therefore require different strategies. For workers currently employed in fossil fuel extraction or use, incumbent companies must support workers and either offer career progress in non-fossil fuel parts of the company or provide them with transferable skills to navigate the labor market with better chances for success. For communities and workers that depend indirectly on fossil fuel economic activity, public authorities must anticipate the need for new sources of revenue and support investments to transform their economies.

The most critical questions lie in how industry and policymakers will conduct an orderly and managed decline of fossil fuel extraction, with robust planning for economic and energy diversification. As Anabella Rosemberg of the International Trade Union Confederation writes, "Job losses are not an automatic consequence of climate policies, but the consequence of a lack of investment, social policies, and anticipation."[102]

National governments should seek to stimulate new economic growth in regions previously dependent on fossil fuel industries, and in new industries to take their place. Most importantly, leaving things until carbon budgets are mostly exhausted would result in disruptive change that would be sudden, costly, and painful. By starting now, the transition can be managed efficiently and fairly, to the maximum benefit of everyone involved.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6. CONCLUSION

In the Paris Agreement, 195 governments agreed to limit global warming to "well below 2°C" above pre-industrial levels, and to aim for a temperature increase of not more than 1.5°C. In this report, we have used the concept of carbon budgets, drawn from the Fifth Assessment Report of the IPCC, to explore what this would mean in practice.

We find that the oil, gas, and coal in already-developed fields and mines (that is, where the infrastructure has been built) exceeds the amount that can be burned while likely staying below 2°C, and significantly exceeds the amount that can be burned while staying below 1.5°C. Any new fossil fuel infrastructure that is built would require a corresponding early retirement of existing infrastructure. Given the political and economic difficulties of closing down existing facilities, we recommend that:

- No new fossil fuel extraction or transportation infrastructure should be built worldwide.

Instead, we should allow for the gradual decline of existing operations, over the coming decades, and invest strongly in clean energy to make up the difference. We have seen that there is no economic or technical barrier to making this transition over this time frame: the only requirement is political will.

To minimize the costs of the transition, governments should conduct robust planning for economic and energy diversification. The principles of just transition should be applied, to ensure workers and communities benefit from the shift to a clean energy economy, rather than be harmed by it.

The conclusions in this report will take some by surprise, and cause alarm with others. They imply serious alterations to the global economy, will be resisted by some of the most profitable companies ever known, and will necessitate bold and decisive action by governments on a scale not seen thus far.

But the conclusions are also remarkably straightforward at their core. To keep from burning more fossil fuels than our atmosphere can withstand, we must stop digging them out of the ground. With this report, we put forward recommendations on how to go about doing just that in a sufficient, equitable, economically efficient, and just fashion.

Vehicles work at an open-pit coal mine near Ordos in northern China's Inner Mongolia Autonomous Region, 2015.

APPENDIX 1: DEFINITIONS OF RESERVES

Since fossil fuel reserves are located beneath the earth's surface, estimating their quantity is based on inherently limited information drawing on interpretation and judgment of geological data, as well as assumptions about economics and operations. Quantities of reserves are therefore distinguished by the degree of confidence in them: proven, probable, and possible.

The most commonly cited estimates for reserves in fact refer only to proven reserves, a quantity defined (where probabilistic methods are used) as having a 90% likelihood that the amount actually recovered will exceed the estimated amount.[103] This is because the principal use of the concept of reserves is to help investors assess the value of a company by providing an indicator of its future potential production. For this purpose, the most relevant estimate is the more certain one, as it carries less risk.

Since it requires such a high degree of confidence, the proven reserves figure understates what can be expected to in fact be extracted, even based on current knowledge. For anticipating the future impact on the climate (or indeed on energy markets), it is more relevant to consider a realistic estimate of what will be extracted. In this report, we therefore also state probable reserves of oil and gas, taking proven plus probable to refer to the best estimate of the quantity that will ultimately be extracted in the absence of climate constraints. We interpret this as the mean (expected) value.[t]

Contrary to what might then have been expected, the proven-plus-probable reserves figures we use in this report are actually lower than those in the BP Statistical Review of World Energy, which claims to give proven reserves. The reason is that BP takes at face value the amounts claimed by countries such as Venezuela, Saudi Arabia, and Canada, whose measurements lack transparency, are widely suspected to be inflated, and/or rely on broader-than-usual definitions of proven reserves. Rystad Energy – our source of reserves data – instead makes judgments of what reserves are realistically extractable.[104]

Estimates of probable reserves are harder to obtain than of proven. In particular, there are no reliable data available for probable reserves of coal, and definitions vary significantly between countries. Even data on proven coal reserves is of much poorer quality[u] than data on oil and gas, for which there have been efforts to align definitions and compile global reserves data from company and government reports.[v] The IEA notes that due to the sheer scale of coal reserves and substitution by gas, there has been little interest in coal surveys since the start of the twenty-first century.[107]

The implication is that the quantity of reserves is a less important determinant of future production for coal than for oil and gas (another important underlying factor is air pollution regulations).[108] For these reasons, in this report we use only proven reserves for coal.

t While definitions vary, it should be noted that we differ from the more common usage of "proven + probable" to refer to the median estimate. Our reason is that whereas the median is a useful quantity for considering a single field, median values cannot be arithmetically added due to the mathematics of probability, whereas mean values can be.

u For example, the BP Statistical Review takes its coal reserves data from the World Energy Council's World Energy Resources, which is only published every three years: thus the 2016 BP publication contains data relating to 2011. Availability of reliable coal data is especially limited for China, by far the world's largest coal producer. The World Energy Council has not updated its China data since 1992.[105]

v Estimates of reserves held by listed companies are relatively reliable and easily available. This is because listed companies are required by financial regulators to report their reserves, and the definitions and rules are quite strict. But the majority of the world's oil, gas and coal reserves are held by public sector companies, for which reporting is much less standardised and so there is less certainty in the numbers. This uncertainty is reflected for instance in debates on the actual level of Saudi Arabia's oil reserves.[106]

APPENDIX 2: ASSUMPTIONS ON LAND USE AND CEMENT PRODUCTION

This appendix explains the basis for the estimates of future emissions from land use change and cement production, used in Figure 5.

LAND USE

For emission projections from land use, we use IPCC AR5 scenario database found at https://tntcat.iiasa.ac.at/AR5DB/.[109]

There is considerable variation among the scenarios. For the base case assumption, we use the median; for the range calculations we use the interquartile range. All are shown in Table A2-1.

CEMENT MANUFACTURE

Of all CO_2 emissions, the emissions from the calcination reaction in cement manufacture are among the most difficult to reduce, particularly given that cement is such a fundamental material for construction that there are no foreseeable prospects for its widespread substitution. There are four possible routes to reducing these emissions:[110]

- Blending other materials such as fly ash, blast furnace slag, or natural volcanic materials, to reduce the clinker content of cement.
- Using high-performance cement to reduce the cement content in concrete.
- Making clinker from substances other than calcium oxide, such as magnesium oxides derived from magnesium silicates.
- Carbon capture and storage (CCS).

Neither novel clinker ingredients nor CCS are proven technologies, with both existing only in a few pilot settings (see Appendix 3). And in much of the world, the cement content of concrete is already minimized; no estimates are available for potential further optimization.

Blending, the final potential option, is commonly used. The IEA estimates that the average clinker content of cement could be reduced from 79% in 2006 to 71% in 2050.[111] In a subsequent publication, the IEA adjusted this to an improvement from 80% in 2009 to 67% in 2050.[112] In our base case, we assume that CO_2 emissions per metric ton of cement produced are reduced in proportion to the reduced clinker content on a straight-line basis up to 2050 (and that the increased amount of blended substitutes does not cause new emissions), but that no further improvements occur after 2050. In the worst case, we assume no change in emissions intensity from 2015.

The IEA projects an increase in global cement production from 3,800 Mt in 2012 to between 4,475 Mt (low-demand scenario) and 5,549 Mt (high-demand scenario) in 2050.[113] We assume the volume of cement production grows until 2050 according to the IEA's low-demand scenario, and then remains at the 2050 level for the rest of the century.[w] In the worst-case element of the range, we assume the high-demand scenario until 2050, and then continued growth at the same rate for the rest of the century, up to 6,944 Mt in 2100.

If the technologies of novel clinker ingredients and CCS turn out to be successful, emissions from cement manufacture could be reduced to close to zero at some point in the second half of this century. Drawing on the same studies by the IEA and discussions with cement industry experts, climate scientist Kevin Anderson suggests that in this scenario total cement emissions could be limited to 150 Gt of CO_2 from 2011 till eventual phase-out later this century.[115]

Table A2-1: Cumulative CO2 Emissions from Land Use, 2015 to 2100

Median	21 Gt CO_2
1st Quartile	-206 Gt CO_2
3rd Quartile	57 Gt CO_2

Source: IPCC Scenarios Database

Table A2-2: Range of Cement Emissions, 2015 to 2100

	Best Case	Base Case	Worst Case
Cumulative Cement Production, 2015-2100 / Gt	N/K	377	487
Calcination Emissions (t CO_2) per Tonne of Production, 2100 (Declining from 0.49t/t in 2012)	0	0.41	0.49
Total Emissions / Gt CO_2	150	162	241

Sources: IEA, Kevin Anderson

w Once urbanisation and development reach a certain level, a country's cement consumption declines to a lower level as major infrastructure has already been built, and construction is reduced to maintenance and replacement. When this happens in enough countries, the world will reach "peak cement."[114]

APPENDIX 3: CARBON CAPTURE AND STORAGE

Carbon capture and storage (CCS) is a process in which the CO_2 released from burning fossil fuels is captured, compressed, and stored underground in deep geological reservoirs. Although CCS has been strongly advocated since the 1990s by the fossil fuel industry and others, it has barely been deployed to date, a record the Financial Times describes as "woeful."[116] Due to slow development of the technology, even if CCS were developed at scale it is estimated that the carbon budget would only be extended by 12% to 14% by 2050.[117]

While CCS technology is well understood in theory, many actual projects have been beset with problems. The only operating joined-up CCS power project, Boundary Dam, came on line in Canada in 2014. The plant has struggled to operate as planned, suffered considerable cost-overruns, and been forced to pay out for missing contracted obligations.[118] The leading U.S. project, Kemper, is already over two years late and $4.3 billion over budget.[119]

A fundamental question about CCS is whether stored CO_2 might be at risk of leaking from underground reservoirs. If it did, it could add large quantities of CO_2 to the atmosphere, at a time when it is too late to stop emissions. While the reservoir integrity question has been modeled, there is a shortage of empirical evidence, especially over extended periods of time. Part of the problem is that of the twenty-two CCS projects built to date, sixteen have been used in enhanced oil recovery.[120] In these cases, studies have focused largely on the objective of increasing short-term reservoir pressures in order to force more oil out, and not so much on long-term storage integrity.[121] The IPCC believes that the risks are low, for "well-selected, designed, and managed geological storage sites."[122]
In that light, it is troubling that the world's first industrial scale CCS project, the Sleipner project in Norway, started in 1996 and assumed to be safe until it was discovered to have fractures in its caprock in 2013.[123] The other major problem facing CCS is its cost. Even CCS advocates recognize the "outstanding commercial challenges" that projects around the world face.[124] It is estimated that CCS could increase the cost of coal-fired electricity plants by 40% to 63% in the 2020s.[125] In 2015, Shell Chief Executive Officer Ben van Beurden conceded that CCS is too expensive without government subsidies.[126]

Faced with these many challenges, CCS now appears to be experiencing a cooling of government and industry interest.
Last year, the United Kingdom cancelled its competition for commercial-scale CCS projects[127] and the United States terminated funding for the FutureGen CCS retrofitting demonstration project.[128] Earlier in 2015, four leading European utilities pulled out of the European Union's Zero Emission Platform, a long-term project to study and develop CCS technology, jointly stating, "We currently do not have the necessary economic framework conditions in Europe to make CCS an attractive technology to invest in."[129]

A tailings pond at the Suncor Steepbank/Millenium Mine in the Canadian tar sands. Alberta, Canada, 2014.

©Greenpeace/William Akehurst.

APPENDIX 4: OIL AND GAS REQUIREMENT IN CLEAN ENERGY SCENARIOS

This appendix explains the basis for our calculations of renewable energy required to replace depleting fossil fuels, in Figure 15. We use the model of 139 countries developed by Mark Jacobson of Stanford University,[130] to consider two scenarios: 50% average renewable energy in 2035, and 80% in 2045. In both scenarios, steam coal is entirely phased out; we examine therefore the remaining oil and gas requirement.

APPROACH AND ASSUMPTIONS

In the model, all energy-using sectors are progressively electrified, and electricity generated using wind, concentrated solar power, geothermal, solar photovoltaic, tidal, wave, and hydropower. No new hydro dams are built, but existing ones are maintained. A small amount of the electricity is used to produce hydrogen for some transportation and industrial applications.

The estimates are all based on final energy consumption.

We use projections of 2035 and 2045 energy demand by extrapolating on a straight line from the International Energy Agency's 450 Scenario,[131] broken down by sector (industry, transportation and buildings) and fuel. We adjust these demand estimates using Jacobson's conversion factors, to account for the higher energy-to-work conversion efficiency of electricity compared to combustion of fossil fuels.

In the 50%-by-2035 scenario, we use the IEA 450 Scenario's estimates of coking coal use, with zero steam coal. In the 80%-by-2045 scenario, we assign 10% of industrial final energy to coking coal.

To simplify, we further assume:

- 50% renewable energy is achieved by electrifying 90% of energy for buildings, 60% for industry, and 30% for transport; and then generating 84% of electricity with renewables.
- 80% renewable energy is achieved by electrifying 95% of energy for buildings, 85% for industry, and 80% for transport, and generating 90% of electricity with renewables.

Table A4-1: Global Final Energy Consumption by Source With 50% Renewable Penetration in 2035 and 80% in 2045 (Using Jacobson Model)

mtoe	50% by 2035	80% by 2045
Industry		
Coal	473	332
Oil	69	0
Gas	298	0
Electricity	1,565	2,057
Heat	56	0
Bioenergy	128	0
Other RE	19	31
SUB-TOTAL	**2,608**	**2,420**
Transport		
Oil	1,180	149
Electricity	703	1,392
Biofuels	271	123
Other	191	76
SUB-TOTAL	**2,345**	**1,739**
Buildings		
Coal	0	0
Oil	17	0
Gas	22	0
Electricity	1,995	2,428
Heat	17	0
Bioenergy	70	0
Other RE	96	161
SUB-TOTAL	**2,217**	**2,589**
TOTAL	**7,168**	**6,748**
Power		
Coal	0	0
Oil	95	90
Gas	463	437
Nuclear	226	213
Bioenergy	42	40
Renewable	3,436	5,097
SUB-TOTAL	4,263	5,876
Totals by fuel		
Oil	1,360	239
Gas	783	437
Coal	473	332
Nuclear	226	213
Bioenergy	511	163
Other	264	76
Renewable	3,551	5,289
TOTAL	**7,169**	**6,748**

Sources: IEA, Mark Jacobson et al, Oil Change International analysis

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	Clean energy	Fossil fuels
Brazil	37.1	21.2
Germany	9.7	7.6
Indonesia	99.1	22
Korea	14.6	13.6
South Africa	70.6	33.1

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Bn bbl	Rystad 2P reserves	BP Statistical Review "proven" reserves
Saudi Arabia	182	267
United States	128	55
Russia	109	102
Iran	100	158
Canada	92	172
Iraq	90	143
Qatar	52	26
Venezuela	44	301
UAE	43	98
China	42	19
Kuwait	41	102
Brazil	40	13
Kazakhstan	29	30
Nigeria	19	37
Norway	16	8
Libya	15	48

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The Potential Greenhouse Gas Emissions from

U.S. Federal Fossil Fuels

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CENTER for BIOLOGICAL DIVERSITY

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The Potential Greenhouse Gas Emissions from U.S. Federal Fossil Fuels

August 2015

Prepared for

Center for Biological Diversity

Friends of the Earth

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Acknowledgements

We are grateful to Stephen Russell, Senior Associate at World Resources Institute, for providing external expert review of this report, and for sharing his expertise and feedback on its analyses and findings. We also thank Mary Ann Shmueli of IgneoDesign for laying out this report.

I. Executive Summary

This report was undertaken to facilitate a better understanding of the consequences of future federal fossil fuel leasing and extraction in the context of domestic and global efforts to avoid dangerous climate change. We estimate the potential greenhouse gas (GHG) emissions from developing the remaining fossil fuels in the United States (U.S.) is as much as 492 GT CO_2e, including the emissions from developing publicly owned, unleased federal fossil fuels.

We report the volume of these fossil fuels, including that of leased and unleased federal fossil fuels located beneath federal and non-federal lands and the outer continental shelf. These resource appraisals are used to estimate the life-cycle GHG emissions associated with developing crude oil, coal, natural gas, tar sands, and oil shale—including emissions from extraction, processing, transportation, and combustion or other end uses. We express potential emissions in gigatons ("Gt" - one gigaton equals one billion tons) of carbon dioxide equivalent (CO_2e), and discuss them below in the context of global emissions limits and nation-specific emissions quotas.

Major findings:

- The potential GHG emissions of federal fossil fuels (leased and unleased) are 349 to 492 Gt CO_2e, representing 46% to 50% of potential emissions from all remaining U.S. fossil fuels. Federal fossil fuels that have not yet been leased for development contain up to 450 Gt CO_2e.

- Unleased federal fossil fuels comprise 91% of the potential GHG emissions of all federal fossil fuels. The potential GHG emissions of unleased federal fossil fuel resources range from 319 to 450 Gt CO_2e. Leased federal fossil fuels represent 30 to 43 Gt CO_2e.

- The potential emissions from unleased federal fossil fuels are incompatible with any U.S. share of global carbon limits that would keep emissions below scientifically advised levels.

Our results indicate that a cessation of new federal fossil fuel leasing could keep up to 450 Gt CO_2e from the global pool of potential future GHG emissions. (Figure 1.) This is equivalent to 13 times the global carbon emissions in 2014 or annual emissions from 118,000 coal-fired power plants. This represents a significant potential for GHG emissions savings that is best understood in the context of global limits and national emissions quotas.

Carbon emissions quotas are the maximum amount of greenhouse gases humanity can emit while still preserving a given chance of limiting average global temperature rise to a level that will not be catastrophic. The Intergovernmental Panel on Climate Change has recommended efforts to ensure that temperature increases remain below 2°C by century's end, a level at which dramatic adverse climate impacts are still expected to occur. Nation-specific emissions quotas are the amount of greenhouse gas emissions that an individual country can emit.[i]

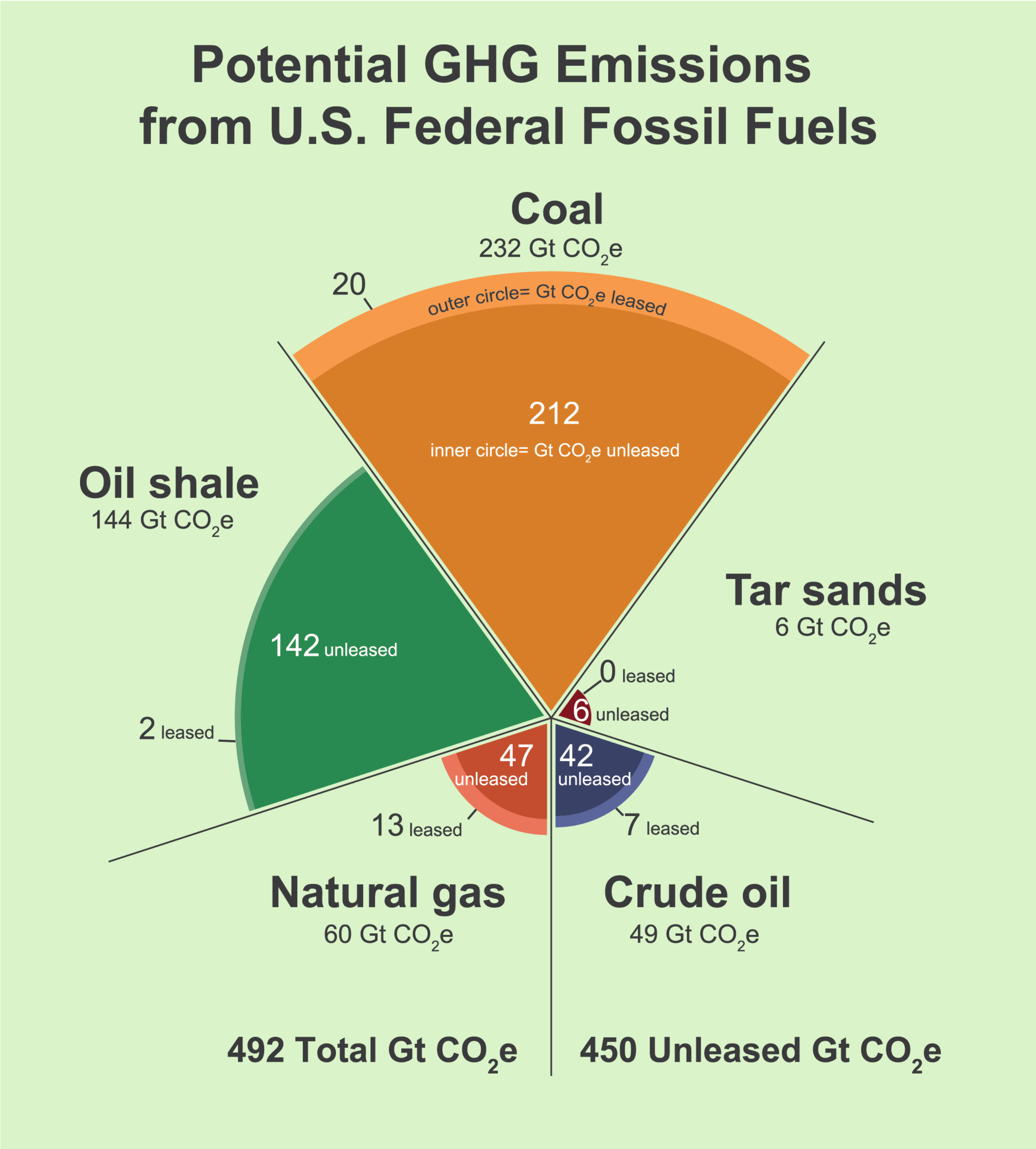

Figure 1. Potential emissions of leased and unleased federal fossil fuels.

Studies that have apportioned global emissions quotas among the world's countries indicate that the U.S. share of the global emissions is limited, with varying estimates depending on the equity principles used. For example, Raupach et al. (2014) provide three U.S. GHG emissions quota scenarios of 85 Gt CO_2e, 220 Gt CO_2e, and 356 Gt CO_2e necessary to maintain only a 50 percent likelihood of avoiding 2°C (3.6°F) warming by century's end, depending on the equity assumptions used within a total global emissions limit. These represent a range of approximate equity assumptions for apportioning emissions quotas.[ii] Under any of those quotas, emissions from new federal fossil fuel leasing are precluded after factoring in the emissions of developing non-federal and already leased fossil fuels. (Figure 2.)

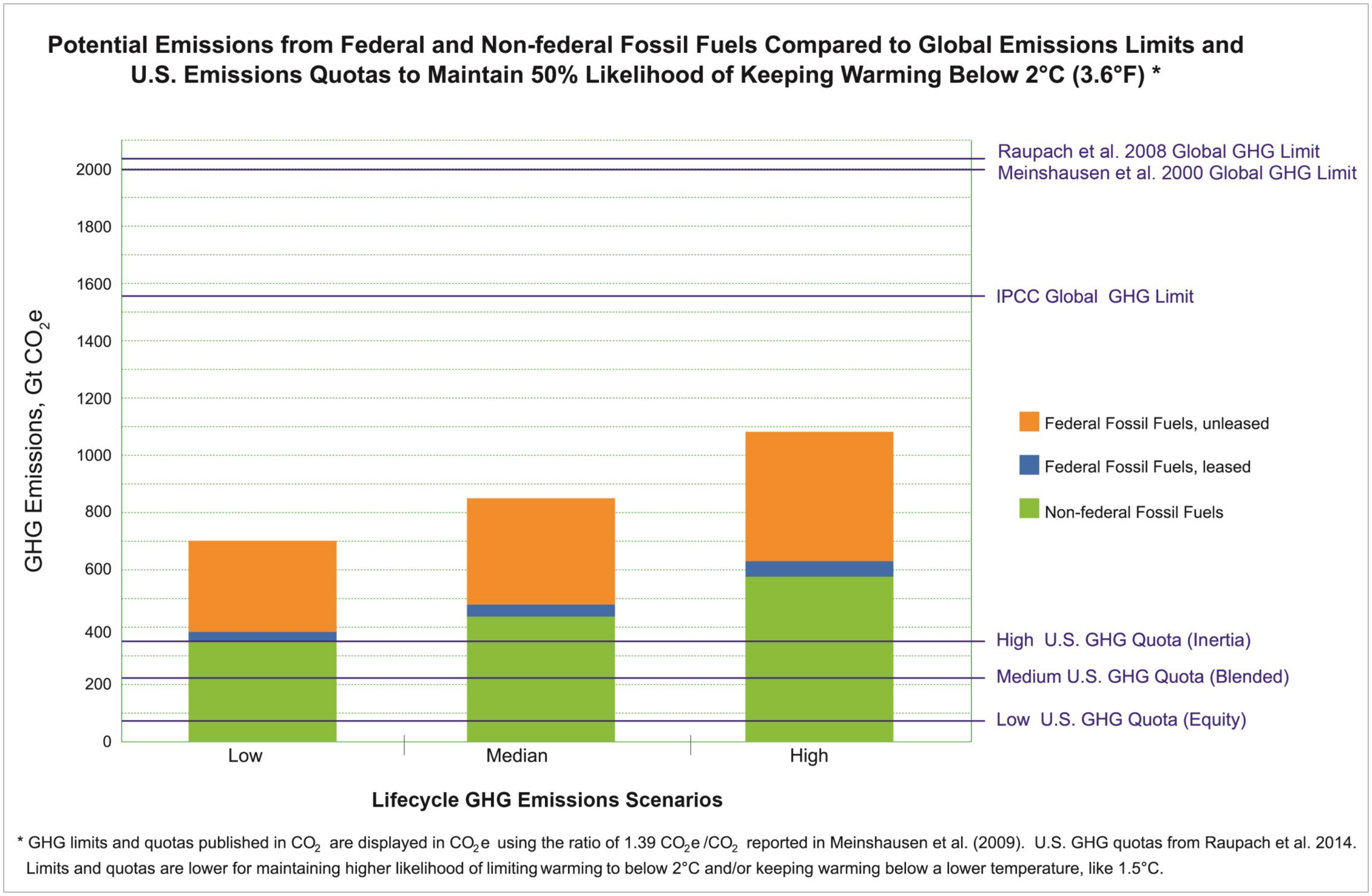

Figure 2. Global carbon limits, U.S. emissions quotas and potential emissions from federal and non-federal fossil fuels.

[i]In this report we use the terms "share of limit" and "quota" interchangeably and define them in the context of scientifically advised emission limitations exclusive of sequestration. In some cases, studies and reports also use the term "budget". Much of the literature, coverage, and usage of these issues utilizes the terms in this way; however, in some cases carbon "budgets" are defined more broadly to encompass sources, fluxes and sinks, while "quotas" are defined more narrowly to encompass only limits on future emissions necessary to meet a certain average global temperature target. We feel this usage is appropriate here since "carbon budgets" generally refer to the total cumulative mass of carbon emissions allowable over time, while this report describes the total cumulative mass of carbon under federal and non-federal lands which may or may not be emitted into the atmosphere over time.

[ii]We use Raupach et al. (2014) U.S. emissions quotas for illustration purposes only; this report and its authors do not endorse equity assumptions made therein. We use the ratio of 1.39 CO_2e/CO_2 reported in Meinshausen et al. (2009) to convert the values reported in Raupach et al. (2014) from CO_2 to CO_2e. We also exclude Raupach et al.'s "future committed emissions" from their published -30, 67 and 165 Gt CO_2 U.S. quotas to isolate the quotas from assumptions about "future committed emissions." Notably, under Raupach et al.'s "equity" scenario, "future committed emissions" already exceed the remaining U.S. quota; Raupach et al. thus report a remaining "equity" scenario quota of -30 Gt CO_2.

II. Introduction

The Intergovernmental Panel on Climate Change (IPCC) recently warned that humanity must adhere to a strict "carbon limit" in order to preserve a likely chance of holding average global warming to less than 2°C (3.6°F) by the end of the century—a level of warming that still will cause extreme disruption to both human communities and natural ecosystems.[1] According to the IPCC, all future global emissions must be limited to about 1,000 gigatons ("Gt," one gigaton equals one billion tons) of carbon dioxide (CO_2) to have a likely (>66%) chance of staying below 2°C.[2] The International Energy Agency has projected that the entire remaining 1,000 Gt CO_2 (1,390 Gt CO_2e[iii]) carbon budget will be consumed by 2040 on the current emissions course.[3]

In 2013, the U.S. emitted 6.67 Gt CO_2e,[4] the majority (85%) coming from the burning of fossil fuels,[5] and accounting for 15% of global emissions.[6] A 2015 analysis by an international team of climate experts[7] suggests that for a likely probability of limiting warming to 2°C, the U.S. must reduce its GHG emissions in 2025 by 68 to 106% below 1990 levels, with the range of reductions depending on the sharing principles used.[8] Accordingly, U.S. GHG annual emissions in 2025 would have to range between 2 Gt CO_2e (i.e., 68% below 1990) and negative emissions of -0.4 Gt CO_2e (i.e., 106% below 1990), significantly below current emissions of ~6.7 Gt CO_2e. Where negative emissions are required, the remaining carbon budget has been exhausted.

Carbon quotas are the maximum amount of greenhouse gases humanity can emit while still preserving a given chance of limiting average global temperature rise to a level that will not be catastrophic. The Intergovernmental Panel on Climate Change has used a carbon limit to keep temperature increases below 2°C by century's end, a level at which dramatic adverse climate impacts are still expected to occur. Nation-specific emissions quotas are the amount of greenhouse gas emissions that an individual country can emit.[iv]

Studies that have apportioned global emissions quotas among the world's countries indicate that the U.S. share of the global emissions is limited, with varying estimates depending on the equity principles used. For example, Raupach et al. (2014) estimated three U.S. GHG emissions quota scenarios of 85 Gt CO_2e, 220 Gt CO_2e, and 356 Gt CO_2e necessary to maintain only a 50 percent likelihood of avoiding 2°C (3.6°F) warming by century's end, depending on the equity assumptions used within a total global emissions limit. These represent a range of approximate equity assumptions for apportioning emissions quotas.[v] Under any of those quotas, emissions from new federal fossil fuel leasing are precluded given the potential emissions from already-leased federal fossil fuels and those of non-federal fossil fuels.

Raupach et al.'s three scenarios are based on:

- **High (inertia):** Favors "grandfathering" of emissions, favoring a distribution of quota emissions to nations or regions with higher historical emissions.
- **Medium (blended):** Blends "inertia" and "equity" emissions.
- **Low (equity):** Favors a distribution of quota emissions based on population distribution, or emissions per capita, in regions or nations.

Under the current U.S. “all of the above” energy policy, federal agencies lease lands to private companies to extract and sell federal fossil fuel resources, including submerged offshore lands of the outer continental shelf. Leases initially last ten years, or twenty years in the case of coal, and may continue indefinitely once successful mineral extraction begins. Though these leases collectively span many tens of millions of acres, federal agencies have not been compelled by law or policy to track or report resultant GHG emissions on a cumulative basis. There have been studies that account for past emissions from federal fossil fuel leasing. For example, a 2014 Stratus Consulting report completed for The Wilderness Society, titled “Greenhouse Gas Emissions from Fossil Energy Extracted from Federal Lands and Waters: An Update,” estimated that, in calendar year 2012, emissions from federal fossil fuel production were 1.344 Gt CO_2e, or 21% of all U.S. GHG emissions that year.[9] A 2015 analysis completed by the Climate Accountability Institute for the Center for Biological Diversity and Friends of the Earth estimated that federal fossil fuel production accounted for 1.278 Gt CO_2e of emissions in 2012, and during the past decade contributed approximately 25% of all U.S. GHG emissions associated with fossil fuel consumption, which represents around 3-4% of global fossil fuel emissions during that time.[10] Yet, until now there has been no assessment of the potential GHG savings from sequestering remaining unleased federal fossil fuels.

Craig, Colorado — Coal Power Plant

[iii]Intergovernmental Panel on Climate Change, Climate Change 2013 Synthesis Report: Approved Summary for Policymakers at SPM-8 (Nov. 1, 2014).

[iv]Emissions quotas are one among many mechanisms for determining equity and fairness in international climate negotiations. Equity principles generally include assumptions about different countries’ historical responsibility for climate emissions and their ability to mitigate emissions, as well as measures of developed country support for emissions mitigation and adaptation in developing countries. While we are only using emissions quotas to illustrate the size of U.S. fossil fuel resources, we recognize that emissions quotas cannot be discussed independently from climate finance commitments.

[v]We use Raupach et al. (2014) U.S. emissions quotas for illustration purposes only; this report and its authors do not endorse equity assumptions made therein. We use the ratio of 1.39 CO_2e/CO_2 reported in Meinshausen et al. (2009) to convert the values reported in Raupach et al. (2014) from CO_2 to CO_2e. We also exclude Raupach et al.’s “future committed emissions” from their published -30, 67 and 165 Gt CO_2 U.S. quotas to isolate the quotas from assumptions about “future committed emissions.” Notably, under Raupach et al.’s “equity” scenario, “future committed emissions” already exceed the remaining U.S. quota; Raupach et al. thus report a remaining “equity” scenario quota of -30 Gt CO_2.

This report models the total amounts and potential GHG emissions associated with the remaining federal and non-federal fossil fuels in the U.S. We compiled federal and industry inventories of total fossil fuel resources and, using standard life-cycle assessment guidelines, we calculated life-cycle GHG emissions associated with all phases of developing federal and non-federal coal, crude oil, natural gas, tar sands, and oil shale resources. We evaluated low, median, and high emission scenarios for each of the fossil fuels studied to account for some of the uncertainties associated with producing fossil fuels.

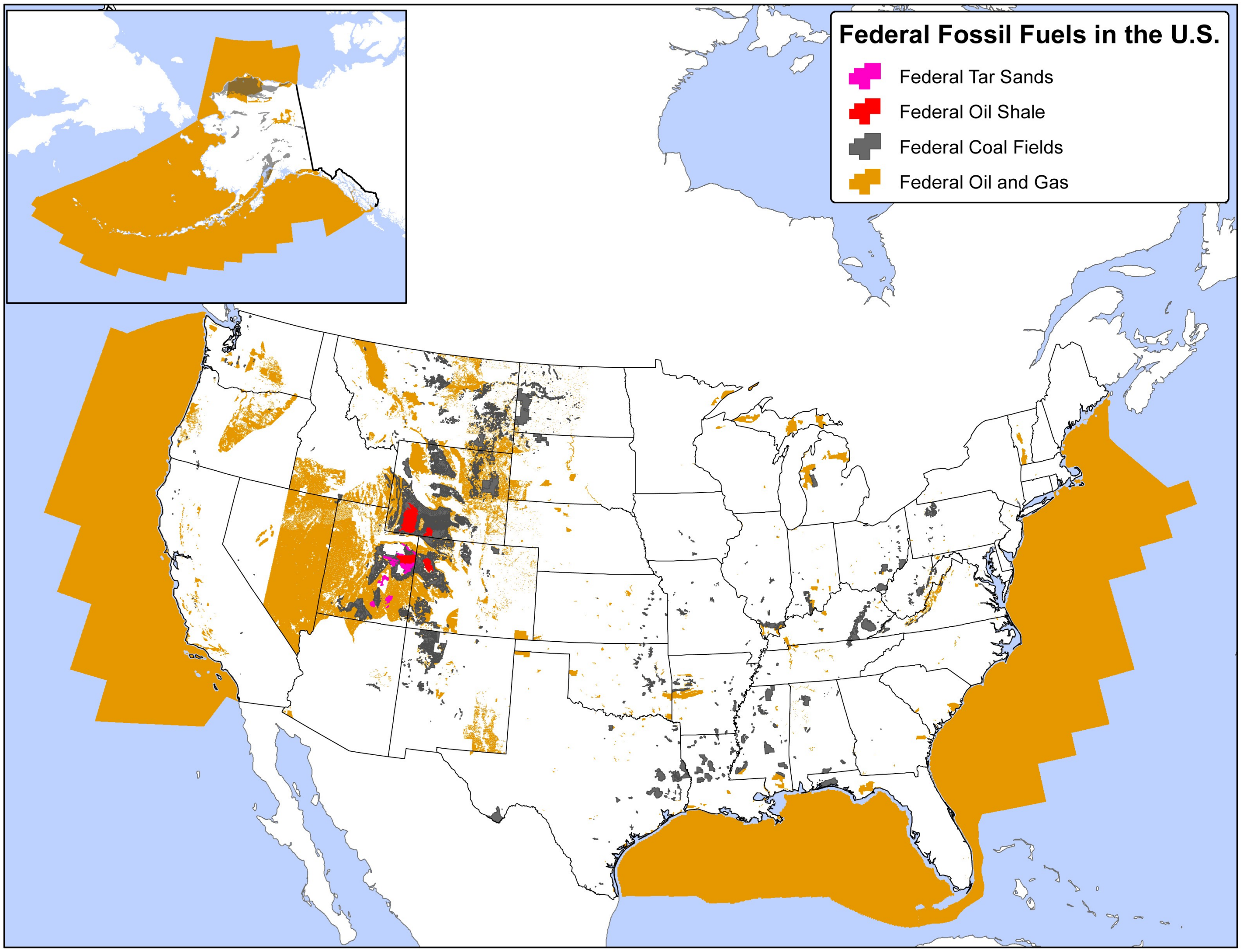

Figure 3. Map of U.S. Federal Fossil Fuels. Map by Curt Bradley, Center for Biological Diversity.

Our analysis focuses on the potential GHG emissions from the remaining unleased federal fossil fuel resources in the U.S. Keeping these fossil fuels in the ground would contribute significantly to global efforts to prevent combustion emissions from remaining fossil fuel resources. For the purposes of this report, unleased federal fossil fuels are those federal fossil fuel resources that are not currently leased to private companies. They include unleased recoverable federal coal reserves, federal oil shale, federal crude oil, federal natural gas, and federal tar sands. Unleased federal fossil fuels include resources that are available for leasing under current federal policy and that could become available for leasing under future federal policy.[11]

Key terms

All U.S. fossil fuels include all federal and non-federal recoverable coal reserves, oil shale, crude oil, natural gas, and tar sands (onshore and offshore).

Federal fossil fuels are federally controlled, publicly owned fossil fuel resources. Federal fossil fuels are located beneath lands under federal and other ownerships, where the federal government owns subsurface mineral rights. They are also located "offshore," beneath submerged public lands of the outer continental shelf. Federal fossil fuels include recoverable federal coal reserves, federal oil shale, federal crude oil, federal natural gas, and unleased federal tar sands.

Leased federal fossil fuels are federal fossil fuel resources, including proved reserves and resources under non-producing leased land, as classified by the Bureau of Ocean Energy Management (BOEM) and Bureau of Land Management (BLM), which are currently leased to private companies. These include leased federal recoverable coal reserves, leased federal oil shale, leased federal crude oil, leased federal natural gas, and leased federal tar sands.

Non-federal fossil fuels are fossil fuel resources calculated by subtracting federal fossil fuel amounts from total technically recoverable oil resources, total technically recoverable natural gas resources, and total recoverable coal reserves in the U.S. as provided by Environmental Impact Assessment 2012a.

Unleased federal fossil fuels are federal fossil fuel resources that are not leased to private companies. These include unleased recoverable federal coal reserves, unleased federal oil shale, unleased federal crude oil, unleased federal natural gas, and unleased federal tar sands.

Recoverable coal reserves are the portion of the Demonstrated Reserve Base that the Energy Information Agency estimates may be available or accessible for mining. **Federal recoverable coal reserves** are the federally controlled portion of recoverable coal reserves.

Crude oil is onshore and offshore technically recoverable federal and non-federal crude oil resources. **Federal crude oil** is federally controlled crude oil.

Natural gas is onshore and offshore technically recoverable federal and non-federal natural gas resources. **Federal natural gas** is federally controlled natural gas.

Federal oil shale is federally controlled oil shale that is geologically prospective according to deposit grade and thickness criteria in the BLM's 2012 Final Oil Shale and Tar Sands Programmatic Environmental Impact Statement and Record of Decision. Geologically prospective oil shale resources in Colorado and Utah are deposits that yield 25 gallons of oil per ton of rock (gal/ton) or more and are 25 feet thick or greater. In Wyoming, geologically prospective resources are deposits that yield 15 gal/ton or more and are 15 feet thick or greater.

Tar sands are estimated in-place tar sands resources. **Federal tar sands** are federally controlled tar sands.

Proved or proven reserves are estimated volumes of hydrocarbon resources that analysis of geologic and engineering data demonstrates with reasonable certainty are recoverable under existing economic and operating conditions. Reserve estimates change from year to year as new discoveries are made, existing fields are more thoroughly appraised, existing reserves are produced, and prices and technologies change. Because establishing proved reserves requires drilling, which first requires leasing, proved federal fossil fuel reserves are necessarily leased, and unleased federal fossil fuels necessarily are not proved.

Technically recoverable refers to oil and gas resources that are unleased but producible using current technology without reference to their economic viability.

In-place resource is the entire fossil fuel resource in a geologic formation regardless of its recoverability or economic viability.

III. Research Methodology

Greenhouse gas (GHG) emissions associated with developing fossil fuel resources were estimated by (a) quantifying the volume and energy value of federal and non-federal fossil fuels, (b) determining the end uses and proportions of different end-use products made from fossil fuels, and (c) estimating the total GHG emissions from developing these resources and processing them into end-use products, by multiplying the total volume of energy value of fossil fuel products by their life-cycle emissions factors.

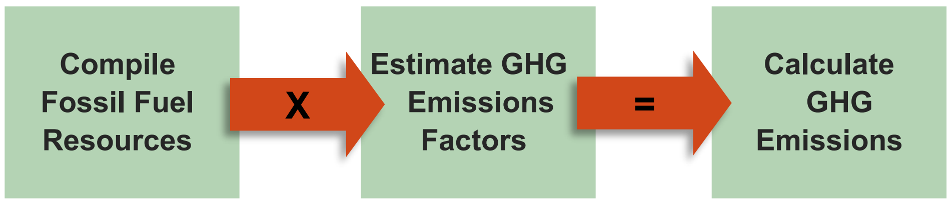

Figure 4. Research methodology

A) Quantifying Fossil Fuel Resources Volumes and Energy Values

Federal and non-federal fossil fuel quantities were obtained from federal estimates by the Bureau of Land Management (BLM), Energy Information Agency (EIA), U.S. Geological Survey (USGS), Office of Natural Resource Revenue (ONRR), the Department of Interior (DOI), and Congressional Research Service (CRS). Federal agencies similarly report the technically recoverable resources for crude oil and natural gas based on a consistent definition. For coal, agencies estimate recoverable coal by assessing the accessibility and recovery rates for the demonstrated coal base. For oil shale and tar sands the quantity is based on the resource available and in-place resources, which do not attempt to characterize the resource based on the likelihood of development. Unleased volumes of federal fossil fuels were calculated by subtracting leased volumes from the sum of technically recoverable quantities.

Quantities of federal and non-federal crude oil, natural gas, coal, oil shale and tar sands were summed and converted into values that represent each fossil fuel's energy content, called its primary energy value. This was done by multiplying the fossil fuel volumes by a heating value factor that represents the resource's energy content. Lower heating values were used for all fuels except coal, where the higher heating value was taken as per convention for solid fuels in the U.S. Heating values for each resource were taken from Oak Ridge National Laboratory (ORNL), and can be found in the *Fossil Fuel Volumes to Primary Energy Conversions* section in Appendix I.

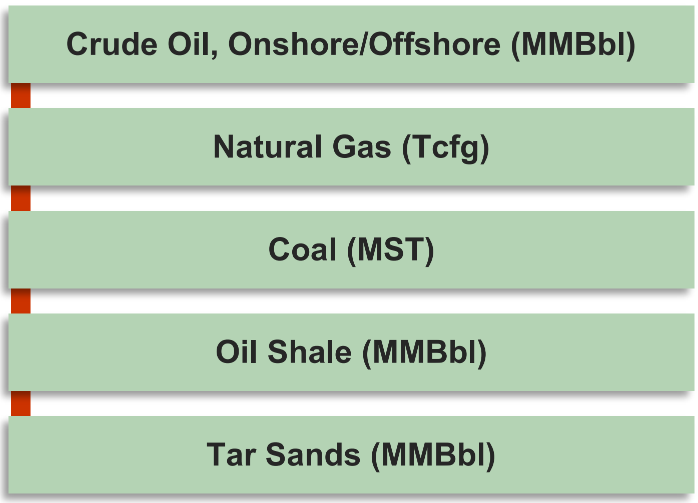

Figure 5. Fossil fuels analyzed

Figure 5 above shows the five fossil fuel types analyzed as they are broadly defined by federal agencies: Oil (onshore and offshore), gas (onshore and offshore), coal, oil shale, and tar sands. The hydrocarbons included within federal oil and gas definitions are reported in Table 1 below.

Fossil Fuel Type	Crude oil	Condensate	Natural gas liquids	Dry natural gas	Gas, wet after lease separation	Non-associated gas, wet after separation	Natural gas associated—dissolved, wet after lease separation	Coalbed methane
Onshore oil	X	X	X					
Offshore oil	X	X	X					
Onshore gas				X	X	X	X	X
Offshore gas				X	X	X	X	X

Table 1. Hydrocarbons in the categories of crude oil and natural gas

B) Determining the End-Use Products Made from Fossil Fuels

Each fossil fuel resource was converted to a value that represents its energy content and divided into amounts used as inputs for different end-use products. We allocated the proportions of each resource into end-use products as follows:

- The energy in crude oil resources was proportionally divided into: finished motor gasoline, distillate fuel oil, kerosene, liquefied petroleum gases (LPG), petroleum coke, still gas, and residual fuel oil.
- The energy in natural gas resources was split into residential, commercial, industrial, electric power, and transportation end-use sectors.
- The energy in coal reserves was divided into electric power, coke, and other industrial uses.
- Energy in tar sands and oil shale was assumed to be processed into end-use products analogous to crude oil.

These proportions make it possible to apply end-use product-specific life-cycle emissions factors. For each product we determined the amount that could be yielded from the initial energy after processing, using a "primary energy factor" derived from figures and conversion factors from sources in the literature, such as those developed at the National Renewable Energy Laboratory (NREL).

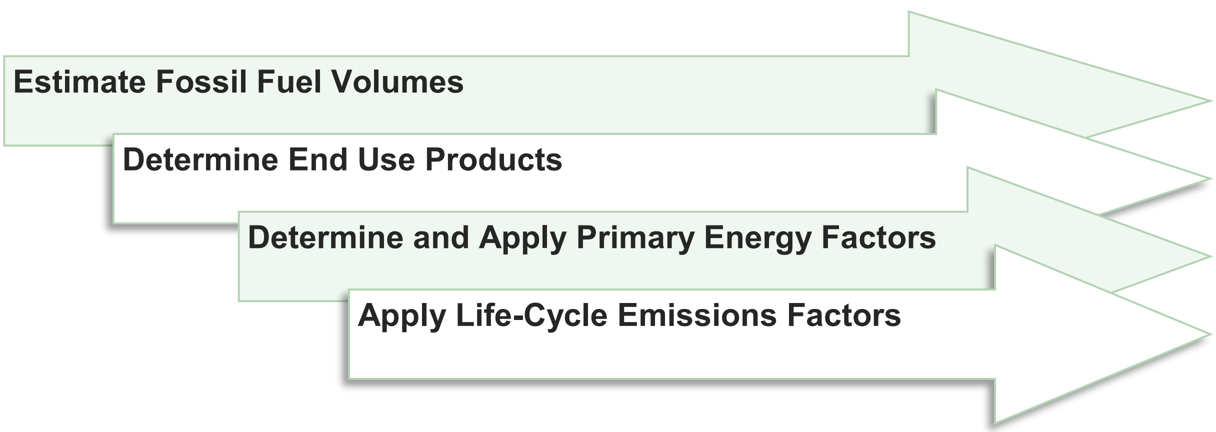

Figure 6. Steps to determine fossil fuel amounts and apply specific energy and emissions factors

Fossil fuel resource	End-use products and sectors
Crude Oil	• Finished Motor Gasoline • Distillate Fuel Oil • Kerosene • Liquefied Petroleum Gases • Petroleum Coke • Still Gas • Residual Fuel Oil
Natural Gas	• Residential Sector • Commercial Sector • Industrial Sector • Electric Power Sector • Transportation Sector
Coal	• Electric Power Sector • Metallurgical Coke • Other Industrial Use
Oil Shale	• Finished Motor Gasoline • Distillate Fuel Oil • Kerosene • Liquefied Petroleum Gases • Petroleum Coke • Still Gas • Residual Fuel Oil
Tar Sands	• Finished Motor Gasoline • Distillate Fuel Oil • Kerosene • Liquefied Petroleum Gases • Petroleum Coke • Still Gas • Residual Fuel Oil

Figure 7. Fossil fuel resources and end-use products and sectors

C) Multiplying the Quantity of Fossil Fuel Energy by GHG Emissions Factors

The total energy value of each fossil fuel product end use was multiplied by product-specific life-cycle emissions factors to estimate the total GHG emissions. Life-cycle GHG emissions factors represent the amount of GHGs released when burning one unit of energy. In peer-reviewed life-cycle assessments of fossil fuels, there are uncertainties associated with the GHG emissions of some fuels. For example, the life-cycle emissions associated with land use change resulting from coal extraction can be a source of uncertainty given differing amounts of methane leakage. To account for these uncertainties, the analysis used three scenarios for each fossil fuel corresponding to high, median, low GHG emissions factors reported in the scientific literature. The low GHG emissions factor scenario was chosen as the base case, and the high emissions factor scenario is the worst case scenario (most inefficient use of fossil fuels).

Each scenario represents different magnitudes (high, median, and low) of global warming pollution associated with different fossil fuels. The high emissions scenario represents the worst-case GHG pollution scenario. Where available we used emissions factors from research by the U.S. national energy laboratories including Argonne National Laboratories' GREET tool and several meta-analyses from NREL that produced harmonized emissions factors based on extensive prior research. Although emissions factors can vary following changes in any of the parameters in the underlying study, Table 2 in Appendix II highlights key parameters that significantly affect the emissions factor and consequently influence whether it is characterized as low, median, or high.

Where necessary, the following end-use product-specific adjustments were made to improve the accuracy of life-cycle emissions factors:

- A carbon storage factor was determined for the following end-use products: metallurgical coke from coal, distillate fuel, liquefied petroleum gases (LPGs), petroleum coke from crude oil, and still gas.[12] This is to account for a proportion of carbon in the fossil fuel resource that is stored in the end product and not combusted or otherwise emitted. For example, some of the carbon in petroleum coke remains in products such as urea and silicon carbide, and the carbon storage factor reflects this.
- A shale-play weighting factor was applied to calculate emissions from natural gas to account for some studies that suggest that there may be higher amounts of methane released with natural gas extracted from shale versus conventional resources.[13]
- These calculations were summed to present results in 100-year Global Warming Potentials, represented as gigatons CO_2 equivalent (Gt CO_2e).

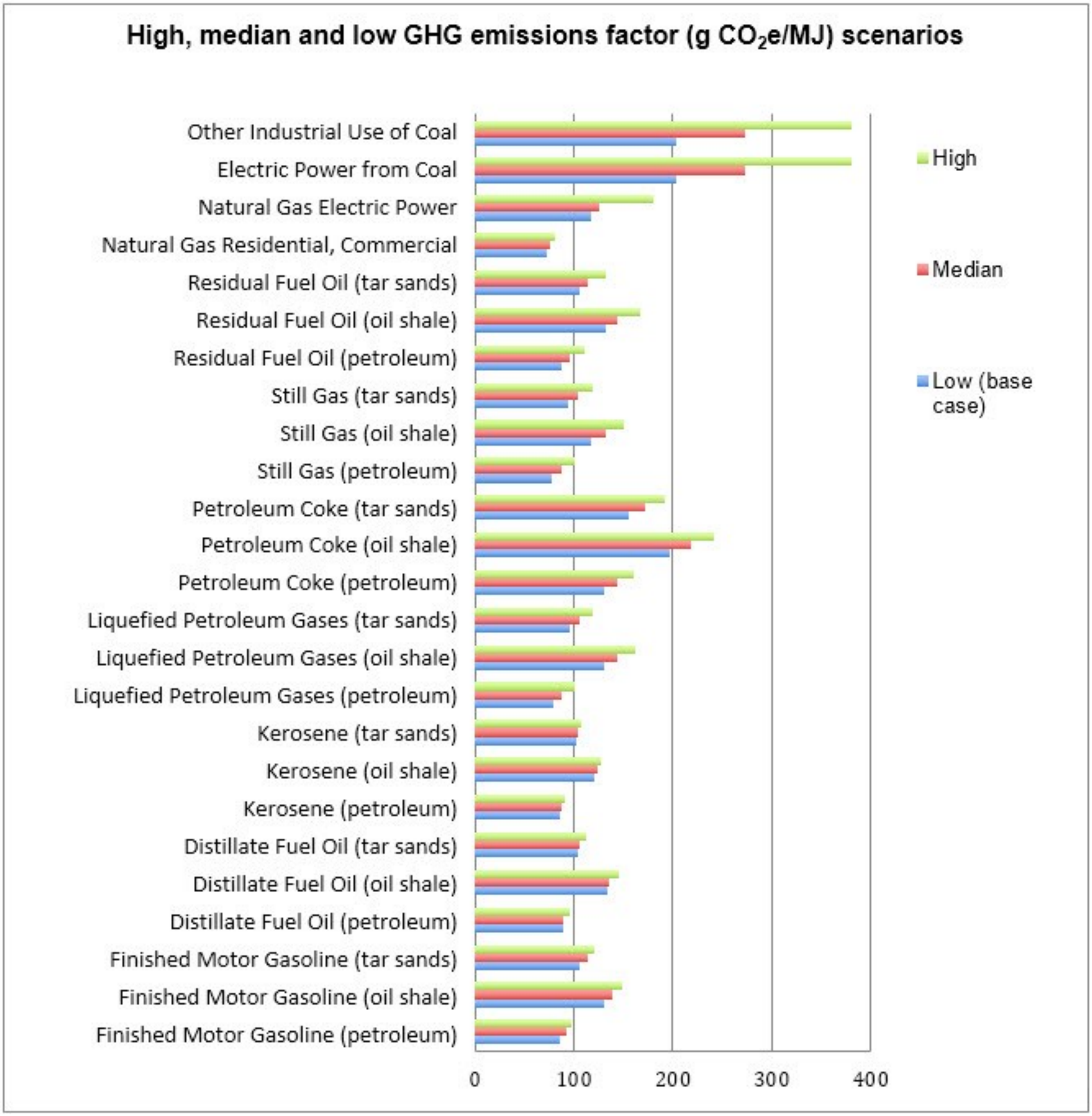

Figure 8. High, median and low (base case) GHG emissions factor scenarios

Appendix I provides detailed methodologies for estimating fossil fuel volumes, converting fossil fuel volumes to primary energy, and calculating resource and end-use product-specific life-cycle emission factors. The full list of sources used to estimate fossil fuel amounts, primary energy factors, proportions of end-use products and sectors, carbon storage factors, and product-specific life-cycle emissions factors is available in Appendix II.

III. Results

Our results indicate that:

1. The potential GHG emissions from federal fossil fuels, leased and unleased, are 348.96 to 492.22 Gt CO_2e, representing 46% to 50% of potential emissions from all remaining U.S. fossil fuels. The potential GHG emissions of federal and non-federal fossil fuels are 697-1,070 Gt CO_2e. Unleased federal fossil fuels comprise 91% of the potential GHG emissions of all federal fossil fuels. The potential GHG emissions of unleased federal fossil fuel resources range from 319.00 to 449.53 Gt CO_2e. Leased federal fossil fuels represent from 29.96 to 42.69 Gt CO_2e.
2. Unleased federal recoverable coal accounts for 36% to 43% of the potential GHG emissions of all remaining federal fossil fuels, from 115.32 to 212.26 Gt CO_2e. Leased federal recoverable coal represents from 10.68 to 19.66 Gt CO_2e of potential emissions.
3. Unleased federal oil shale accounts for 29% to 35% of potential GHG emissions of all remaining federal fossil fuels, ranging from 123.17 to 142.07 Gt CO_2e. Leased federal oil shale accounts for 0.3% to 0.6% of potential GHG emissions of all remaining federal fossil fuels, representing 2 Gt CO_2e.
4. Unleased federal natural gas accounts for 10% to 11% of potential GHG emissions of all remaining federal fossil fuels, ranging from 37.86 to 47.26 Gt CO_2e, of which 36% are onshore and 64% are offshore. Leased federal gas represents 10.39 to 12.88 Gt CO_2e, 47% of which are onshore and 53% are offshore.
5. Unleased federal crude oil accounts for 9% to 12% of potential GHG emissions of all remaining federal fossil fuels, ranging from 37.03 to 42.19 Gt CO_2e, of which 28% are onshore and 72% are offshore. Potential emissions from leased federal crude oil represents from 6.95 to 7.92 Gt CO_2e, of which 33% are onshore and 67% are offshore.
6. Unleased federal tar sands accounts for 1% to 2% of potential GHG emissions of all remaining federal fossil fuels, ranging from 5.62 to 5.75 Gt CO_2e.

Federal Versus Non-Federal Fossil Fuels

The potential GHG emissions from federal and non-federal fossil fuels were compared to contextualize the proportion that is federally owned. The results indicate that 34% of all remaining fossil fuels, based on the energy content of those fuels, are federally owned; these represent 348.96 to 492.22 Gt CO_2e of potential GHG emissions.

	Low	Median	High
Federal Leased	29.96	34.65	42.69
Federal Unleased	319.00	369.98	449.53
Non-federal	348.49	435.14	577.78
TOTAL	**697.45**	**839.77**	**1,070.00**

Table 2. GHG emissions (Gt CO_2e), from federal and non-federal fossil fuels

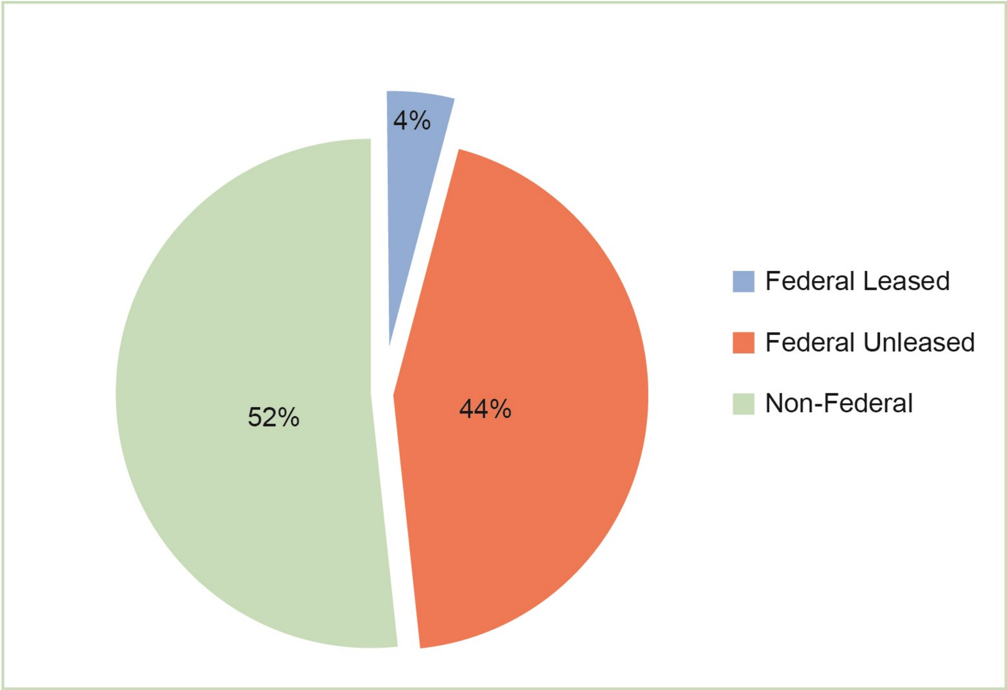

Figure 9. Relative potential emissions of federal and non-federal fossil fuels

Leased and Unleased Federal Fossil Fuels

Unleased and leased federal fossil fuels were examined to measure the GHG pollution from past leasing and to estimate the potential GHG emissions of unleased federal fossil fuels. Leased emissions are calculated using volumes of proved offshore and onshore oil and gas, volumes of offshore and onshore oil and gas underlying non-producing leased land, amounts of leased coal, and volumes of leased oil shale. The potential GHG emissions from unleased fossil fuel resources are approximately ten times greater than the emissions from currently leased federal fossil fuels.

	Low	Median	High
Federal Leased (Total)	29.96	34.65	42.69
Crude Oil	6.95	7.38	7.92
Natural Gas	10.39	11.01	12.88
Coal	10.68	14.19	19.66
Oil Shale	1.94	2.07	2.23
Federal Unleased (Total)	319.00	369.98	449.53
Crude Oil	37.03	39.32	42.19
Natural Gas	37.86	40.13	47.26
Coal	115.32	153.19	212.26
Oil Shale	123.17	131.67	142.07
Tar Sands	5.62	5.67	5.75

Table 3. GHG Emissions (Gt CO_2e) from leased and unleased federal fossil fuels

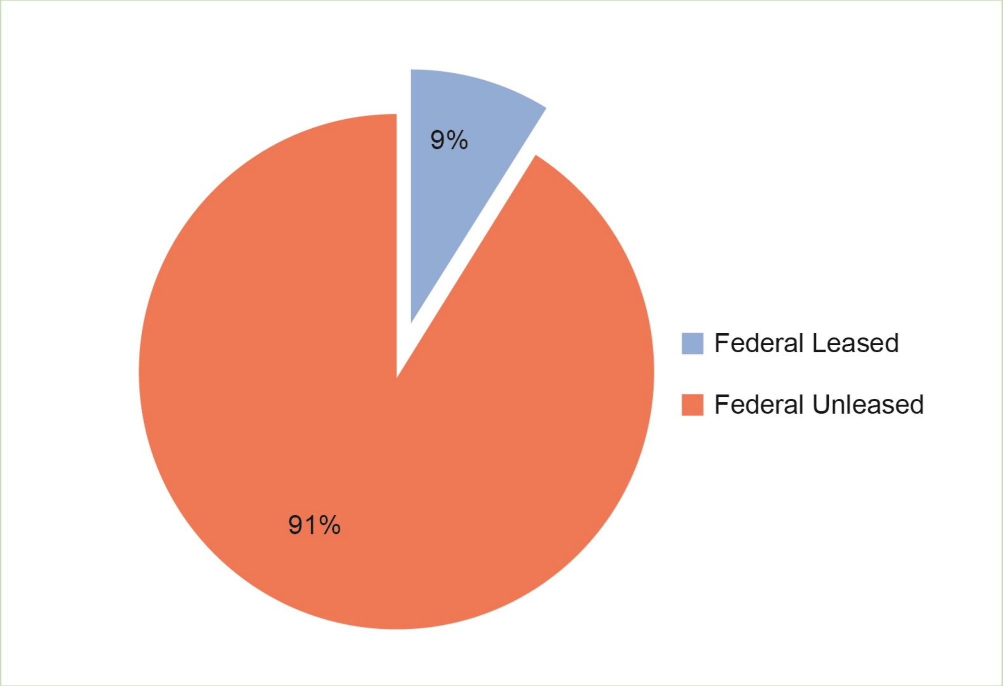

Figure 10. Low GHG emission (Gt CO_2e) factor scenario for leased and unleased federal fossil fuels

Unleased Federal Fossil Fuels by Resource Type

The GHG emissions from unleased federal fossil fuels were evaluated by resource type. In a low emissions factor scenario, coal and oil shale are the biggest contributors of greenhouse gases. Under a high emissions factor scenario, coal is the biggest contributor of GHG pollution.

	Low	Median	High
Federal Unleased			
Crude Oil	37.03	39.32	42.19
Natural Gas	37.86	40.13	47.26
Coal	115.32	153.19	212.26
Oil Shale	123.17	131.67	142.07
Tar Sands	5.62	5.67	5.75

Table 4. GHG emissions (Gt CO_2e) from unleased federal fossil fuels by resource type

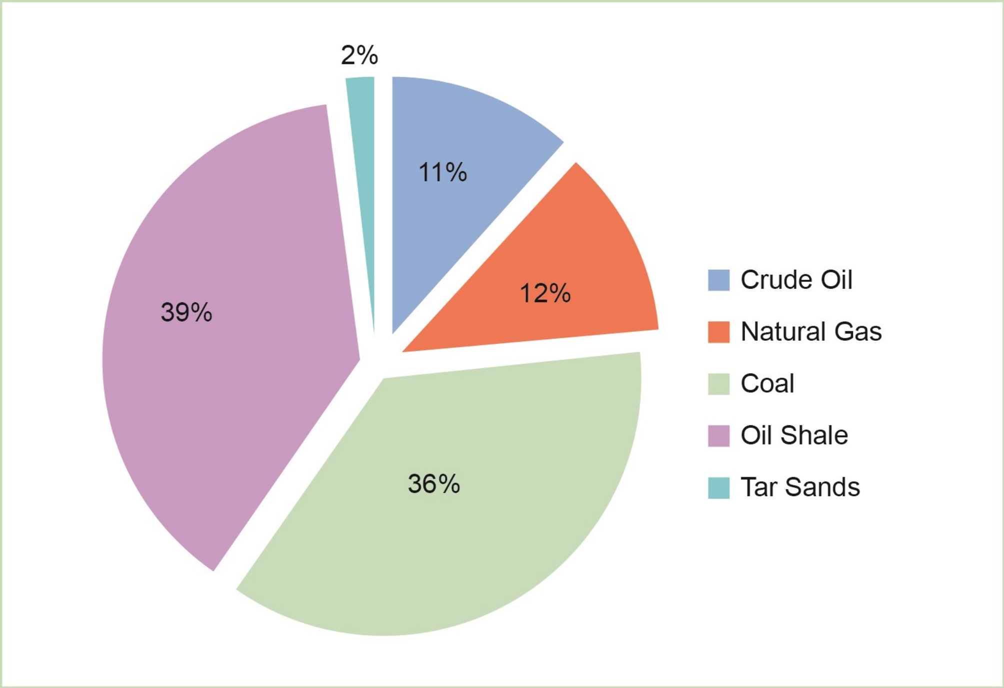

Figure 11. GHG emissions from unleased federal fossil fuels by resource type (low emissions scenario)

Coal

The potential greenhouse gas emissions from unleased recoverable coal reserves and leased recoverable coal reserves range from 115 to 212 Gt CO_2e. This analysis used “recoverable coal reserves” when estimating the GHG emissions from coal, which is a common and conservative estimate of the portion of coal that could be extracted.

	Mass (MMST)	Low	Median	High
Federal Recoverable Coal Reserves				
Unleased	86,204	115.32	153.19	212.26
Leased	7,376	10.68	14.19	19.66

Table 5. GHG emissions (Gt CO_2e) from federal coal

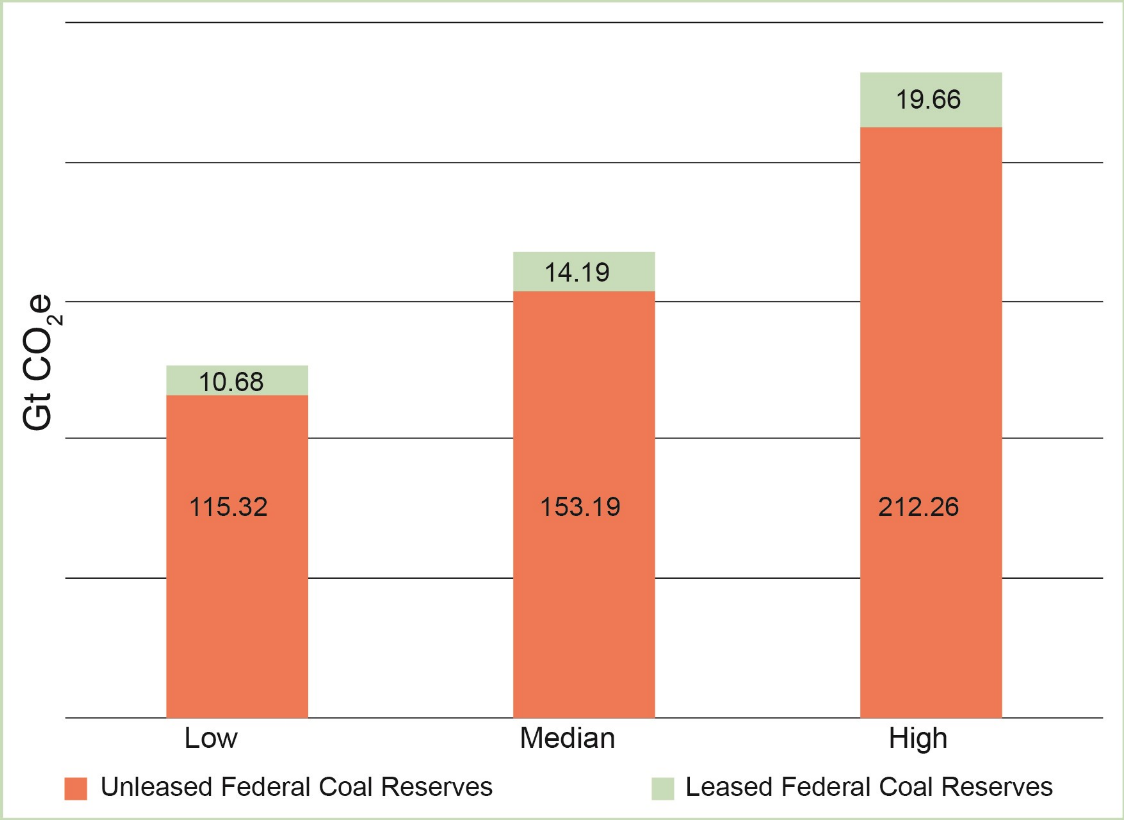

Figure 12. GHG emissions (Gt CO_2e) from federal coal under low, median and high emissions scenarios

Oil Shale

We analyzed the potential GHG emissions of federal oil shale and the portion of federal oil shale that is available for leasing under current federal policies. Since the life-cycle GHG emissions of oil shale extraction and production are more than 50% greater than conventional crude oil per unit of energy, oil shale resource results in the most potential GHG emissions per unit of energy delivered for all fossil fuels except coal. Federal oil shale includes only the resource that is geologically prospective according to deposit grade and thickness criteria in the Bureau of Land Management's (BLM) 2012 Final Oil Shale and Tar Sands Programmatic EIS and Record of Decision. Geologically prospective oil shale resources in Colorado and Utah are deposits that yield 25 gallons of shale oil per ton of rock (gal/ton) or more and are 25 feet thick or greater. In Wyoming geologically prospective resources are deposits that yield 15 gal/ton or more and are 15 feet thick or greater. Our analysis assumes that geologically prospective federal oil shale resources that are not currently available for leasing can potentially become available for leasing in the future because they are under federal mineral rights.

	Volume (MMBbls)	Low	Median	High
Federal Oil Shale				
Available for Lease Under PEIS and ROD & RD&D Leases	75,606	24.65	26.35	28.44
Total in Place Resource	383,678	123.17	131.67	142.07

Table 6. GHG emissions (Gt CO_2e) from federal geologically prospective oil shale

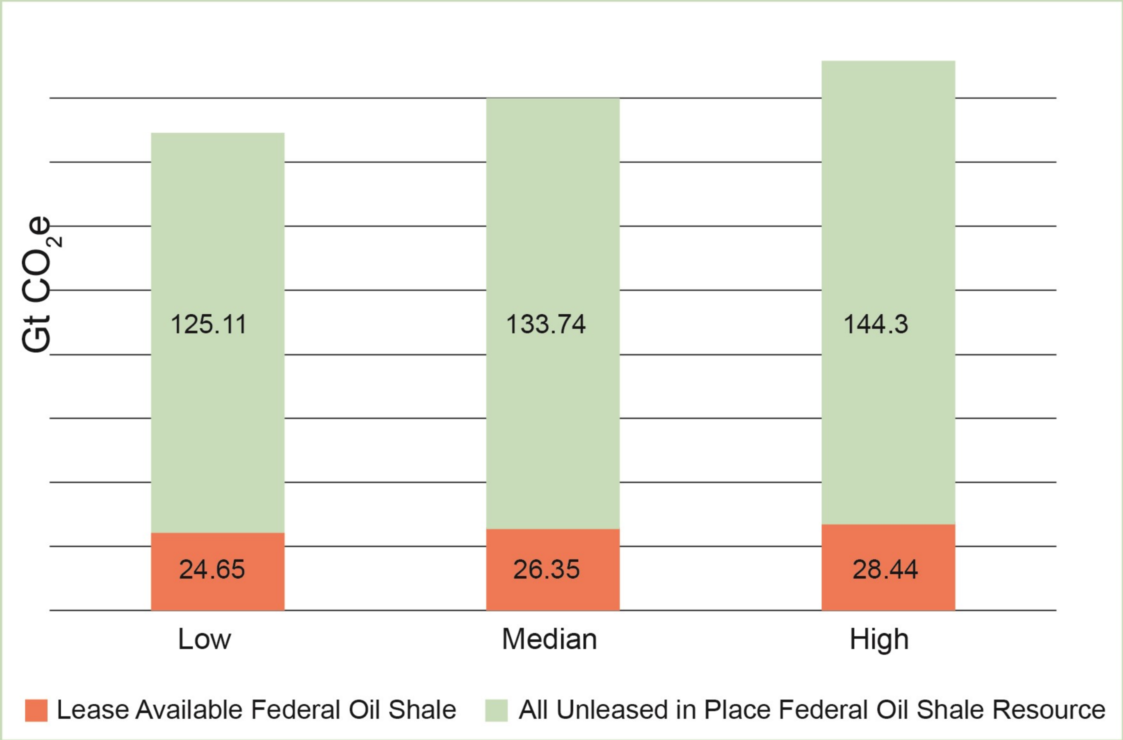

Figure 13. GHG emissions (Gt CO_2e) from federal oil shale under low, median and high emissions scenarios

Crude Oil

The potential GHG emissions of onshore and offshore federal crude oil range from 9.38 to 10.69 and 27.65 to 31.50 Gt CO_2e respectively. The potential GHG emissions of all federal crude oil range from 37.03 to 42.19 Gt CO_2e.

	Volume (MMBbls)	Low	Median	High
Unleased Federal Crude Oil				
Onshore	33,648	9.38	9.96	10.69
Offshore	74,649	27.65	29.36	31.50
Total	120,433	37.03	39.32	42.19

Table 7. GHG emissions (Gt CO_2e) from federal crude oil

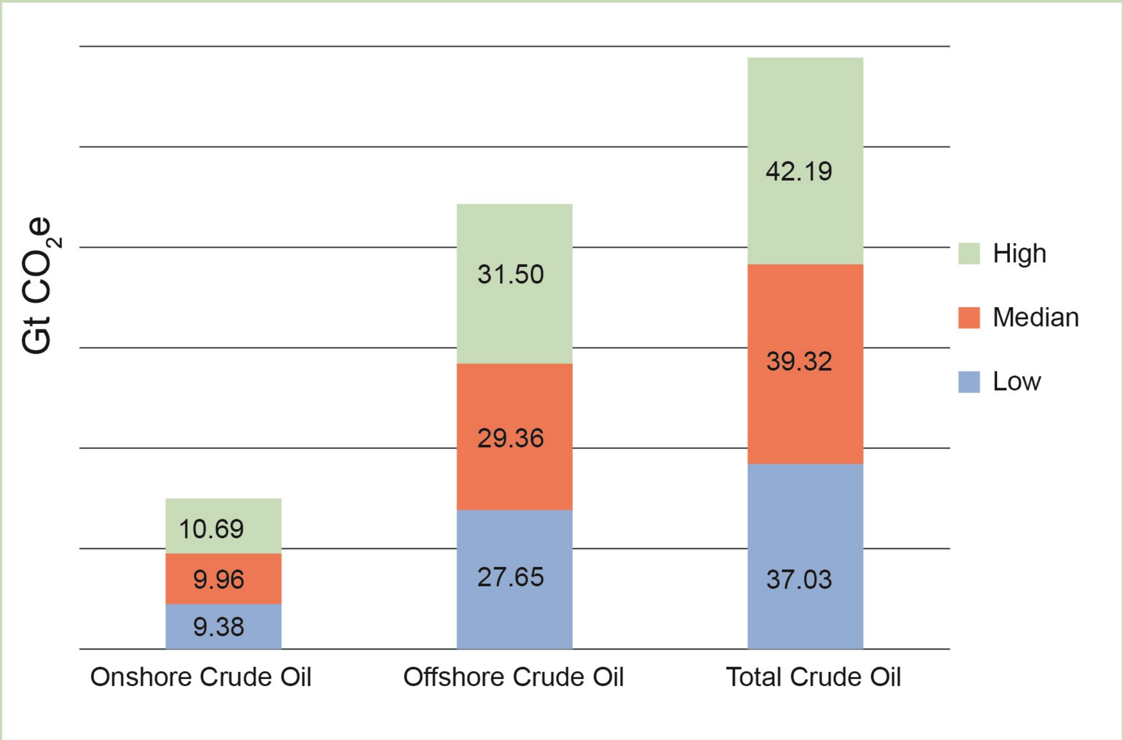

Figure 14. GHG emissions (Gt CO_2e) from unleased federal crude oil

Natural Gas

Natural gas emissions were found to be 8-9% of total potential GHG emissions from federal fossil fuels.

	Volume (Tcfg)	Low	Median	High
Unleased Federal Natural Gas				
Onshore	231	13.79	14.61	17.21
Offshore	405	24.07	25.52	30.05
Total	635	37.86	40.13	47.26

Table 8. GHG emissions (Gt CO_2e) from federal natural gas

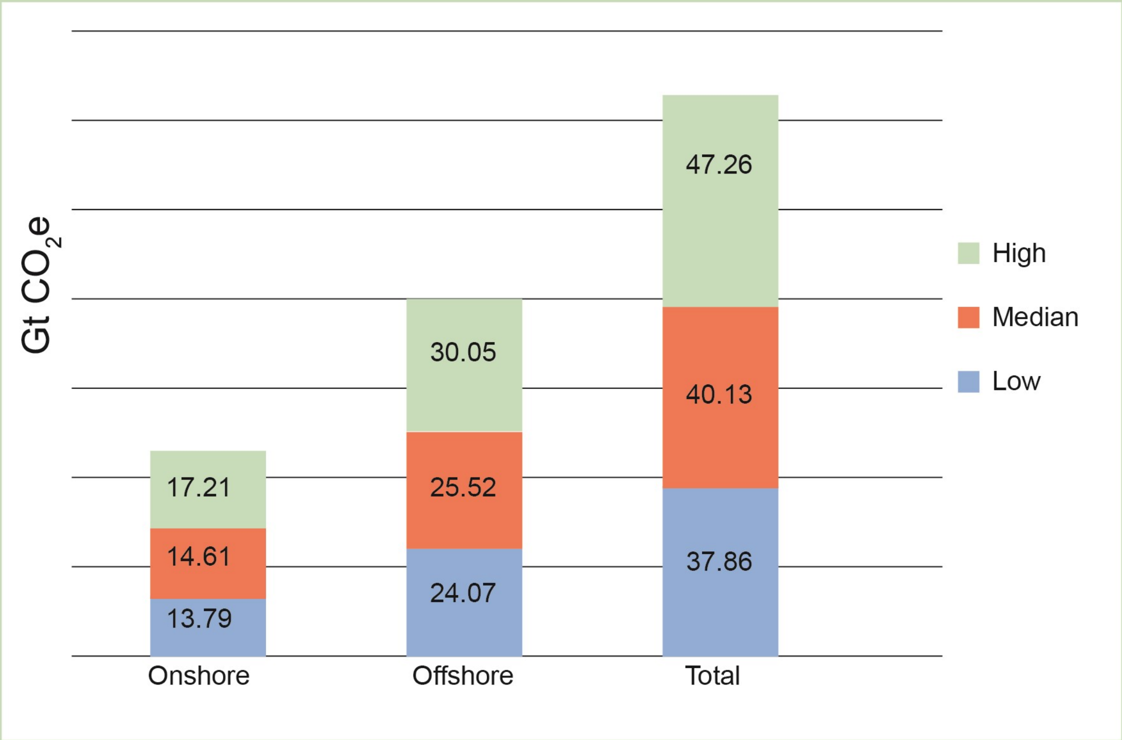

Figure 15. GHG emissions (Gt CO_2e) from unleased federal natural gas

Tar Sands

Federal tar sands account for 1-2% of total potential GHG emissions from federal fossil fuels. However, it should be noted that the emissions per barrel of oil processed from tar sands is significantly greater than that of crude oil per unit of energy. Processing tar sands into gasoline increases the GHG intensity of gasoline compared to gasoline made from conventional petroleum sources.

	Volume (MMBbls)	Low	Median	High
Federal Tar Sands				
Lease Available	4,125	1.40	1.41	1.43
Total In Place Resource	16,551	5.62	5.67	5.75

Table 9. GHG emissions (Gt CO_2e) from federal tar sands

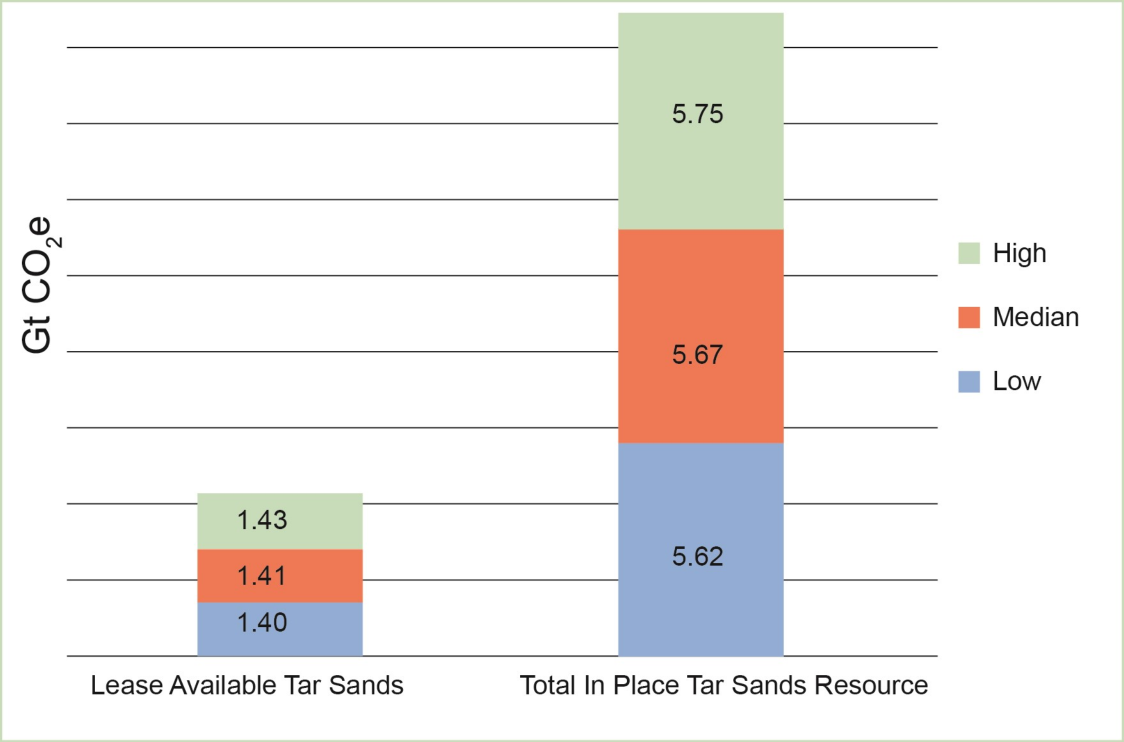

Figure 16. GHG emissions (Gt CO_2e) from federal tar sands

IV. Conclusion

This report is the first to estimate the GHG emissions associated with developing federal and non-federal fossil fuels in the United States. Our results show the 100-year global warming potential of emissions resulting from the potential extraction, processing and combustion of fossil fuels under federal mineral rights. The potential GHG emissions savings associated with all federal fossil fuels, leased and unleased, is 349 to 492 Gt CO_2e. Our results indicate that a cessation of new federal fossil fuel leasing could keep up to 450 Gt CO_2e from the global pool of potential future GHG emissions.

Studies that have apportioned global emissions quotas among the world's countries indicate that the U.S. share of the remaining global emissions is limited, with varying estimates depending on the equity principles used. For example, Raupach et al. (2014) estimated three U.S. GHG emissions quota scenarios of 85 Gt CO_2e, 220 Gt CO_2e, and 356 Gt CO_2e necessary to maintain only a 50 percent likelihood of avoiding 2°C (3.6°F) warming by century's end, depending on the equity assumptions used within a total global emissions limit. These represent a range of approximate equity assumptions for apportioning emissions quotas. Under any of those quotas, emissions from new federal fossil fuel leasing are precluded given the potential emissions from already-leased federal fossil fuels and those of non-federal fossil fuels.

Piceance Basin, Oil Shale Development, Colorado

Appendix I: Methodology

A1. Quantity of Fossil Fuels on Federal Lands

Determining the available fossil fuel volumes on federal lands is the starting point for analyzing the potential GHG emissions (see Appendix II: Table 1). Our approach classified fossil fuels into five broad categories: crude oil, natural gas, coal, oil shale, and tar sands. We reviewed the resources used in prior research and determined that the most reliable sources for volumes of fossil fuels on federal lands are the agencies that manage them such as the Bureau of Land Management (BLM), Energy Information Agency (EIA), US Geological Survey (USGS), Office of Natural Resource Revenue (ONRR), and the Department of Interior (DOI).

Where possible we have used the volumes of fossil fuels on federal lands as they are presented in our sources. Where no volume was available, we had to estimate volumes. Onshore and offshore crude oil and natural gas under lease do not have volume estimates available. Data from the ONRR on fiscal year 2014 lease volume revenue and acreage were used, alongside other fossil fuel resource data, to estimate volumes of crude oil and natural gas under lease. Oil shale available under BLM research, development and demonstration (RD&D) leases and its oil shale and tar sands programmatic environmental impact statement and record of decision (OSTS PEIS and ROD) do not have associated volume estimates. Volume estimates were constructed for:

- *Onshore Crude Oil Under Lease*
- *Offshore Crude Oil Under Lease*
- *Onshore Natural Gas Under Lease*
- *Offshore Natural Gas Under Lease*
- *Coal Under Lease*
- *Oil Shale Available for Lease Under PEIS and ROD*
- *Oil Shale Available Under RD&D Leases*
- *Total In Place Federal Oil Shale Resources*
- *Tar Sands: In Place Federally Owned Resources*
- *Tar Sands: Lease Available Special Tar Sands Areas*
- *Unleased Federal Crude Oil*
- *Unleased Federal Natural Gas*
- *Unleased Federal Coal*
- *Unleased Federal Oil Shale*
- *Unleased Federal Tar Sands*
- *Non-federal fossil fuels*

Onshore Crude Oil Under Lease

The 2008 EPCA inventory estimates the amount of crude oil and natural gas. We used 2014 data to estimate what portion is under active lease. To calculate onshore crude oil under lease, we use the following equation:

$$OCO_{UL} = [ONG_{AUL} \times (FLA_{TRO} \div TA_{AFL})] + OCO_{PR}$$

Where:

OCO_{UL} = Onshore Crude Oil Under Lease, in MMBls

ONG_{AUL} = Fiscal Year 2014 Oil & Natural Gas Nonproducing Acres Under Active Lease

FLA_{TRO} = Federal lease Available Technically Recoverable Onshore Oil

TA_{AFL} = Total Acres Available for Lease from Figure ES3 of EPCA Phase 3 Inventory 2008

OCO_{PR} = Onshore Crude Oil, Proved, from EPCA Phase 3 Inventory 2008

Offshore Crude Oil Under Lease

To calculate offshore crude oil under lease, we use the following equation:

$$OFCO_{UL} = [OFA_{UAL} \times (OFCO_{LGM} \div OFCO_{LGMA})] + OFCO_{P}$$

Where:

$OFCO_{UL}$ = Offshore Crude Oil Under Lease, in MMBblsa

OFA_{UAL} = 2015 Offshore Nonproducting Acres Under Active Lease

$OFCO_{LGM}$ = Offshore Crude Oil Leased in Gulf of Mexico Nonproducing Volume

$OFCO_{LGMA}$ = Offshore Crude Oil Nonproducing Acres Leased in Gulf of Mexico

$OFCO_{PR}$ = Offshore Crude Oil, Proved, from EPCA Phase 3 Inventory 2008

Onshore Natural Gas Under Lease

To calculate onshore natural gas under lease, we use the following equation:

$$ONG_{UL} = [ONG_{AUL} \times (FLA_{TRNG} \div TA_{AFL})] + ONG_{PR}$$

Where:

ONG_{UL} = Onshore Natural Gas Under Lease, in TCfg

ONG_{AUL} = Fiscal Year 2014 Oil and Natural Gas Nonproducing Acres Under Lease

FLA_{TRNG} = Federal Lease Available Technically Recoverable Onshore Natural Gas

TA_{AFL} = Total Acres Available for Lease from Figure ES3 of Phase 3 Inventory 2008

ONG_{PR} = Onshore Natural Gas,Proved,from EPCA Phase 3 Inventory 2008

Offshore Natural Gas Under Lease

To calculate offshore natural gas under lease, we use the following equation:

$$OFNG_{UL} = [OFA_{UAL} \times (OFNG_{LGM} \div OFNG_{NP})] + OFNG_{PR}$$

Where:

$OFNG_{UL}$ = Offshore Natural Gas Under Lease, in Tcfg

OFA_{UAL} = *Offshore Nonproducing Acres Under Active Lease*

$OFNG_{LGM}$ = *Offshore Natural Gas Leased in Gulf Of Mexico Nonproducing Volume*

$OFNG_{NP}$ = *Offshore Natural Gas Nonproducing Acres Leased in Gulf of Mexico*

$OFNG_{PR}$ = *Offshore Natural Gas,Proved, from EPCA Phase 3 Inventory*

Coal Under Lease

Since nominal amounts of coal under lease were not available, we had to estimate them based on data from GAO, BLM, and the percentage of leased and unmined coal reserves remaining in the Powder River Basin. To calculate coal under lease, we used the following equation:

$$C_L = \sum RLC\,[(LFC_{A,1990\text{-}2012} \div LFC_{T,\,1990\text{-}2012}) \times LFC_{A,2013}] \times RFC_R$$

Where:

C_L= *Coal Under Lease,in MST*

$\sum RLC$ = *Sum of Remaining Leased Coal for each of the following States (AL, CO, KY, MT, NM, ND, OK, UT, WY, Eastern States)*

$LFC_{A,1990\text{-}2012}$ = *Leased Federal Coal in Acres (for each state)for the period 1990-2012,from Table 1 in GAO 2013*

$LFC_{T,\,1990\text{-}2012}$ = *Total Leased Federal Coal Acres in Effect (for each state) in 2013 from BLM 2014*

RFC_R = *Percentage of leased and unmined coal reserves remaining in Powder River Basin(40.4%) from Wright 2015*

Oil Shale Available for Lease Under PEIS and ROD

To calculate the volume of oil shale available for lease under both the PEIS and ROD, we separately estimate the available resource in Utah, Colorado and Wyoming, and sum these estimates.

To estimate the available resource for lease in Utah, we use the following equation:

$$OSR_{UT} = AAROD_{UT} \times AR_{UT}$$

Where:

OSR_{UT} = *Oil Shale Resource for lease in Utah, in MMBbls*

$AAROD_{UT}$ = *Available Area in Utah According to Record of Decision*

AR_{UT} = *Average Resource in Utah' s Uintah Basin, in bbl/acre*

To estimate the available resource for lease in Colorado, we use the following equation:

$$OSR_{CO} = AAROD_{CO} \times AR_{CO}$$

Where:

OSR_{CO} = *Oil Shale Resource in Colorado,in MMBbls*

$AAROD_{CO}$ = *Available Area in Colorado According to Record of Decision*

AR_{CO} = *Average Resource in Colorado's Piceance Basin,in bbl/acre*

To estimate the available resource for lease in Wyoming, we use the following equation:

$$OSR_{WY} = AAROD_{WY} \times AR_{WY}$$

Where:

OSR_{WY} = *Oil Shale Resource in Wyoming, in MMBbls*

$AAROD_{WY}$ = *Available Area in Wyoming According to Record of Decision*

AR_{WY} = *Average Resource in Wyoming's Green River and Washakie Basins, comprised of the average of 6 members, in bbl/acre*

Oil Shale Available Under RD&D Leases

To calculate the volume of oil shale available under RD&D leases, we summed up the estimated volumes for the 9 leases detailed in the *Assessment of Plans and Progress on US Bureau of Land Management Oil Shale RD&D Leases in the United States*.[14] Since volume estimates for the American Shale Oil LLC and AuraSource leases are not available in the document, we estimate them using the following equations:

$OSR_{ASO} = AAL_{ASO} \times AR_{CO}$

Where:

OSR_{ASO} = *Oil Shale Resource in the American Shale Oil, LLC Lease, in MMBbls*

AAL_{ASO} = *Area Available For Lease (including preference right area) for the American Shale Oil, LLC lease*

AR_{CO} = *Average Resource in Colorados's Piceance Basin, in bbl/acre*

and

$OSR_{AS} = AAL_{AS} \times AR_{UT}$

Where:

OSR_{AS} = *Oil Shale Resouce in the AuraSource Lease, in MMBbls*

AAL_{AS} = *Area Available For Lease (including preference right area) for the AuraSource lease*

AR_{UT}= *Average Resource in Utah's Uintah Basin, in bbl/acre*

Total In Place and Geologically Prospective Federal Oil Shale Resources

To calculate the total in place federal oil shale resources, we summed the federal resource available in the Piceance Basin with a yield of over 25 GPT (gallon per ton) in USGS 2010, the federal resource available in the Green River and Washakie Basins of over 15 GPT in USGS 2011, and separately estimated the federal resource available in the Uintah basin.

To estimate the federal resource in the Uintah basin, we use the following equation:

$FOSR_{UB} = AAROD_{UT} \times AR_{UT}$

Where:

$FOSR_{UB}$= *Federal Oil Shale Resource in the Uintah Basin, in MMBbls*

$AAROD_{UT}$ = *Available Area in Utah According to Record of Decision*

AR_{UT}= *Average Resource in Utah's Uintah Basin, in bbl/acre*

Tar Sands: In Place Federally Owned Resources

To calculate the volume of in place federally owned tar sands resources, we use the following equation:

$$TS_{FOR} = \sum SR_{fp}$$

Where:

TS_{FOR} = *In Place Federally Owned Tar Sands Resources, in MMBbl*

$\sum SR_{fp}$ = *The sum of the federally owned percentages of tar sands resource for each state*

As mentioned above, we sum the federally owned percentages of tar sands resources as listed in *Natural Bitumen Resources of the United States*.[15] Where no federal ownership percentage is given in the document, we cite research by Keiter et al. 2012 for the percentage of Utah tar sands that are federal and Gorte et al. 2011 for all other states.

Tar Sands: Lease Available STSAs

To calculate the volume for Lease Available STSAs (Special Tar Sands Area, a specific designation from the BLM), we multiply the area available for each STSA by the resource for that area. STSA areas are taken as presented in the 2013 ROD.[16]

The available resource for each area is taken from *Unconventional Energy Resources: 2013 Review*.[17] This review unfortunately does not provide estimates for Raven Ridge or San Rafael STSAs; for those, we used a low per-acre estimate (from the P.R. Spring STSA) of 25,900 barrels per acre. We then sum all of these volumes.

Unleased Federal Crude Oil

To calculate unleased federal offshore crude oil, we use the following equation:

$$OFCO_{ULL} = OFCO_{TR}$$

Where:

$OFCO_{ULL}$ = *Unleased Federal Offshore Crude Oil*

$OFCO_{TR}$ =*Technically Recoverable Federal Offshore Crude Oil*

To calculate unleased federal onshore crude oil, we use the following equation:

$$OCO_{ULL} = OCO_{TR}$$

Where:

OCO_{ULL} = *Unleased Federal Onshore Crude Oil*

OCO_{TR} = *Technically Recoverable Federal Onshore Crude Oil*

Unleased Federal Natural Gas

To calculate unleased federal offshore natural gas, we use the following equation:

$$OFNG_{ULL} = OFNG_{TR}$$

Where:

$OFNG_{ULL}$= *Unleased Federal Offshore Natural Gas*

$OFNG_{TR}$= *Technically Recoverable Federal Offshore Natural Gas*

To calculate unleased federal onshore natural gas, we use the following equation:

$$ONG_{ULL} = ONG_{TR}$$

Where:

ONG_{ULL}= *Unleased Federal Onshore Natural Gas*

ONG_{TR}= *Technically Recoverable Federal Onshore Natural Gas*

Unleased Federal Coal

To calculate unleased federal coal, we use the following equation:

$$FC_{ULL} = FC_{RR} - \left\{ \left(\frac{FC_{TIR}}{BLM_{AUM}} \right) \times CLA_{2013} \right\}$$

Where:

FC_{ULL}= *Unleased Federal Coal*

FC_{RR}= *Federal Recoverable Coal Reserves from NMA 2012*

FC_{TIR} = *Total Federal In Place Coal Resource from USDA,USDOE,USDOI 2007*

BLM_{AUM} = *Acres Under BLM Management from BLM 2014*

CLA_{2013} = *2013 Leased Coal Acres from BLM 2014*

Unleased Federal Oil Shale

To calculate unleased federal oil shale, we subtract Federal Oil Shale Available under RD&D Leases from DOE/BLM 2013 from Total In Place Geologically Prospective Federal Oil Shale Resources as described earlier.

Unleased Federal Tar Sands

To calculate unleased federal tar sands, we assume the total in place federal tar sands resources are unleased.

Non-federal Fossil Fuels

Non-federal fossil fuels volumes are calculated for each fossil fuel category by subtracting federal fossil fuel volumes from total technically recoverable oil resources, total technically recoverable natural gas resources, and total U.S. recoverable coal reserves as provided by EIA 2012a. There are no non-federal tar sands and oil shale resources examined in this study.

For each oil, natural gas and coal resource:

NFFF = TTR - FFF

Where:

NFFF= Non-federal Fossil Fuel

TTR = Total Technically Recoverable Resource

FFF = Federal Fossil Fuel

A2. Fossil Fuel to Primary Energy Conversions

We converted volumes of fossil fuels into primary energy as this allowed us to make necessary adjustments and apply resource-specific life-cycle GHG emissions factors, as those are presented in units of energy. For example, the life-cycle GHG emissions factors are typically on a product-delivered basis (kWh of electricity, MJ of thermal energy), so the fossil fuel reserves must be adjusted because only a portion of the fossil fuel becomes a final product delivered.

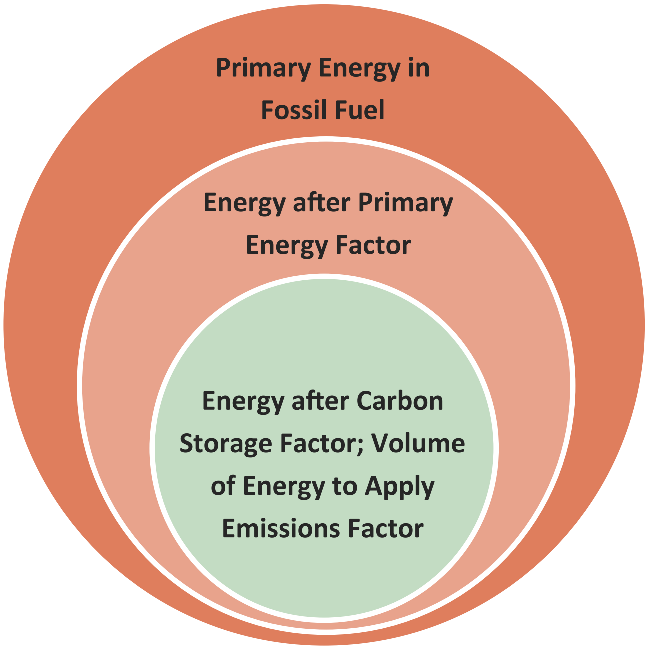

Figure A17. Determining quantities of energy to multiply by emissions factor

We used the following assumptions to convert fossil fuel amounts to primary energy:

Fossil Fuel	Energy Content	Source
Crude Oil	5,746 MJ / barrel (LHV)	ORNL 2011
Natural Gas	983 btu / ft3 (LHV)	ORNL 2011
Coal	20.61 btu / ton (HHV)	ORNL 2011
Oil Shale	5,746 MJ / barrel (LHV)	ORNL 2011
Tar Sands	5,746 MJ / barrel (LHV)	ORNL 2011

Table A10. Energy content of fossil fuels

Proportions of Resource Used as Input for End-use Products

The proportions of resource used as input for end-use products were needed in order to appropriately divide the initial fossil fuel amounts. The proportions make it possible to apply end-use product-specific life-cycle emissions factors, which account for the full life-cycle GHG emissions associated with each end-use product. These proportions do not take into account the energy required to process the fossil fuel resource and move it downstream. They only describe a percentage of the fossil fuel resource that will ultimately be used in end-use products and sectors.

Crude Oil

Proportions of crude oil used for various end-use products were derived from the EIA.[18] To calculate proportions each of the top seven petroleum products consumed in 2013 was divided by the total annual consumption of petroleum products. These top seven products are:

- ***Finished Motor Gasoline***
- ***Distillate Fuel Oil***
- ***Kerosene***
- ***Liquefied Petroleum Gases (LPG)***
- ***Petroleum Coke***
- ***Still Gas***
- ***Residual Fuel Oil***

Dividing the consumption of each end-product by the total annual consumption of petroleum products enabled us to reconstruct the demand for petroleum products, and thus the hypothetical product output of a crude oil refinery.

For this method, we used the following equation:

$CO_{EUPP} = AC_{EUP} \div AC_{APP}$

Where:

CO_{EUPP} = *Crude Oil End Use Product Proportion*

AC_{EUP} = *Annual Consumption of End Use Product*

AC_{APP} = *Annual Consumption of All Petroleum Products*

Natural Gas

Proportions of natural gas used for each end-use sector were derived from the EIA's *Natural Gas Consumption by Sector in the Reference case, 1990-2040: History: U.S. Energy Information Administration, Monthly Energy Review*.[19] For each end-use sector, the sector specific annual natural gas consumption was divided by the total annual natural gas consumption. These end-use sectors are:

- ***Residential***
- ***Commercial***
- ***Industrial***
- ***Electric Power***
- ***Transportation***

For this method we used the following equation:

$NG_{EUSP} = AC_{EUS} \div AC_{ANG}$

Where:

NG_{EUSP} = *Natural Gas End Use Sector Proportion*

AC_{EUS} = *Annual Consumption by End Use Sector*

AC_{ANG} = *Annual Consumption of All Natural Gas*

Coal

Proportions of coal used for each end-use sector were derived from the EIA's *Quarterly Coal Report – April – June 2014: Table 32 - U.S. Coal Consumption by End-Use Sector, 2008 – 2014*.[20] For each end-use sector, the sector specific annual coal consumption was divided by the total annual coal consumption. These end-use sectors are:

- *Electric Power*
- *Coke*
- *Other Industrial Use*

For this method we used the following equation:

$C_{EUSP} = AC_{EUS} \div AC_{AC}$

Where:

C_{EUSP} = *Coal End Use Sector Proportion*

AC_{EUS} = *Annual Consumption by End Use Sector*

AC_{AC} = *Annual Consumption of All Coal*

Oil Shale

For oil shale we assume the same proportions of end-use products will be refined from a barrel of oil shale as is currently derived from a barrel of crude oil. We apply the same end-use product proportions as calculated for crude oil.

Tar Sands

For tar sands we assume the same end-use products will be refined from a barrel of crude oil derived from tar sands as has been assumed in other research.[21] We apply the same end-use product proportions as calculated for crude oil.

Primary Energy Factors

Making energy products requires energy. To account for the energy in the reserve required to make the final end products, we determined a ratio of primary energy to the end use, resulting in a Primary Energy Factor. The Primary Energy Factor represents the relationship between the amount of energy required to make the end product and the amount of end product. In the case of coal-based electricity, it is the amount of energy needed to make 1 kWh of coal-fired electricity, which will always be >1 kWh. For this study only about 30% of the total coal resource becomes electricity delivered from coal-fired generation; it requires about 3.3 kWh of coal resource to make and deliver 1 kWh of coal electricity. Our methodology assumes the energy required to process the fossil fuel resource into the end-product is internal, meaning it comes from the resource. This means that some portion of the fossil fuel resource is consumed making the fossil fuel product. The primary energy factor helps understand the total amount of fossil fuel products and has no impact on the life-cycle GHG emissions, which are accounted for in the emissions factors.

For many end-products, primary energy factors are available, as “source energy factors” from the National Renewable Energy Laboratory’s *Fuels and Energy Precombustion LCI Data Module*.[22] We used these source energy factors, which represent the energy required to extract, process, and deliver fuel, as Primary Energy Factors. We used NREL’s ‘source energy factors’ for all end products except:

- ***Natural Gas Use in the Electric Power Sector***
- ***Coal Use in the Electric Power Sector***
- ***Coal Use in manufacturing Metallurgical Coke***
- ***Coal Use in Other Industrial Use***
- ***End Products Derived from Oil Shale and Tar Sands***

Natural Gas Use in the Electric Power Sector

To calculate the Primary Energy Factor for Natural Gas Use in the Electric Power Sector, we converted the volume (ft^3) of Natural Gas delivered in 2013 to customers in the Electric Power Sector from EIA’s *February*

2015 Monthly Energy Review[23] into kWh, took the 2013 net electrical generation from Natural Gas (kWh) by Electric Power Sector customers in EIA's *February 2015 Monthly Energy Review*,[24] and the source energy factor for Natural Gas from Deru and Torcellini 2007.

To calculate the Primary Energy Factor for Natural Gas Use in the Electric Power Sector, we used the following equation:

$$PEFNG_{EPS} = NGD_{EPS} \div NEGNC_{EPS}$$

Where:

$PEFNG_{EPS}$ = *Primary Energy Factor for Natural Gas Use in the Electric Power Sector*

NGD_{EPS}= *Natural Gas Delivered to Electric Power Sector Customers in 2013*

$NEGNC_{EPS}$ = *Net Electrical Generation from Natural Gas by Electric Power*

For other natural gas end-use sectors, we assume all heat not converted to electricity is useful. For the Electric Power Sector, however, we assume all heat is lost.

Coal Use in the Electric Power Sector

For Coal Use in the Electric Power Sector, we converted the quantity of coal consumed by the Electric Power Sector in *Quarterly Coal Report – April – June 2014: Table 32 - U.S. Coal Consumption by End-Use Sector, 2008 – 2014*[25] into kWh, we took the 2013 net electrical generation from Coal (kWh) by Electric Power Sector customers in EIA's *February 2015 Monthly Energy Review* (2015b), and the source energy factor for Coal.[26]

To calculate the Primary Energy for Coal Use in the Electric Power Sector, we used the following equation:

$$PEFC_{EPS} = CD_{EPS} \div NEGC_{EPS}$$

Where:

$PEFG_{EPS}$ = *Primary Energy Factor for Coal Use in the Electric Power Sector*

CD_{EPS} = *Coal Delivered to Electric Power Sector Customers in 2013*

$NEGC_{EPS}$ = *Net Electrical Generation from Coal by Electric Power Customers in 2013*

For Coal Use in the manufacture of Metallurgical Coke, we used values in World Coal Association 2015. For Coal Use in Other Industrial Use, we use the same Primary Energy Factor as that calculated for Coal Use in the Electric Power sector.

End Products Derived From Oil Shale and Tar Sands

The primary energy resource available for end products derived from oil shale and tar sands needs to be adjusted for the increased energy required to extract and process both the oil shale and tar sands. We assume the additional energy required for these processes comes from the primary energy resource itself, otherwise referred to as 'internal' energy. Since the primary energy factors used[27] are aggregates of several components (exploration, extraction, processing, and refining into end products), and do not list the primary energy factors for each of these components, we had to disaggregate the factors and backwards calculate the primary energy factor of just the refining component. To do this we use the following equation for each end product derived from crude oil:

$$PEFCO_{REP} = (PEFCO_{EP}) - \left(\frac{1}{EROI_{CO}}\right)$$

Where:

$PEFCO_{REP}$ = *Primary Energy Factor of Refining the End Product From Crude Oil, exclusive of energy required for exploration, extraction, and processing*

$PEFCO_{EP}$ = *Primary Energy Factor of End Product, inclusive of all processes*

$EROI_{CO}$ = *Energy Return On Investment from Crude Oil*

For End Products Derived from Oil Shale, we adjust the Primary Energy Factors of refining components of end products derived from Crude Oil by the following adjustment mechanism:

$$PEFOS_{EP} = PEFCO_{REP} + \left(\frac{1}{EROI_{OS}}\right)$$

Where:

$PEFOS_{EP}$ = *Primary Energy Factor of Oil Shale Derived End Product*

$PEFCO_{REP}$ = *Primary Energy Factor of Refining Component of End Product*

$EROI_{OS}$ = *Energy Return ON Investment from Oil Shale, from Brand 2009*

For End Products Derived from Tar Sands, we adjust the Primary Energy Factors of refining components of end products derived from Crude Oil by the following adjustment mechanism:

$$PEFTS_{EP} = PEFCO_{REP} + \left(\frac{1}{EROI_{TS}}\right)$$

Where:

$PEFTS_{EP}$ = *Primary Energy Factor of Tar Sands Derived End Product*

$PEFCO_{REP}$ = *Primary Energy Factor of Refining Component of End Product*

$EROI_{TS}$ = *Energy Return ON Investment from Tar Sands*[28]

Emissions Factors

The approach used in this study was to use emissions factors that represent the functional units for which we had data on fossil fuels amounts. For example, if the functional unit of the emissions factor was a kWh worth of electricity, we estimated the total amount of resource that can be converted into this functional unit. Where the emissions factor is provided on an energy unit basis that is not equivalent to that of the fossil fuel resource, we make the appropriate conversion.

All life-cycle emissions factors used in this study, and nearly all in the literature, are on an end-use product basis (i.e., kWh of electricity, MJ of final fuel combusted, km-travelled, etc.). To account for the energy in the feedstock required to make the end-use products, we determined a ratio of primary energy to the end-use product, as described earlier in this Appendix. This represents the relationship between the amount of energy required to make the final product.

We were able to find resource-specific life-cycle emissions factors for all fossil fuel categories. These life-cycle emissions factors account for the greenhouse gas emissions associated with all life-cycle stages associated with the production of an end-product derived from a fossil fuel feedstock.

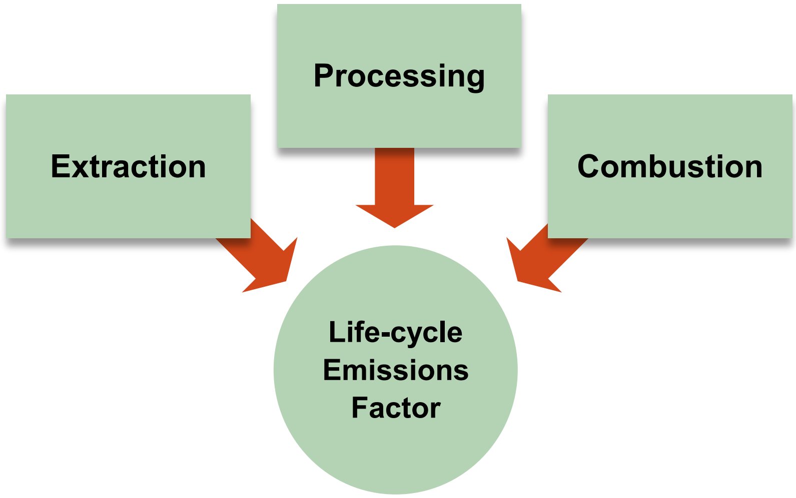

Figure A18. Example life-cycle stages accounted for in a life-cycle emissions factor

For each emissions factor we evaluated low, median and high emission factor scenarios. The base case in this study is the low emissions factor scenario, which is the most conservative estimate of the GHG emissions from developing fossil fuels. This was done to account for a static emissions factor; we optimistically assume that GHG emissions per unit of energy improve over time compared to *ex post* emissions factors in the literature as more efficient energy and public policy and best practices limit fugitive emissions.

Where possible we used harmonized life-cycle emissions factors found in the literature. Harmonization is a meta-analytical process used to develop robust, analytically consistent and current comparisons of estimates of life-cycle GHG emissions factors, which have been scientifically studied and published in academic, peer-reviewed literature.

For some end-use products, however, specific emissions factors were not available in the literature. We make adjustments to the emissions factors for the following:

- ***Natural Gas extracted from non-conventional, shale based natural gas resource***
- ***All end products (except Gasoline) derived from Oil Shale***
- ***Liquefied petroleum gas , Petroleum Coke, Still Gas, and Residual Fuel Oil derived from Tar Sands***
- ***Natural Gas Used in the Transportation Sector***

Natural Gas Extracted From Non-Conventional, Shale-based Natural Gas Resource

To account for the difference in emissions resulting from conventional natural gas extraction and non-conventional natural gas extraction, we apply shale gas-specific emissions factors to a percentage of the total natural gas fossil fuel volume. We assume this to be 27% and take this figure from EIA's *Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States* (2013). We use shale gas-specific emissions factors from Burnham et al. 2012 and Heath et al. 2014.

All End Products (Except Gasoline) Derived From Oil Shale

Specific emissions factors for finished motor gasoline derived from oil shale were available in the literature. Emissions factors for the remainder of the end-products, however, were not.

To account for the difference in emissions between conventional crude oil extraction and processing and the extraction and processing of oil shale into an equivalent barrel of standard crude oil, we adjust the end-product-specific emissions factors using the following equation:

$$OSE_{AF} = (FMG_{OS} - FMG_{CO}) \div FMG_{CO}$$

Where:

OSE_{AF} = *Oil Shale Emissions Adjustment Factor*

FMG_{OS} = *Finished Motor Gasoline from Oil Shale Emissions Factor from Brandt 2009*

FMG_{CO} = *Finished Motor Gasoline from Crude Oil Emissions Factor from Burnham,et al.2012*

We then multiply each crude oil end product specific emissions factor by (1 + OSE_{AF}) to appropriately increase the emissions factor due to the increased emissions resulting from Oil Shale extraction and processing. The emissions factor from Brandt 2009 used above is an Oil Shale specific emissions factor.

LPG, Petroleum Coke, Still Gas and Residual Fuel Oil Derived From Tar Sands

Specific emissions factors for finished motor gasoline, distillate fuel oil and kerosene were available in the literature. However, specific emissions factors for other end-use products were not. To account for the difference in emissions between conventional crude oil extraction and processing and the extraction and processing of Tar Sands into an equivalent barrel of standard crude oil, we adjust the end product specific emissions factors using the following equation:

TSE_{AF} = the average of:

$(FMG_{TS} - FMG_{CO}) \div FMG_{CO}$;

$(DFO_{TS} - DFO_{CO}) \div DFO_{CO}$;

and

$(K_{TS} - K_{CO}) \div K_{CO}$

Where:

TSE_{AF} = *Tar Sands Emissions Adjustment Factor*

FMG_{TS} = *Finished Motor Gasoline from Tar Sands Emissions Factor*[29]

FMG_{CO} = *Finished Motor Gasoline from Crude Oil Emissions Factor*[30]

DFO_{TS} = *Distillate Fuel Oil from Tar Sands Emissions Factor*[31]

DFO_{CO} = *Distillate Fuel Oil from Crude Oil Emissions Factor*[32]

K_{TS} = *Kerosene from Tar Sands Emissions Factor*[33]

K_{CO} = *Kerosene from Crude Oil Emissions Factor*[34]

We then multiply the LPG, Petroleum Coke, Still Gas and Residual Fuel Oil from Crude Oil emissions factors by $(1 + TSE_{AF})$.

Natural Gas Used in the Transportation Sector

In order to more accurately estimate the emissions from natural gas use in the transportation sector, we use EIA data[35] to determine what percentage of natural gas is used by light duty compressed natural gas (CNG) vehicles, and what percentage is used by medium and heavy duty CNG vehicles. We then apply these proportions to the transportation portion of natural gas primary energy volumes.

To calculate GHG emissions, we use life-cycle emissions factors for CNG transportation.[36] Since the emissions factors from Burnham et al. are measured in km-travelled, we need the fuel economy to determine the distance each mode of transport can travel based upon a unit of gas. We use EPA data to estimate the fuel economy of light duty vehicles.[37] For the fuel economy of medium and heavy duty vehicles, we cite research from NREL.[38] Once energy available is expressed in the functional units of the life-cycle emissions factors, we can estimate potential GHGs.

Research Limitations

There are several limitations to this model. The major limitation is the unavailability of some kinds of data that would allow for a better approximation of global warming potential from developing fossil fuels. For example, tar sands reserves are not well characterized as amounts are reported in “acres” and estimates must be made by applying a “barrel per acre” estimate instead of absolute amounts, which would be easier to compare with other reserves. In addition, existing fossil fuel amounts under lease were mostly unavailable. There is also no specific data for all of the crude oil end products. Literature on life-cycle emissions factors for oil shale and tar sands is not as extensive as for other resources and comes with higher ranges of uncertainty. There is also no federal ownership of figures for tar sands in Alabama, Texas, California, Kentucky, New Mexico, Wyoming and Oklahoma. Finally, emissions factors used in this study were static over time and based on *ex post* (actual) data. Our GHG emissions model assumes that the combustion efficiency or GHG intensity across the fleet of U.S. fossil fuel-fired power plants remains static over time.

Appendix II: Data Sources

Crude Oil		
Offshore		
Federal Technically Recoverable	89,930 MMBbls	BOEM 2014
Federal Proved (2013)	5,137 MMBbls	EIA 2015a
FY 2014 Crude Oil Volume Revenues Reported	396.36 MMBbls	ONRR 2014
February 2015 Producing Leases – Acreage	4,980,054 acres	BOEM 2015
Acreage Under Active Lease	32,184,001 acres	BOEM 2015
Leased in Gulf of Mexico (non-producing/not subject to exploration & development plans)	17,900 MMBbls	DOI 2012
Non-producing Acreage Leased in Gulf of Mexico	23,849,584 acres	BOEM 2015
All Non-producing Acreage Leased	27,203,947 acres	DOI 2012
Onshore		
Federal Technically Recoverable	30,503 MMBbls	EPCA Phase 3 Inventory 2008
Federal Lease Available Technically Recoverable*	18,989 MMBbls	EPCA Phase 3 Inventory 2008
Federal Proved	5,344 MMBbls	EPCA Phase 3 Inventory 2008
FY 2014 Crude Oil Volume Revenues Reported	146.23 MMBbls	ONRR 2014
FY 2014 O&NG Producing Leases –Acreage	12,690,806 acres	BLM 2014a
FY 2014 O&NG Acres Under Lease	34,592,450 acres	BLM 2014a
Total Technically Recoverable Resource	220,200 MMBbls	EIA 2012a
Natural Gas		
Offshore		
Technically Recoverable	404.52 Tcfg	BOEM 2014
Federal Proved Gas	25.33 Tcfg	EIA 2014c
FY 2014 Natural Gas Volume Revenues Reported	0.85 Tcg	ONRR 2014
February 2015 Producing Leases –Acreage	4,980,054 acres	BOEM 2015
Acreage Under Active Lease	32,184,001 acres	BOEM 2015
Leased in Gulf of Mexico (non-producing/not subject to exploration & development plans)	49.70 Tcfg	DOI 2012
Non-producing Acreage Leased in Gulf of Mexico	23,849,584 acres	BOEM 2015
All Non-producing Acreage Leased	27,203,947 acres	BOEM 2015

Onshore		
Technically Recoverable	230.98 Tcfg	EPCA Phase 3 Inventory 2008
Lease Available Technically Recoverable*	194.907 Tcfg	EPCA Phase 3 Inventory 2008
Proved Gas	68.76 Tcfg	EPCA Phase 3 Inventory 2008
Total Technically Recoverable Resource	2,203.30 Tcfg	EIA 2012a
Coal		
In Place Federal Coal Resources	957,000 MST	USDA, DOE, DOI 2007
Federal Recoverable Coal Reserves	87,000 MST	National Mining Association 2012
Total U.S. Recoverable Reserves	256,000 MST	EIA 2012b
2013 Leased Coal Acres	474,025 acres	BLM 2014b
2013 Coal Production	422.25 MST	ONRR 2013
Oil Shale		
Available Area According to ROD – UT*	360,400 acres	BLM ROD 2013
Available Area According to ROD – CO*	26,300 acres	BLM ROD 2013
Available Area According to ROD – WY*	292,000 acres	BLM ROD 2013
Average Resource – UT	74,093 bbl/acre	BLM OSTS 2012
Average Resource – WY	120,117 bbl/acre	BLM OSTS 2012
Average Resource – CO	300,000 bbl/acre	Mercier, et al. 2010
Resource Available in Piceance Basin	284,800 MMBbls	USGS 2010
Resource Available in Green River and Washakie Basins	72,179 MMBbls	USGS 2011
Resource Available in Uinta Basin	26,699 MMBbls	BLM OSTS 2012; BLM ROD 2013
Available Under RD&D Leases	5,938 MMBbls	DOE/BLM 2013
Tar Sands		
In Place Tar Sands Resources	54,095 MMBbls	USGS 2006
Federal Ownership of Utah Tar Sands	58%	Keiter et al. 2011
Federal Ownership of Other Tar Sands	28%	Gorte et al. 2012
Lease Available STSAs*	4,125 MMBbls	BLM OSTS 2012

Table A11. Fossil fuel amounts and sources

* “Lease-available” federal fossil fuels are unleased federal fossil fuels that are available for leasing under current federal policies and plans.

End-use Product / Sector	Key Parameter(s) for Influencing Low, Median, High Emissions Scenarios	Life-Cycle Emissions Factor Source(s) Used
Crude Oil		
Gasoline	Associated gas venting and flaring; vehicle end-use efficiency	Burnham et al. 2012
Distillate Fuel Oil	Extraction and transport	NETL 2008, 2009 as cited in US DOS 2014
Kerosene	Extraction and transport	NETL 2008, 2009 as cited in US DOS 2014
Liquefied Petroleum Gases (LPG)	Extraction and transport	Venkatesh et al. 2010
Petroleum Coke	Extraction and transport	Venkatesh et al. 2010
Still Gas	Extraction and transport	Venkatesh et al. 2010
Residual Fuel Oil	Extraction and transport	Venkatesh et al. 2010
Natural Gas		
Residential	Liquid unloadings (venting); well equipment (leakage and venting); transmission and distribution (leakage and venting)	Burnham et al. 2012
Commercial	Liquid unloadings (venting); well equipment (leakage and venting); transmission and distribution (leakage and venting)	Burnham et al. 2012
Industrial	Liquid unloadings (venting); well equipment (leakage and venting); transmission and distribution (leakage and venting)	Burnham et al. 2012
Electric Power	Power conversion efficiency	Heath et al. 2014
Transportation	Liquid unloadings (venting); well equipment (leakage and venting); transmission and distribution (leakage and venting)	Burnham et al. 2012
Coal		
Electric Power	Transmission and distribution losses; power conversion efficiency; coal mine methane	Whitaker et al. 2012
Coke		EPA 2004
Other Industrial Use		Whitaker et al. 2012
	Transmission and distribution losses; power conversion efficiency; coal mine methane	
Oil Shale		
Gasoline	Retorting; upgrading; refining	Brandt 2009
Distillate Fuel Oil	Retorting; upgrading; refining; extraction	Brandt 2009; Burnham et al. 2012; NETL 2008, 2009 as cited in US DOS 2014
Liquefied Petroleum Gases (LPG)	Retorting; upgrading; refining; extraction; transport	Brandt 2009; Burnham et al. 2012; Venkatesh et al. 2010

Kerosene	Retorting; upgrading; refining; extraction; transport	Brandt 2009; Burnham et al. 2012; NETL 2008, 2009 as cited in US DOS 2014
Petroleum Coke	Retorting; upgrading; refining; extraction; transport	Brandt 2009; Burnham et al. 2012; Venkatesh et al. 2010
Still Gas	Retorting; upgrading; refining; extraction; transport	Brandt 2009; Burnham, et al. 2012; Venkatesh et al. 2010
Residual Fuel Oil	Retorting; upgrading; refining; extraction; transport	Brandt 2009; Burnham et al. 2012; Venkatesh et al. 2010
Tar Sands		
Gasoline	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	Jacobs 2009, NETL 2008, 2009, and TIAX 2009 as cited in DOS 2014
Distillate Fuel Oil	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	Jacobs 2009, and NETL 2008, 2009 as cited in DOS 2014
Liquefied Petroleum Gases (LPG)	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	Jacobs 2009, NETL 2008, 2009, and TIAX 2009 as cited in US DOS 2014; Venkatesh et al. 2010
Kerosene	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	NETL 2008, 2009 as cited in DOS 2014
Petroleum Coke	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	Jacobs 2009, NETL 2008, 2009, and TIAX 2009 as cited in DOS 2014; Venkatesh et al. 2010
Still Gas	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	Jacobs 2009, NETL 2008, 2009, and TIAX 2009 as cited in DOS 2014; Venkatesh et al. 2010
Residual Fuel Oil	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	Jacobs 2009, NETL 2008, 2009, and TIAX 2009 as cited in DOS 2014; Venkatesh et al. 2010

Table A12. End-use products/sectors and life-cycle emissions factor sources

Crude Oil End-use Product	Proportion of Resource Used as Input for End-use Product	Carbon Storage Factor	Low Emissions Factor	Median Emissions Factor	High Emissions Factor	Primary Energy Factor
Finished Motor Gasoline	46.46%	0.00	86 tons CO_2e / TJ Fuel Combusted	92 tons CO_2e / TJ Fuel Combusted	98 tons CO_2e / TJ Fuel Combusted	1.19
Distillate Fuel Oil	17.92%	0.50	89 tons CO_2e / TJ Fuel Combusted	90 tons CO_2e / TJ Fuel Combusted	96 tons CO_2e / TJ Fuel Combusted	1.16
Kerosene	7.51%	0.00	86 tons CO_2e / TJ Fuel Combusted	88 tons CO_2e / TJ Fuel Combusted	91 tons CO_2e / TJ Fuel Combusted	1.21
Liquefied Petroleum Gases	12.75%	0.59	80 tons CO_2e / TJ Fuel Combusted	88 tons CO_2e / TJ Fuel Combusted	100 tons CO_2e / TJ Fuel Combusted	1.15
Petroleum Coke	1.87%	0.30	130 tons CO_2e / TJ Fuel Combusted	144 tons CO_2e / TJ Fuel Combusted	160 tons CO_2e / TJ Fuel Combusted	1.05
Still Gas	3.72%	0.59	78 tons CO_2e / TJ Fuel Combusted	87 tons CO_2e / TJ Fuel Combusted	100 tons CO_2e / TJ Fuel Combusted	1.09
Residual Fuel Oil	1.70%	0.00	88 tons CO_2e / TJ Fuel Combusted	95 tons CO_2e / TJ Fuel Combusted	110 tons CO_2e / TJ Fuel Combusted	1.19
Asphalt*	1.71%	1.00		--		--
Other Oils	0.56%	1.00		--		--
Lubricants	0.64%	1.00		--		--
Other	5.16%	1.00		--		--

Table A13. Crude oil end products and emissions factors

Natural Gas End-use Sector (product)	Proportion of Resource Used as Input for End-use Product	Primary Energy Yield Factor	Low Emissions Factor	Median Emissions Factor	High Emissions Factor	Primary Energy Factor
Residential (CHP)	18.76%	100%	72 tons CO_2e / MJ of fuel combusted	76 tons CO_2e / MJ of fuel combusted	81 tons CO_2e / MJ of fuel combusted	1.092
Commercial (CHP)	12.44%	100%	72 tons CO_2e / MJ of fuel combusted	76 tons CO_2e / MJ of fuel combusted	81 tons CO_2e / MJ of fuel combusted	1.092
Industrial (CHP)	34.14%	100%	72 tons CO_2e / MJ of fuel combusted	76 tons CO_2e / MJ of fuel combusted	81 tons CO_2e / MJ of fuel combusted	1.092
Electric Power (kWh)	31.69%	43.39%	117 tons CO_2e / MJ of fuel combusted	125 tons CO_2e / MJ of fuel combusted	180 tons CO_2e / MJ of fuel combusted	1.092
Transportation (km-travelled)	2.98%	100%	210 grams CO_2e / km travelled	230 grams CO_2e / km travelled	250 grams CO_2e / km travelled	1.092

Table A14. Natural gas end-use sectors and factors

Coal End-use Sector (product)	Proportion of Resource Used as Input for End-use Product	Primary Energy Yield Factor	Low Emissions Factor	Median Emissions Factor	High Emissions Factor	Primary Energy Factor
Electric Power (kWh)	92.78%	31.65%	203 tons CO_2e / TJ of fuel combusted	272 tons CO_2e / TJ of fuel combusted	381 tons CO_2e / TJ of fuel combusted	1.048
Metallurgical Coke (pig iron)	2.32%	n/a		1.35 tons of CO_2e / ton of pig iron produced		1.167
Other Industrial Use (kWh)	4.89%	31.65%	203 tons CO_2e / TJ of fuel combusted	272 tons of CO_2e / TJ of fuel combusted	381 tons CO_2e / TJ of fuel combusted	1.048

Table A15. Coal end-use sectors and factors

Oil Shale End-use Product	Proportion of Resource Used as Input for End-use Product	Carbon Storage Factor	Low Emissions Factor	Median Emissions Factor	High Emissions Factor	Primary Energy Factor
Finished Motor Gasoline	46.46%	0.00	130 tons CO_2e / TJ Fuel Combusted	141 tons CO_2e / TJ Fuel Combusted	150 tons CO_2e / TJ Fuel Combusted	1.187
Distillate Fuel Oil	17.92%	0.50	135 tons CO_2e / TJ Fuel Combusted	138 tons CO_2e / TJ Fuel Combusted	147 tons CO_2e / TJ Fuel Combusted	1.158
Kerosene	7.51%	0.00	130 tons CO_2e / TJ Fuel Combusted	135 tons CO_2e / TJ Fuel Combusted	139 tons CO_2e / TJ Fuel Combusted	1.205
Liquefied Petroleum Gases	12.75%	0.59	121 tons CO_2e / TJ Fuel Combusted	135 tons CO_2e / TJ Fuel Combusted	153 tons CO_2e / TJ Fuel Combusted	1.151
Petroleum Coke	1.87%	0.30	197 tons CO_2e / TJ Fuel Combusted	221 tons CO_2e / TJ Fuel Combusted	245 tons CO_2e / TJ Fuel Combusted	1.048
Still Gas	3.72%	0.59	118 tons CO_2e / TJ Fuel Combusted	133 tons CO_2e / TJ Fuel Combusted	153 tons CO_2e / TJ Fuel Combusted	1.092
Residual Fuel Oil	1.70%	0.00	133 tons CO_2e / TJ Fuel Combusted	146 tons CO_2e / TJ Fuel Combusted	168 tons CO_2e / TJ Fuel Combusted	1.191
Asphalt	1.71%	1.00		--		--
Other Oils	0.56%	1.00		--		--
Lubricants	0.64%	1.00		--		--
Other	5.16%	1.00		--		--

Table A16. Oil shale end-use products and factors

Tar Sands End-use Product	Proportion of Resource Used as Input for End-use Product	Carbon Storage Factor	Low Emissions Factor	Median Emissions Factor	High Emissions Factor	Primary Energy Factor
Finished Motor Gasoline	46.46%	0.00	106 tons CO_2e / TJ Fuel Combusted	106 tons CO_2e / TJ Fuel Combusted	106 tons CO_2e / TJ Fuel Combusted	1.187
Distillate Fuel Oil	17.92%	0.50	105 tons CO_2e / TJ Fuel Combusted	105 tons CO_2e / TJ Fuel Combusted	105 tons CO_2e / TJ Fuel Combusted	1.158
Kerosene	7.51%	0.00	96 tons CO_2e / TJ Fuel Combusted	102 tons CO_2e / TJ Fuel Combusted	110 tons CO_2e / TJ Fuel Combusted	1.205
Liquefied Petroleum Gases	12.75%	0.59	102 tons CO_2e / TJ Fuel Combusted	102 tons CO_2e / TJ Fuel Combusted	102 tons CO_2e / TJ Fuel Combusted	1.151
Petroleum Coke	1.87%	0.30	156 tons CO_2e / TJ Fuel Combusted	167 tons CO_2e / TJ Fuel Combusted	176 tons CO_2e / TJ Fuel Combusted	1.048
Still Gas	3.72%	0.59	93 tons CO_2e / TJ Fuel Combusted	101 tons CO_2e / TJ Fuel Combusted	110 tons CO_2e / TJ Fuel Combusted	1.092
Residual Fuel Oil	1.70%	0.00	105 tons CO_2e / TJ Fuel Combusted	146 tons CO_2e / TJ Fuel Combusted	121 tons CO_2e / TJ Fuel Combusted	1.191
Asphalt*	1.71%	1.00		--		--
Other Oils*	0.56%	1.00		--		--
Lubricants*	0.64%	1.00		--		--
Other*	5.16%	1.00		--		--

Table A17. Tar sands end-use products and factors

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nature climate change

LETTERS

PUBLISHED ONLINE: 19 DECEMBER 2016 | DOI: 10.1038/NCLIMATE3186

Equitable mitigation to achieve the Paris Agreement goals

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Benchmarks to guide countries in ratcheting-up ambition, climate finance, and support in an equitable manner are critical but not yet determined in the context of the Paris Agreement[1]. We identify global cost-optimal mitigation scenarios consistent with the Paris Agreement goals and allocate their emissions dynamically to countries according to five equity approaches. At the national level, China's Nationally Determined Contribution (NDC) is weaker than any of the five equity approaches, India's and the USA's NDC are aligned with two, and the EU's with three. Most developing countries' conditional (Intended) NDCs (INDCs) are more ambitious than the average of the five equity approaches under the 2 °C goal. If the G8 and China adopt the average of the five approaches, the gap between conditional INDCs and 2 °C-consistent pathways could be closed. For an equitable, cost-optimal achievement of the 1.5 °C target, emissions in 2030 are 21% lower (relative to 2010) than for 2 °C for the G8 and China combined, and 39% lower for remaining countries. Equitably limiting warming to 1.5 °C rather than 2 °C requires that individual countries achieve mitigation milestones, such as peaking or reaching net-zero emissions, around a decade earlier.

To achieve its global mitigation objectives (Fig. 1a), the Paris Agreement binds countries to periodically take stock of collective progress 'in light of equity and the best available science'[1], starting in 2018. The Agreement did not indicate national mitigation targets aligned with the long-term goals and Parties note 'with concern that the estimated aggregate greenhouse gas emissions levels in 2025 and 2030 resulting from the intended nationally determined contributions do not fall within cost-optimal 2 °C scenarios'[1]. Indeed, the current 'bottom-up' situation, whereby countries determine their own mitigation targets, results in projected annual global emissions of 52.5 $GtCO_2eq$ (ref. 2) in 2030 (average of 49.4 $GtCO_2eq$ and 55.6 $GtCO_2eq$, respectively the 'high-ambition' and 'low-ambition' estimates of ref. 3, SAR GWP-100, Methods), inconsistent with Integrated Assessment Models' (IAMs) cost-optimal trajectories to 2 °C or 1.5 °C (ref. 4, Fig. 1a).

In 1992, under the United Nations Framework Convention on Climate Change (UNFCCC), all countries agreed to pursue mitigation efforts according to their 'Common but Differentiated Responsibilities and Respective Capabilities'[5] (CBDR-RC), with efforts differentiated between developed (Annex I) and developing countries. The Paris Agreement moved to a sliding scale of self-differentiation on emissions mitigation. While co-benefits and self-interest can drive rapid mitigation actions[6], current contributions are insufficient to match the ambition of the Paris Agreement. Therefore, equity is still central for the ratcheting process and when discussing the adequate magnitude of climate finance and support[7]. All ratifying Parties must communicate successive NDCs that represent a progression and reflect the 'highest possible ambition' in relation to their CBDR-RC[1]. The Paris Agreement still invites developed countries, without naming them[8], to take the lead in reducing economy-wide emissions and mobilizing climate finance.

Historically, few countries have indicated which guiding principle[9–11] or formula[12] could be used to ensure equitable mitigation contributions. Instead, most countries merely declared their INDCs to be 'fair and ambitious', either explicitly (for example, India and the USA[13]) or implicitly by stating their contribution. Here we inform the question of fairness by quantifying national emissions allocations using five 'equity approaches'. Unlike most earlier studies, we use a methodology that aligns aggregate emissions allocations with IAM global emissions scenarios that are consistent with the Paris Agreement's long-term goals.

Several studies have modelled equity principles to allocate 2 °C-consistent emissions scenarios across countries[12,14–24]. The Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report (IPCC-AR5) grouped the distributive justice concepts of over 40 studies into five equity categories[18,25] (Table 1). Most of these studies allocate emissions of different global scenarios that are not always cost-optimal; comparing allocations at a specific point in time is therefore difficult. More recent studies developed frameworks that allocate emissions from a unique global scenario across countries following multiple equity approaches, and derived national greenhouse gas[21,24] (GHG) or CO_2-only[20,23] scenarios consistent with the 2 °C limit. However, national equitable emissions allocations consistent with the 1.5 °C goal have not yet been assessed in the literature.

We use the five IPCC-AR5 equity categories[25] to define five equity approaches[24] (Table 1). These allocation approaches are applied to cost-optimal scenarios selected from the database accompanying the IPCC-AR5 and ref. 26 that have net-zero emissions by 2100 and at least a likely (>66%) chance of limiting warming to 2 °C (Methods). We explore five 'sets' of GHG emissions scenarios based on this selection (Table 1): (i) 32 scenarios peaking by 2020 ('2 °C-pre2020peak'), (ii) 39 peaking by 2020 with a more likely than not (>50%) chance of returning to 1.5 °C in 2100 ('1.5 °C-pre2020peak'), (iii) 6 scenarios peaking in 2030 ('2 °C-2030peak'), (iv) a custom '2 °C-statedINDC' scenario with interpolated emissions between 2030 pledged INDC levels[3] and, from 2050 onwards, the average of the '2 °C-2030peak' scenarios, and (v) a '2 °C-fairINDC' scenario equal to global scenario (iv) but with allocations starting in 2010 (Fig. 1a). The '2 °C-2030peak' scenarios are only loosely consistent with the Paris Agreement

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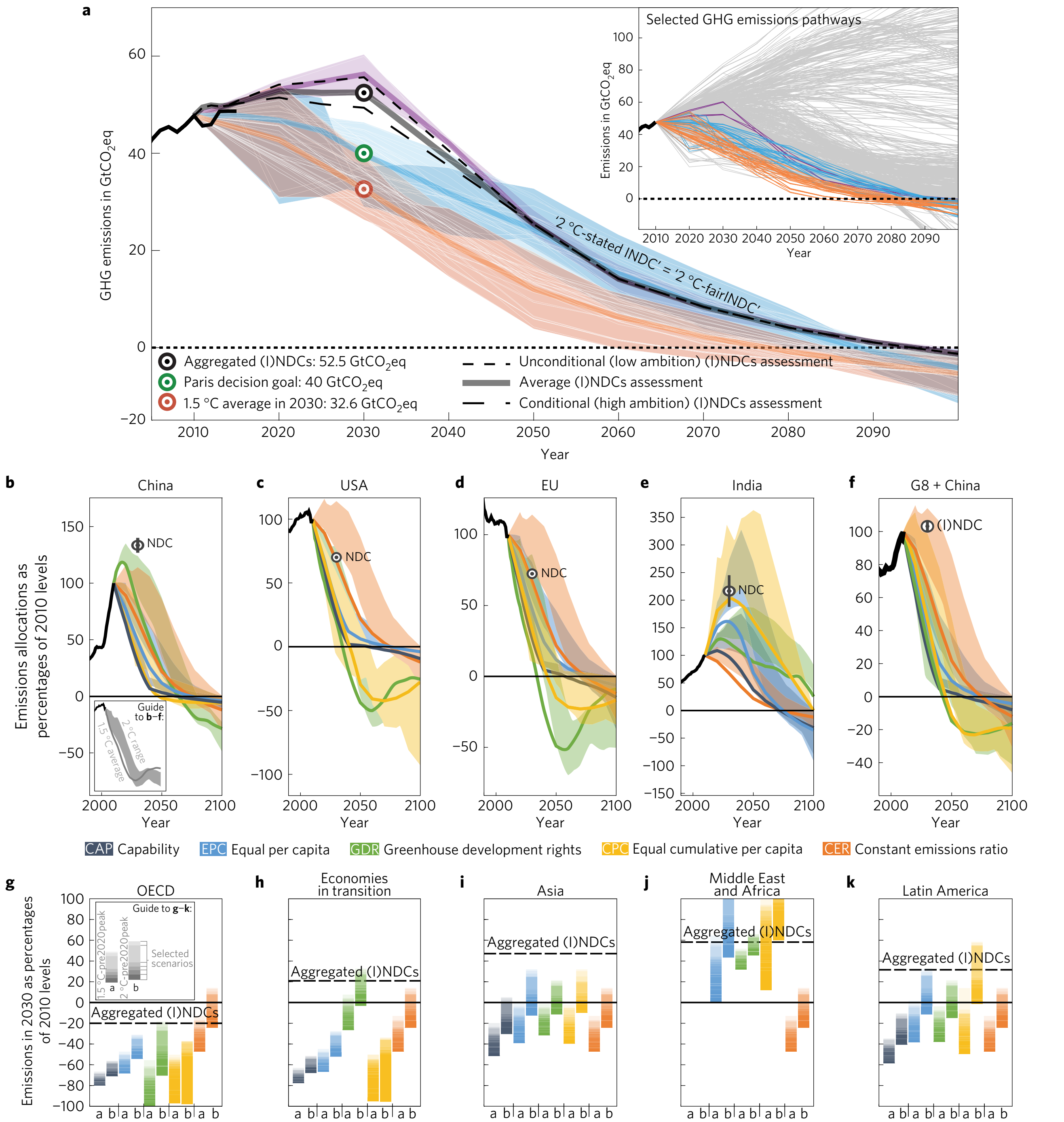

Figure 1 | Global, national and regional emissions consistent with the Paris Agreement and five equity principles compared with current pledges. **a**, IAM scenarios consistent with the Paris Agreement under '1.5 °C-pre2020peak' (red), '2 °C-pre2020peak' (blue) and '2 °C-2030peak' cases (purple), and their averages (thicker lines). Scenarios consistent with the 2030 Paris decision target (green circles) are more opaque. Inset, comparison with IPCC-AR5 database scenarios (grey lines). **b**–**f**, National emissions allocations excluding LULUCF compared with (I)NDCs (black circles). Coloured patches and lines show allocation ranges of global '2 °C-pre2020peak' scenarios, and averages over the range of global '1.5 °C-pre2020peak' scenarios, respectively. **g**–**k**, Regionally aggregated 2030 allocations for '1.5 °C-pre2020peak' and '2 °C-pre2020peak' scenarios compared with aggregated (I)NDCs.

(Methods). Emissions allocations of all sets start in 2010, except for (iv), which starts in 2030 at national (I)NDCs levels.

The '2 °C-pre2020peak' scenario set has a 2030 average of 39.7 $GtCO_2eq$, similar to the Paris decision indicative target of 40 $GtCO_2eq$, and becomes net zero as early as 2080 (Fig. 1a). The '1.5 °C-pre2020peak' set averages at 32.6 $GtCO_2eq$ in 2030 and becomes negative between 2059 and 2087. Average annual global emissions reduction rates over the 2030–2050 period, as a fraction of 2010 levels, are 1.6% yr^{-1} for early-action '2 °C-pre2020peak' scenarios (reaching 2.1% yr^{-1} in 2025), 2.2% yr^{-1} for 1.5 °C scenarios (reaching 2.3% yr^{-1} in 2039), and 3.2% yr^{-1} for delayed-action '2 °C-2030peak' scenarios (reaching 3.5% yr^{-1} from 2040 to 2050).

The selected cost-optimal scenarios rely on the IAM's assumptions of harmonized international policies and emissions trading systems that are currently not in place. However, the Paris Agreement has recognized the voluntary 'use of internationally transferred mitigation outcomes towards nationally determined contributions'[1]. The emissions allocations determined here

Table 1 | Allocation approaches and global scenario set descriptions.

Allocation code	Allocation name	IPCC category	Allocation characteristics
CAP	Capability	Capability	High mitigation for countries with high GDP per capita.
EPC	Equal per capita	Equality	Convergence towards equal annual emissions per person.
GDR	Greenhouse development rights	Responsibility–capability–need	High mitigation for countries with high GDP per capita and high historical per capita emissions.
CPC	Equal cumulative per capita	Equal cumulative per capita	High mitigation for countries with high historical per capita emissions.
CER	Constant emissions ratio	Staged approaches	Maintains current emissions ratios.
Scenario set	**Scenario type**	**IPCC category**	**Scenario characteristics**
1.5 °C-pre2020peak	1.5 °C scenarios	39 P1P2 scenarios	More likely than not (>50%) chance of returning to 1.5 °C in 2100. Global emissions peaking by 2020. National emissions allocated from 2010 onwards.
2 °C-pre2020peak	2 °C early-action scenarios	32 P1P2 scenarios	Likely (>66%) chance of staying below 2 °C by 2100. Global emissions peaking by 2020. National emissions allocated from 2010 onwards.
2 °C-2030peak	2 °C delayed-action scenarios	6 P3 scenarios	Likely (>66%) chance of staying below 2 °C by 2100. Global emissions peaking in 2030. National emissions allocated from 2010 onwards.
2 °C-statedINDC	2 °C delayed-action scenario	1 P3 custom scenario	*De facto* likely (>66%) chance of staying below 2 °C by 2100. Global emissions peaking in 2030. National emissions allocated from 2030 (I)NDC levels onwards.
2 °C-fairINDC	2 °C delayed-action scenario	1 P3 custom scenario	*De facto* likely (>66%) chance of staying below 2 °C by 2100. Global emissions peaking in 2030. National emissions allocated from 2010 onwards.

The allocation framework modelling and parameterization follow those of ref. 24. More details on the scenario selection are in the Supplementary Methods.

Table 2 | Mitigation targets, timing of peaking and net-zero emissions, and emissions budgets of selected countries for the '1.5 °C-pre2020peak' and '2 ° C-pre2020peak' cases, averaged over the five equity allocations.

Country	Goal	2030 change to 2010 levels (in %)	2050 change to 2010 levels (in %)	Peaking year	Net-zero year	Budget to 2050 in $GtCO_2eq$	Budget to 2100 in $GtCO_2eq$
World	2 °C	−5	−47	2020	2082	1,523	1,749
	1.5 °C	−33	−78	Immediate	2075	1,134	1,156
China	2 °C	−27 (−59 to 6)	−70 (−95 to −44)	Immediate	2075	329	345
	1.5 °C	−48 (−71 to −19)	−88 (−102 to −76)	Immediate	2065	254	237
USA	2 °C	−44 (−66 to −5)	−89 (−119 to −47)	Immediate	2067	154	104
	1.5 °C	−64 (−80 to −33)	−109 (−144 to −78)	Immediate	2057	109	57
EU	2 °C	−38 (−62 to −5)	−86 (−122 to −47)	Immediate	2068	114	94
	1.5 °C	−62 (−84 to −33)	−106 (−149 to −78)	Immediate	2057	80	54
India	2 °C	72 (−5 to 155)	40 (−47 to 152)	2033	2087	162	236
	1.5 °C	30 (−33 to 102)	−24 (−78 to 63)	2022	2081	122	161

Target ranges indicate the extrema across the five approaches' averages. Emissions from LULUCF and bunkers are excluded. Data for all countries are available in the Supplementary Tables. Emissions budgets are accounted from 2010.

could be met through a combination of domestic mitigation, internationally traded emissions mitigation[1] and international financial contributions toward global mitigation[24]. Under any of our modelled equity approaches, the national emissions scenarios are not cost-optimal if applied domestically. However, they are consistent with a global cost-optimal scenario if countries choose the right mix of domestic mitigation and transfer of support for additional mitigation elsewhere. National mitigation costs are allocated indirectly through the allocation of emissions allowances. A fair distribution of mitigation costs could be used to derive equitable emissions allocations when comprehensive national-level mitigation cost estimates are available.

We allocate to all countries GHG emissions scenarios that add up, under each of the five equity approaches (Supplementary Tables), to global cost-optimal IAM scenarios—excluding emissions from Land Use, Land-Use Change and Forestry (LULUCF), and international shipping and aviation (Methods).

At the regional level (Fig. 1g–k), Middle East and Africa's aggregated (I)NDCs are consistent with all approaches except the constant emissions ratio (CER) under all scenario sets. Asia's aggregated (I)NDCs are not consistent with any allocation under early-action scenarios, while the Organisation for Economic Co-operation and Development's (OECD's) are consistent with the greenhouse development rights (GDR) and CER under the '2 °C-pre2020peak' and with none under '1.5 °C-pre2020peak'. Only the aggregated (I)NDCs of the Middle East and Africa are consistent with some 1.5 °C allocations (with great disparities at the sub-regional level, Supplementary Discussion).

At the national level (Fig. 1b–f), all equity approaches require China's emissions to peak earlier and lower than its current NDC. The USA's and the EU's NDCs are in line with the CER allocation and just within the '2 °C-pre2020peak' range under the GDR. The EU's NDC is also within the equal per capita (EPC) range. India's NDC is consistent with the equal cumulative per capita (CPC) and

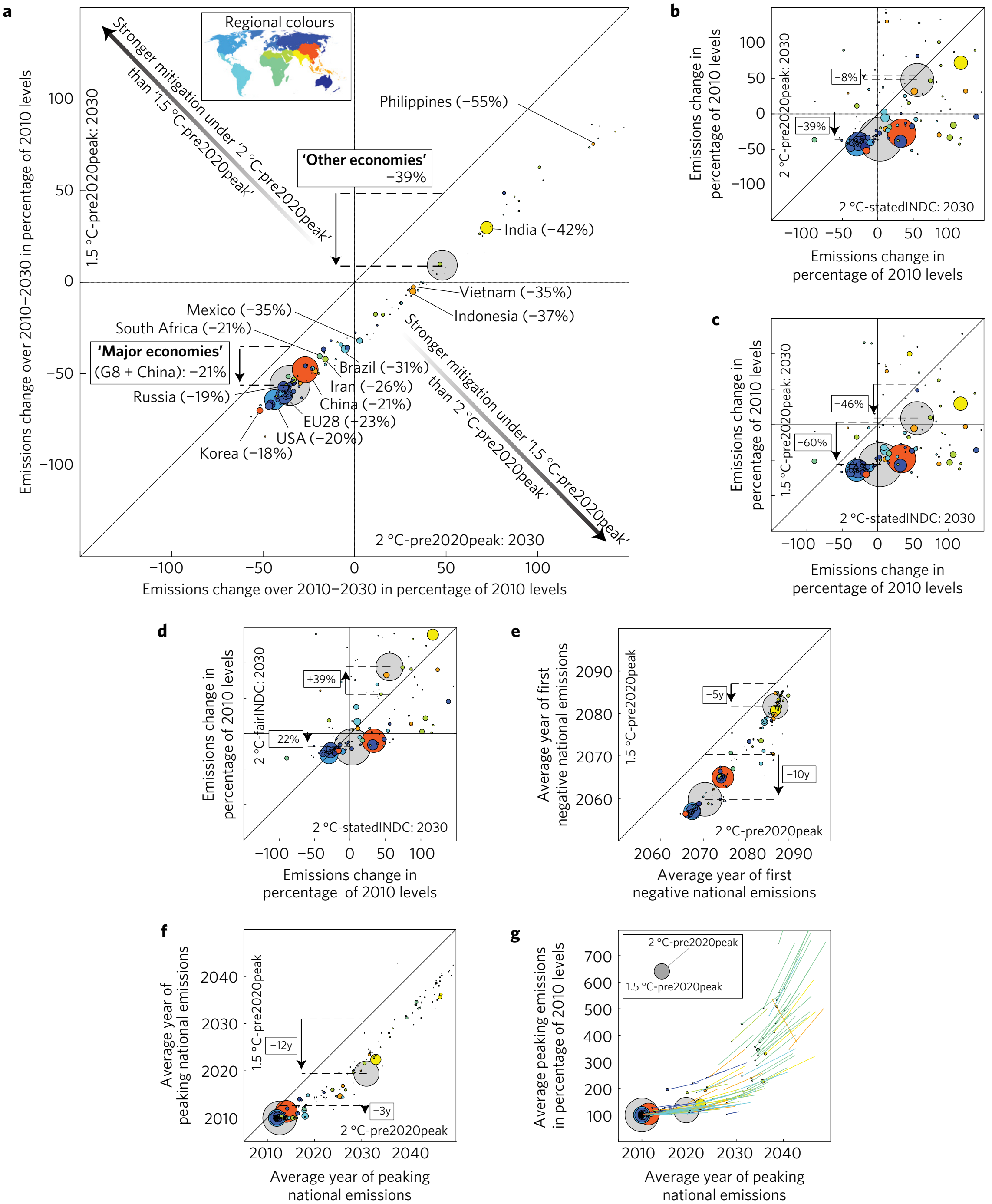

Figure 2 | Comparisons of national emissions change under different global goals. a–d, Relative changes between '1.5 °C-pre2020peak', '2 °C-pre2020peak', '2 °C-statedINDC' and '2 °C-fairINDC' cases over the 2010–2030 period (excluding LULUCF). **e**,**f**, Comparison of timing of first net-zero emissions and peaking national emissions averaged over the five equity approaches for the '1.5 °C-pre2020peak' and '2 °C-pre2020peak' cases. **g**, Average of peaking emissions levels versus average peaking emissions years for '1.5 °C-pre2020peak' and '2 °C-pre2020peak' cases. Disc sizes are proportional to 2010 emissions levels. Colours indicate world regions. G8+China (larger disc) and the rest of the world (smaller disc) are shown in grey.

EPC allocations of '2 °C-pre2020peak' scenarios, and the CPC allocation averaged over the '1.5 °C-pre2020peak' scenarios lies within the NDC assessment's uncertainty range (other countries in Supplementary Tables and provided at: www.paris-equity-check.org).

Combining multiple visions of equity—using weighting factors[20] or a leadership-based approach[22]—is not necessarily equitable by design but can represent a political compromise[20], and is useful to compare national allocations under different global goals or scenario sets. The fairness of the CER, or 'grandfathering', approach is criticized in the literature[23,27] and not supported as such by any Party. However, we include CER in the average because it represents one of the five IPCC equity categories, stressing national circumstances regarding current emissions levels, and is implicitly followed by many of the developed countries[23,24]. The average allocation of the EU and the USA becomes negative soon after mid-century under both the '1.5 °C-pre2020peak' and '2 °C-pre2020peak' sets. China's average allocation becomes negative 10 years later, and India's only at the end of the century (Table 2).

Recent studies using alternative implementation[24] or modelling[21,22] of similar equity approaches towards 2 °C find

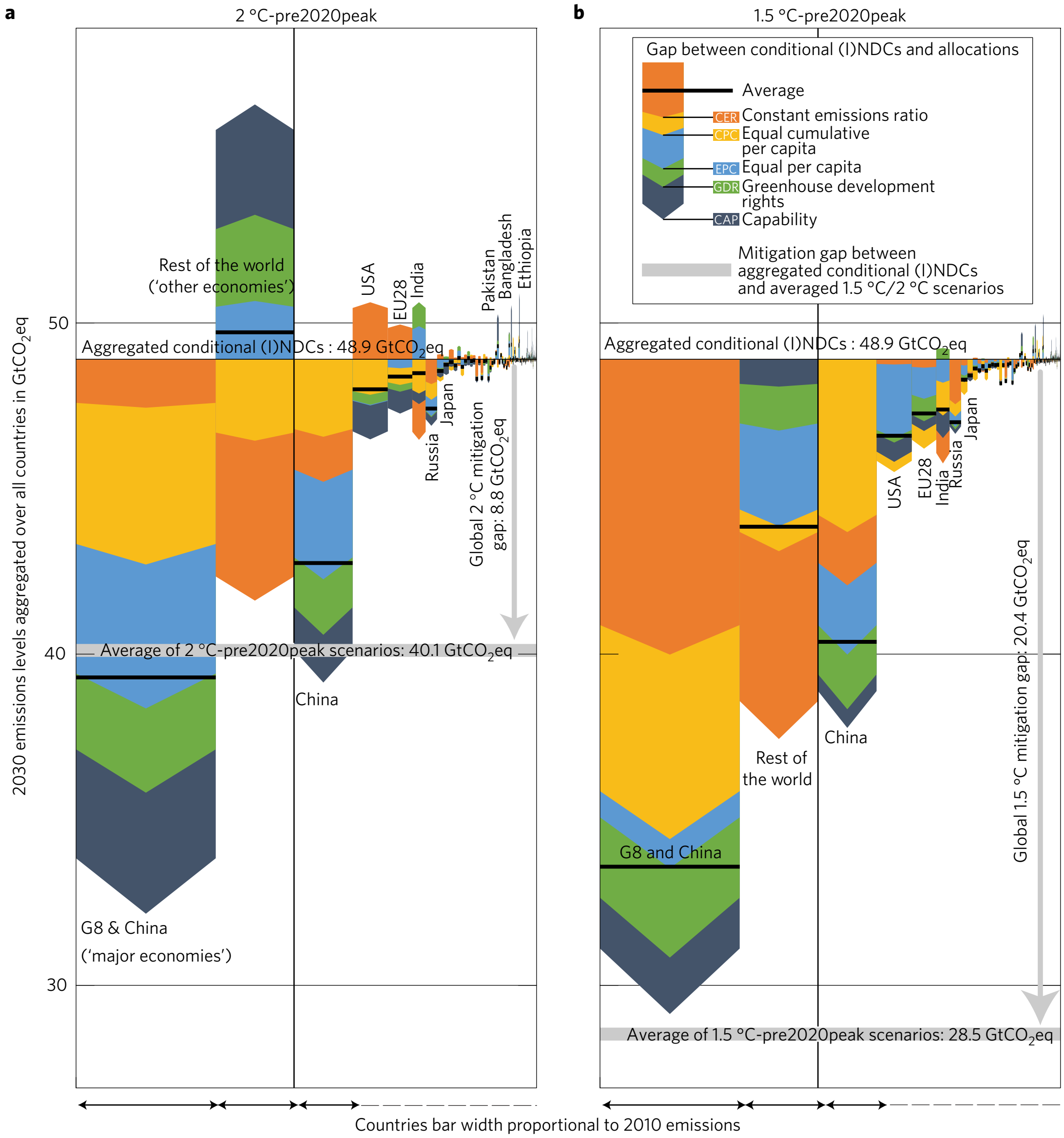

Figure 3 | Gaps between equitable mitigation allocations and conditional (I)NDCs in 2030. a,**b**, Countries following individual approaches (tip of coloured patches), or their average (black lines) under the 2 °C (**a**) or 1.5 °C goals (**b**), reduce or increase the projected 2030 global emissions levels (excluding LULUCF and bunker emissions) compared with aggregated conditional (I)NDCs. Countries are sorted left to right in decreasing order of 2010 emissions (proportional to bar width). The global gaps (grey arrow) between current aggregated conditional (I)NDCs and the average scenarios consistent with the Paris 2 °C or 1.5 °C goals (grey bar) are shown in each panel.

significant differences in some national emissions allocations, but generally reach similar conclusions (Supplementary Discussion). Overall, literature focusing on CO_2 emissions *de facto* ignores other GHGs[20,23], and often allocates carbon budgets[20] impossible to compare with single-year (I)NDCs.

Reflecting the global goals, equitable national allocations towards 1.5 °C require earlier mitigation than for 2 °C (Fig. 2, results per-approach in the Supplementary Discussion). To achieve the 1.5 °C goal 'major economies' (G8 and China as a group) need to lower their 2030 emissions targets by an additional 21 percentage points relative to 2010 emissions, compared with the '2 °C-pre2020peak' case, and other countries ('other economies') altogether by 39 additional percentage points (Fig. 2a). However, increasing current (I)NDCs by these additional percentages would not result in fair contributions towards the 1.5 °C goal. Indeed, the aggregated (I)NDCs of the 'major economies' should already be 39 percentage points more stringent than they currently are to be in line with their averaged allocation under the '2 °C-pre2020peak' case (Fig. 2b). In contrast, the aggregated (I)NDCs of the 'other economies' are only 8 percentage points above '2 °C-pre2020peak' average allocations. Consequently, pledges in line with the 1.5 °C goal should be respectively 60 and 46 percentage points more stringent than current (I)NDCs for 'major economies' and 'other economies' respectively (Fig. 2c).

To compare the relative fairness of (I)NDCs under the current global ambition (52.5 $GtCO_2eq$ for 2030), we compare (I)NDCs ('2 °C-statedINDC' set) with the '2 °C-fairINDC' allocations (Fig. 2d). We find that the (I)NDCs of 'other economies', the USA, and the EU are more ambitious or aligned with their average allocation under current international 2030-ambition, while the (I)NDCs of Canada, Japan, and especially Russia and China are substantially less ambitious.

Emissions budgets and timings of when peaking or net-zero emissions may constitute more easily actionable targets than temperature goals[28]. Figure 2e–g compares the average timing of when emissions allocations peak or reach net zero under the five equity approaches for '1.5 °C-pre2020peak' and '2 °C-pre2020peak'. Net-zero emissions are allocated five years earlier for 1.5 °C for developing countries, and ten years earlier for developed countries (that is, around 2055–2060). Developing countries' allocations peak about ten years earlier and up to 40% lower for 1.5 °C than 2 °C, which implies lower domestic emissions or lower revenues from emissions trading. Overall, aiming at 1.5 °C rather than towards 2 °C requires earlier but not faster or deeper mitigation at the national level (Supplementary Discussion).

The lower emissions end of our (I)NDC quantification ('high-ambition' target) is set by the conditional targets and sometimes by the quantification uncertainty. Hence, in most countries, these 'high-ambition' targets have implicitly been identified as feasible. The implementation of these 'high-ambition' (I)NDCs[3] would lead to 2030 emissions of 48.9 $GtCO_2eq$ and leave an 8.8 $GtCO_2eq$ gap with the average of '2 °C-pre2020peak' scenarios and a 20.4 $GtCO_2eq$ gap with the '1.5 °C-pre2020peak' average (excluding LULUCF and bunkers emissions, Methods). The aggregated 'high-ambition' (I)NDCs of 'other economies' are collectively slightly more ambitious than the average of their 2 °C allocations (Fig. 3 and Supplementary Discussion), although some individual (I)NDCs are less ambitious (for example, Iran, Saudi-Arabia and Turkey). Therefore, the 'other economies' altogether could meet their average 'fair' allocation by increasing their current unconditional contribution to the aggregate level of their conditional (I)NDCs. The average 'fair' allocations of 'major economies' is 9.6 $GtCO_2eq$ below their current aggregated 'high-ambition' (I)NDCs. Put simply, the average 'fair' allocation of 'major economies' alone closes the global 2030 mitigation gap to 2 °C, provided that other countries achieve their 'high-ambition' (I)NDC targets. Closing the 2030 gap to average '1.5 °C-pre2020peak' scenarios requires most countries to increase their ambition beyond their current conditional (I)NDCs.

Current aggregate (I)NDCs fall substantially short of meeting either the 2 °C or 1.5 °C goals[2,4]. The ratchet mechanisms established by the Paris Agreement[1] need to achieve an additional 13 $GtCO_2eq$ reduction in 2030 to align with 2 °C cost-optimal scenarios, and 20 $GtCO_2eq$ for 1.5 °C (Fig. 1a). We derived 'Equitably Determined Contributions' consistent with the five IPCC equity approaches towards 2 °C or 1.5 °C goals (Supplementary Tables). Averaging across the five concepts of equity assigns the effort required to close the gap between current conditional (I)NDCs and the 2 °C goal solely to the G8 and China. Equitably meeting the 1.5 °C goal, and avoiding the additional climate impacts of a 2 °C warmer world[29], means that almost all national contributions should be enhanced substantially, with key milestones, such as peaking or reaching net-zero emissions, brought forward by a decade or more.

Methods

Methods and any associated references are available in the online version of the paper.

Received 4 July 2016; accepted 21 November 2016; published online 19 December 2016; corrected after print 1 February 2017

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Acknowledgements

We gratefully acknowledge the work of modellers behind the IPCC-AR5 emissions scenarios. M. Meinshausen is supported by the Australian Research Council (ARC) Future Fellowship (grant number FT130100809). Deep thanks to A. Talberg for her comments on the manuscript.

Author contributions

All authors contributed to discussing the results and writing the manuscript. Y.R.d.P. led the study and performed the calculations. M.L.J. modelled the GDR approach. J.G. downscaled to the national-level global RCP8.5 emissions scenarios using SSP data. Y.R.d.P. and M.M. suggested the study. J.G., M.L.J. and M.M. updated and managed the composite PRIMAP database.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to Y.R.d.P.

Competing financial interests

The authors declare no competing financial interests.

Methods

The equitable emissions allocations of all countries are included in the Supplementary Tables in the online version of the paper and can be visualized at: www.paris-equity-check.org.

Scenario selection. We selected global emissions scenarios from the IPCC-AR5 database (hosted at the International Institute for Applied Systems Analysis and available at: https://tntcat.iiasa.ac.at/AR5DB) and ref. 26 that feature negative GHG emissions by the end of the century and a chance higher than 66% of limiting global warming to 2 °C over the entire twenty-first century, or higher than 50% of returning to 1.5 °C in 2100, compared with pre-industrial levels.

IPCC-AR5 scenarios. The temperature likelihood response to 524 of these 846 Kyoto-GHG scenarios from the IPCC-AR5 database was projected using the simple carbon cycle and climate model MAGICC6[30,31], under a probabilistic set-up[32] (data visualization available at: https://www.pik-potsdam.de/paris-reality-check/ar5-scenario-explorer). First, we selected from the database 155 scenarios that have net negative emissions in 2100. Of these 155 scenarios, a sub-selection was made of the 40 scenarios with a likely (>66%) chance of staying below 2 °C throughout the twenty-first century. Of these 40 scenarios, 2 had a more likely than not (>50%) chance of resulting in a warming below 1.5 °C in 2100. The numbers of scenarios matching each or a combination of these three criteria—negative emissions in 2100, 2 °C (>66% over 2010–2100) and 1.5 °C (>50% in 2100)—are shown in Supplementary Table 1 (Supplementary Information). All the selected scenarios that have a more likely than not chance of warming being below 1.5 °C in 2100 also have a likely chance of remaining below 2 °C over the 2010–2100 period. Only 2 of the 5 scenarios that have a more likely than not chance of being below 1.5 °C in 2100 also have negative emissions in 2100. The model and study names of these scenarios are shown in Supplementary Table 2.

The '2 °C-2030peak' scenarios have higher emissions levels than the '2 °C-pre2020peak' but still have a likely chance of limiting warming to 2 °C and do not result in higher maximal temperatures over the century. However, these '2 °C-2030peak' scenarios are from the MERGE-ETL_ 2011 model (Supplementary Information) that uses exogenous sulfate forcing[33] and feature higher SO_2—an aerosol with a cooling effect—concentrations than other IPCC-AR5 Working Group 3 scenarios[34]. These aerosol emissions are outside the ranges consistent with the underlying CO_2 path[35]. Moreover, the '2 °C-2030peak' scenarios do not peak as soon as possible, as defined in Article 2 of the Paris Agreement[1].

Additional 1.5 °C scenarios. To this selection of 40 IPCC-AR5 scenarios, we added the 37 scenarios from ref. 26 that have a more likely than not (>50%) chance of having warming below 1.5 °C in 2100. All of these scenarios have negative emissions in 2100. These 37 scenarios are from the MESSAGE or REMIND modelling frameworks and the scenario names and descriptions are available in Table 4 of the Supplementary Information of ref. 26.

The average of all selected 1.5 °C scenarios that peak between 2010 and 2020 is 32.6 $GtCO_2$eq in 2030. The UNEP gap report[36] identified a 39 $GtCO_2$eq goal for 2030, which corresponds to the median of the 1.5 °C scenarios (from the same source as our study) with emissions peaking only in 2020.

(I)NDC scenario. In addition to the selected emissions scenarios, we construct a global emissions scenario that is in line with current aggregated (I)NDC targets. Between 2010 and 2030, this global '2 °C-statedINDC' scenario follows the global emissions from the '(I)NDC factsheets'[3] (for 'high-ambition' or 'low-ambition' assessments, and the average of both), which include emissions projections of all countries, national Land Use, Land-Use Change and Forestry (LULUCF), and international shipping and aviation emissions ('bunker emissions') until 2030. Beyond 2030, the global '2 °C-statedINDC' emissions are a 20-year linear interpolation to reach the level of the average of the global '2 °C-2030peak' scenarios (including LULUCF emissions). Beyond 2050, the global '2 °C-statedINDC' scenario follows the average of global '2 °C-2030peak' scenarios. The '2 °C-statedINDC' scenario is expected to have a likely chance of limiting global warming to 2 °C—with the same limitations regarding SO_2 concentrations as the '2 °C-2030peak' scenarios. Indeed, the '2 °C-statedINDC' scenario (whether it follows the INDC's 'high-ambition', 'low-ambition' assessments, or the average of both) has lower emissions than the average of '2 °C-2030peak' scenarios until 2050, and is equal to the average of '2 °C-2030peak' scenarios beyond 2050 (see Fig. 1).

Scenario preparation. We used the Potsdam Real-time Integrated Model for the probabilistic Assessment of emission Paths (PRIMAP)[17] to model allocations approaches. This model contains population, GDP, and GHG emissions historical and projected data from composite sources as detailed in ref. 24.

Kyoto-GHG emissions are aggregated following the 'SAR GWP-100' (Global Warming Potential for a 100 year time horizon) as reported in the Second Assessment Report of the IPCC[37] and used under the UNFCCC.

All these global scenarios, shown in Fig. 1a, are harmonized to the PRIMAP[17] database's 2010 emissions of 47.7 $GtCO_2$eq (including LULUCF, and international shipping and aviation emissions). To do so, emissions are multiplied by a vector that is an interpolation between the 2010 PRIMAP emissions levels divided by the respective 2010 scenarios values, and 1 in 2040 (refs 24,37).

In this study, we allocate emissions of 'bunker-free' scenarios that are in line with the global scenarios selected and constructed as described above, and that exclude LULUCF emissions as follows. Emissions of the LULUCF sector are not considered by all parties as part of the emissions scope to be negotiated. Moreover, no universal accounting method of positive or negative LULUCF emissions is currently in place. Therefore, we exclude LULUCF emissions from the global scenarios before allocating their emissions across countries.

For the IPCC-AR5 scenarios, we excluded the corresponding LULUCF emissions. For the 37 1.5 °C scenarios of ref. 26, where no specific LULUCF emissions were available, we excluded the CO_2 emissions that do not come from fossil fuels combustion. We then subtracted from these IPCC-AR5 and ref. 26 scenarios international shipping and aviation bunker emissions from the QUANTIFY project[38] coherent with the IPCC-SRESB1 scenario that limits global warming to 1.8 °C compared with the 1980–1999 average[24,39]. Shipping emissions are 3.9 times higher in 2100 compared with 2010 levels, and aviation emissions double over that same period, but peak in 2062. While the mitigation targets agreed in Article 4 apply to all GHGs, the Paris Agreement contains no specific reference to bunker emissions. The lack of current policies does not leave ground to project strong mitigation scenarios[40,41]. Lower emissions from this sector would reduce the mitigation burden on all countries.

We also constructed a version of the '2 °C-statedINDC' without bunker and LULUCF emissions following the methodology employed to construct the '2 °C-statedINDC' scenario that includes bunker and LULUCF emissions. This bunker-free '2 °C-statedINDC' emissions scenario is the sum of all national emissions from ref. 3 over the 2010–2030 period. Beyond 2030, the bunker-free '2 °C-statedINDC' emissions follow a 20-year linear interpolation to reach the level of the 2050 average of the bunker-free '2 °C-2030peak' scenarios (excluding bunker and LULUCF emissions). Beyond 2050, the bunker-free '2 °C-statedINDC' scenario follows the average of the bunker-free '2 °C-2030peak' scenarios. The bunker-free '2 °C-statedINDC' scenario is allocated across countries using our allocation framework from 2030 onwards, when countries have the emission level of their (I)NDC target[3]. The '2 °C-fairINDC' global scenario is equal to the '2 °C-statedINDC' scenario, both with and without LULUCF and bunker emissions. At the national level, the emissions allocation of the '2 °C-fairINDC' scenario begins in 2010 and therefore differs from the national emissions of the '2 ° C-statedINDC' scenario.

All these bunker-free scenarios are harmonized to the PRIMAP[17] database's 2010 emissions of 42.5 $GtCO_2$eq (excluding LULUCF, international shipping and aviation emissions). To do so, national emissions are multiplied by a vector that is an interpolation between the 2010 PRIMAP national emissions levels divided by the respective 2010 bunker-free scenarios values, and 1 in 2040 (refs 24,37). These bunker-free scenarios, excluding LULUCF and international shipping and aviation bunker emissions, are shown in Supplementary Fig. 1 (Supplementary Information).

The allocation of the scenarios' bunker-free emissions follows the methodology and the parameterization described in the Supplementary Information of ref. 24. The only exception is the '2 °C-statedINDC' case whose allocation starts in 2030, starting at estimated national (I)NDC levels. All other cases have emissions allocations starting in 2010 at national historical levels[17].

The GDR allocation approach requires business-as-usual emissions projections. We use Representative Concentration Pathway (RCP)8.5, downscaled using the SSP2 scenario (https://tntcat.iiasa.ac.at/SspDb) from the Shared Socioeconomic Pathways framework[42,43]. More details are available in ref. 24. The business-as-usual emissions projections used in the '2 °C-statedINDC' case follow the growth rates of RCP8.5 over the period 2030–2100, starting at national (I)NDC levels in 2030.

The modelling and the parameterization of the equity approaches follow those of a previous study[24]. Notably, a 30-year linear transition period is implemented between national 2010 emissions and the allocations under the capability (CAP) and EPC approaches. Therefore, in 2030 this transition period still slightly favours countries with allocations lower than their 2010 levels—usually developed countries—and slightly disfavours countries with allocations higher than their 2010 levels. Historical emissions are accounted since 1990 under the GDR and CPC approaches. The CPC approach applies a 1.5% annual discount rate to emissions before 2010 and achieves equal cumulative per capita emissions in 2100. The GDR approach allocates emissions reduction, compared with business-as-usual scenarios, to country's citizens earning over US$7,500 (in purchase power parity) annually.

The distribution of regional mitigation action as represented in least-cost mitigation pathways is not necessarily equitable. Our results show how pathways that achieve the global Paris Agreement mitigation goals at lowest cost can be aligned with equity principles at the national scale.

The 2030-(I)NDC assessment in this study is an average of the 'high-ambition' and 'low-ambition' cases from ref. 3, except in Fig. 3, which uses the 'high-ambition' (I)NDC assessment. The 'high-ambition' assessment uses conditional (I)NDCs when available as well as the most ambitious end of the uncertainty associated with the (I)NDC assessment (based on GDP, population, energy demand projections). The 'low-ambition' assessment reflects the lower ambitions end of the uncertainty associated with the assessment of unconditional (I)NDCs. The assessments used in this study[2,3] are based on original (I)NDCs, before their conversion to NDCs.

Countries with missing data. Deriving the CAP and GDR allocations requires national projections of GDP. The PRIMAP database does not contain such projections for all countries due to a lack of available data. Countries with some missing data ('missing countries' whose ISO-Alpha 3 country codes are: 'AFG', 'AGO', 'ALB', 'AND', 'ARE', 'ATG', 'COK', 'DMA', 'FSM', 'GRD', 'KIR', 'KNA', 'LIE', 'MCO', 'MHL', 'MMR', 'MNE', 'NIU', 'NRU', 'PLW', 'PRK', 'QAT', 'SMR', 'SSD', 'SYC', 'TUV', 'ZWE') are mostly developing countries whose emissions allocation could represent a significant fraction of global 2030 emissions, under the CAP allocation in particular given their low GDP per capita (https://www.imf.org/external/pubs/ft/weo/2015/01/weodata/download.aspx). We excluded the countries with missing data from the allocations and the remaining countries share the global 'bunker-free' scenarios' emissions. Figure 3 displays the aggregated conditional (I)NDCs excluding these 'missing countries'. As a consequence, the mitigation gaps between the aggregated (I)NDCs and the aggregated average allocations are affected by the exclusion of countries' 2030 (I)NDC emissions (and is greater or smaller depending on how the sum of average allocations of these countries would compare with the sum of their conditional (I)NDCs). The gap between that sum of all countries' conditional (I)NDCs—49.8 $GtCO_2$eq including the 'missing countries' (51.4 $GtCO_2$eq with bunker emissions), excluding LULUCF emissions—and the sum of available average allocations—40.1 $GtCO_2$eq—would be 9.6 $GtCO_2$eq instead of 8.8 $GtCO_2$eq. As a reminder, the gap between the 'major economies' (G8 plus China) aggregated conditional (I)NDCs and their aggregated allocation is 9.6 $GtCO_2$eq. The conclusions derived from Fig. 3 are still valid in this configuration. Note that the aggregate level of all 'high-ambition' (I)NDCs including LULUCF emissions (including the 'missing countries') is 49.4 $GtCO_2$eq, and 47.8 $GtCO_2$eq excluding bunker emissions.

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Corrigendum: Equitable mitigation to achieve the Paris Agreement goals

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Nature Climate Change **7,** 38–43 (2017); published online 19 December 2016; corrected after print 1 February 2017.

In Fig. 1c of the original version of this Letter, the 2030 assessment of the NDC for the USA was misplotted. This changed the number of equity approaches that the USA's NDC was in line with. The figure and text that referred to the findings of that figure have been updated.

EPA United States Environmental Protection Agency

CLIMATE CHANGE AND SOCIAL VULNERABILITY IN THE UNITED STATES

A Focus on Six Impacts

SEPTEMBER 2021

FRONT MATTER

Acknowledgments

This report was developed by EPA's Office of Atmospheric Programs and contains modeling contributions from Federal agency analysts, academic experts, and consultants, including Industrial Economics, Inc. Support for the report's production was provided by Industrial Economics, Inc. EPA gratefully acknowledges the use of inland flooding risk data from the First Street Foundation.

Peer Review

The methods of the climate change impacts analyses described herein have been peer reviewed in the scientific literature. In addition, this report was peer reviewed by five external and independent experts in a process independently coordinated by ICF International. EPA gratefully acknowledges the following peer reviewers for their useful comments and suggestions: Amit Armstrong, David Hondula, Klaus Moeltner, Colin Polsky, Benjamin Ruddell. The information and views expressed in this report do not necessarily represent those of the peer reviewers, who also bear no responsibility for any remaining errors or omissions. Appendix A provides more information about the peer review.

Recommended Citation

EPA. 2021. Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts. U.S. Environmental Protection Agency, EPA 430-R-21-003. www.epa.gov/cira/social-vulnerability-report

Data Availability

Data used in and generated from the analyses of this report can be accessed on the following website: www.epa.gov/cira/technical-appendices-and-data.

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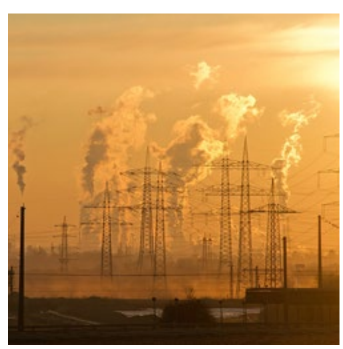
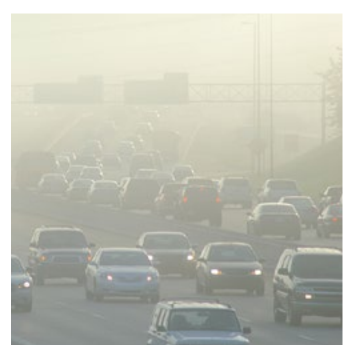




Cover photo credits: Waves in front of houses, AP Photo/Steven Senne; kids in front of fan, AP Photo/Jae C. Hong.

Technical Appendices

Technical appendices that provide detailed documentation and additional results are accessible at https://epa.gov/cira/technical-appendices-and-data. Three additional appendices provide more details on information quality and the peer review process; climate change and social vulnerability; and inputs and projections. Lastly, this website also contains the underlying data and results for each analysis.

EXECUTIVE SUMMARY

Climate change affects all Americans—regardless of socioeconomic status—and many impacts are projected to worsen as temperatures and sea levels continue to rise, snow and rainfall patterns shift, and some extreme weather events become more common.[1] A growing body of literature focuses on the disproportionate and unequal risks that climate change is projected to have on communities that are least able to anticipate, cope with, and recover from adverse impacts. Many studies have discussed climate change impacts on socially vulnerable populations, but few have quantified disproportionate risks to socially vulnerable groups across multiple impacts and levels of global warming.[2,3]

Table ES.1 – Socially Vulnerable Groups Analyzed in this Report

CATEGORY	DEFINITION
Low Income	Individuals living in households with income that is at or below 200% of the poverty level.
Minority	Individuals identifying as Black or African American; American Indian or Alaska Native; Asian; Native Hawaiian or Other Pacific Islander; and/or Hispanic or Latino.
No High School Diploma	Individuals ages 25 and older with a maximum educational attainment of less than a high school diploma or equivalent.
65 and Older	Individuals ages 65 and older.

This report contributes to a better understanding of the degree to which four socially vulnerable populations—defined based on income, educational attainment, race and ethnicity, and age (Table ES.1)—may be more exposed to the highest impacts of climate change in six categories: Air Quality and Health; Extreme Temperature and Health; Extreme Temperature and Labor; Coastal Flooding and Traffic; Coastal Flooding and Property; and Inland Flooding and Property (Figure ES.1).

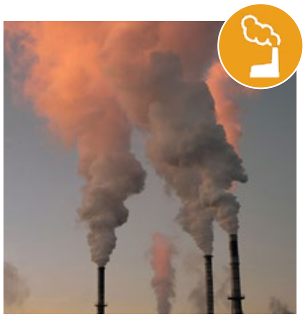
Notes on Terminology

This report adopts the term “minority” for the sake of consistency with government publications and datasets pertaining to environmental justice and climate change. There are important differences, however, in the social vulnerability of the individual communities that are included under the “minority” umbrella. The chapters and appendices of this report therefore include, where possible, results for individual racial and ethnic groups. The report uses the U.S. Census terminology for racial and ethnic groups, as presented in Table ES.1.

Due to data limitations, this report does not analyze the impacts of climate change on socially vulnerable populations living in Hawai’i or Alaska. However, the analyses use demographic data from the U.S. Census which includes individuals living in the contiguous U.S. who identify as “American Indian or Alaska Native” and “Native Hawaiian or Other Pacific Islander.” For more information, please see Appendix C.

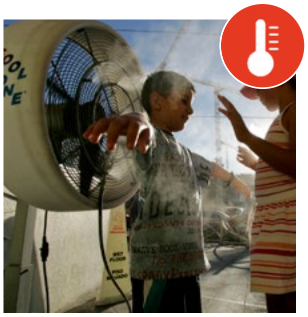
EXECUTIVE SUMMARY

Figure ES.1 – Primary Climate Change Impacts Analyzed in this Report



AIR QUALITY AND HEALTH
New asthma diagnoses in children age 0 to 17 due to particulate air pollution, and premature deaths in adults ages 65 and older due to particulate air pollution.[4]

COASTAL FLOODING AND TRAFFIC
Traffic delays due to high-tide flooding and extreme temperature and precipitation.[5]



EXTREME TEMPERATURE AND HEALTH
Deaths due to extreme temperatures.

COASTAL FLOODING AND PROPERTY
Property inundation due to sea level rise, and exclusion from protective adaptation measures.

EXTREME TEMPERATURE AND LABOR
Labor hours lost by weather-exposed workers due to high-temperature days.

INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

Specifically, the analyses presented in this report first identify the areas in the contiguous United States (U.S.) where impacts are projected to be the highest under future global temperature change and sea level rise. For example, the Extreme Temperature and Labor analysis estimates where weather-exposed workers are projected to lose the most labor hours due to high-temperature days, and the Coastal Flooding and Property analysis estimates where the highest percentage of property is projected to be inundated due to sea level rise. Next, the analyses estimate the likelihood that those who are socially vulnerable live in these areas compared to those who are not. This determination is based on current demographic distributions and projected changes in climate hazards under different levels of global warming and sea level rise. The result is a consistent measure of the disproportionate risk to socially vulnerable individuals, which can be compared across groups, regions, and impact categories.

Due to data limitations, the analyses are limited to the contiguous U.S. Future work will enhance both the coverage of important areas such as Hawai'i and Alaska, and will explore additional impacts. Furthermore, additional dimensions of social vulnerability (e.g., gender and linguistic isolation) are not included and warrant additional analysis. Please see the Introduction and Approach chapters for more information on the analytic scope and limitations.

EXECUTIVE SUMMARY

Key Findings

Figure ES.2 summarizes the results of the six analyses described in this report. These summary findings focus on national-level results for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to the year 2000). Results for additional scenarios and geographic regions are provided in the following chapters and appendices. Note the analyses in this report estimate risks to each socially vulnerable group independently and do not analyze interconnections between the four measures of social vulnerability examined.

Of the four socially vulnerable groups examined, minorities are most likely to currently live in areas where the analyses project the highest levels of climate change impacts with 2°C of global warming or 50 cm of global sea level rise.[6,7]

- Black and African American individuals are 40% more likely than non-Black and non-African American individuals to currently live in areas with the highest projected increases in mortality rates due to climate-driven changes in extreme temperatures. In addition, Black and African American individuals are 34% more likely to live in areas with the highest projected increases in childhood asthma diagnoses due to climate-driven changes in particulate air pollution.
- Hispanic and Latino individuals are 43% more likely than non-Hispanic and non-Latino individuals to currently live in areas with the highest projected labor hour losses in weather-exposed industries due to climate-driven increases in high-temperature days. Hispanic and Latino individuals are also 50% more likely to live in coastal areas with the highest projected increases in traffic delays from climate-driven changes in high-tide flooding.
- American Indian and Alaska Native individuals are 48% more likely than non-American Indian and non-Alaska Native individuals to currently live in areas where the highest percentage of land is projected to be inundated due to sea level rise.[8] American Indian and Alaska Native individuals are also 37% more likely to live in areas with the highest projected labor hour losses in weather-exposed industries due to climate-driven increases in high-temperature days.
- Asian individuals are 23% more likely than non-Asian individuals to currently live in coastal areas with the highest projected increases in traffic delays from climate-driven changes in high-tide flooding.

EXECUTIVE SUMMARY

Key Findings (continued)

Those with low income or no high school diploma are approximately 25% more likely than non-low income individuals and those with a high school diploma to currently live in areas with the highest projected losses of labor hours due to increases in high-temperature days with 2°C of global warming. In addition, individuals in these socially vulnerable groups are approximately 15% more likely to currently live in areas with the highest projected increases in childhood asthma diagnoses due to climate-driven increases in particulate air pollution, and in areas where the highest percentage of land is projected to be inundated due to sea level rise.[9, 10, 11]

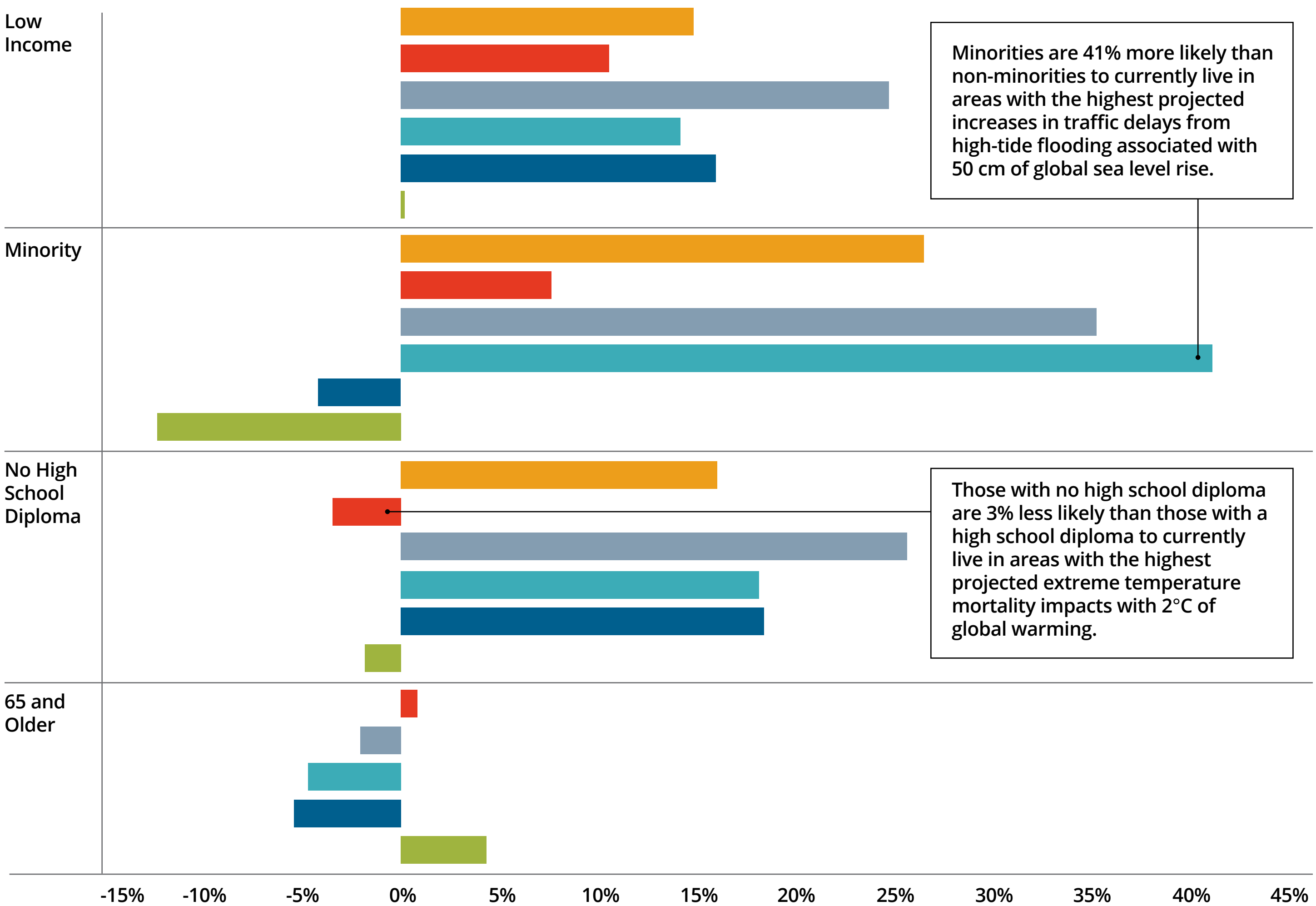
In general, adults ages 65 and older are not projected to be significantly more likely than younger individuals to currently live in areas with the highest projected impacts of climate change. Across all six categories of impacts, the differences in risk to adults ages 65 or older of living in the high-impact areas is only -5% to +4% compared to younger individuals.

With higher levels of global warming and sea level rise, the risks to socially vulnerable groups are generally projected to remain approximately the same or increase. For some groups and in some impact categories, however, the risks of disproportionate impacts are projected to decrease as climate change worsens.

EXECUTIVE SUMMARY

Figure ES.2 – Differences in Risks to Socially Vulnerable Groups Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the following chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

EXTREME TEMPERATURE AND HEALTH
Deaths due to extreme temperatures.

EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

*Impacts not estimated for 65 and Older.

COASTAL FLOODING AND TRAFFIC
Traffic delays from high-tide flooding.

COASTAL FLOODING AND PROPERTY
Property inundation due to sea level rise.

INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

CHAPTER 1
INTRODUCTION

About this Report

The Earth's changing climate is affecting human health and the environment in many ways. Across the U.S., temperatures and sea levels are rising, snow and rainfall patterns are shifting, and some extreme weather events are becoming more common. Many climate change impacts are expected to increase in both magnitude and frequency over the coming decades, with risks to human health, the economy, and the environment.[1]

According to the Fourth National Climate Assessment (NCA4), the impacts of climate change will not be equally distributed across the U.S. population.[2] Those who are already vulnerable due to a range of social, economic, historical and political factors have a lower capacity to prepare for, cope with, and recover from climate change impacts.[3,4] Understanding the comparative risks to vulnerable populations is critical for developing effective and equitable strategies for responding to climate change.

A growing body of literature focuses on the impacts of climate change on socially vulnerable populations, but few studies have quantified disproportionate risks across multiple impacts and levels of global warming.[5,6] This report contributes to a better understanding of the degree to which socially vulnerable populations may be more exposed to the highest impacts of climate change in six categories: Air Quality and Health; Extreme Temperature and Health; Extreme Temperature and Labor; Coastal Flooding and Traffic; Coastal Flooding and Property; and Inland Flooding and Property.

Figure 1.1 depicts the conceptual framework for this report, which is adapted from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).[7] It illustrates how risk to climate change impacts is a product of both exposure and vulnerability to climate hazards. An individual may be vulnerable to climate hazards, but if they are not exposed to those hazards then they are not at risk. Likewise, an individual may be exposed to climate hazards but not vulnerable, rendering their risk far less than an individual who is vulnerable.

This report contributes to a better understanding of the degree to which socially vulnerable populations may be more exposed to the highest impacts of climate change.

Differential exposure to climate hazards can take many forms; for example, some may be more exposed to hazards due to their occupation or where they work. This report uses current data on where people live as an indicator of exposure, recognizing that demographic patterns may change in the future. Similarly, differential vulnerability can result from a wide range of social, economic, and political factors that make some populations less able to anticipate, respond to, recover from, and adapt to climate hazards.[8,9,10] This report focuses on four categories of social vulnerability for which there is evidence that differential vulnerability exists. These groups are based on income, educational attainment, race and ethnicity, and age.

Consistent with the conceptual framework in Figure 1.1, the analyses in this report estimate comparative risks to socially vulnerable groups by first identifying where impacts from climate hazards are projected to be highest and then estimating the likelihood that those who are socially vulnerable live in these areas compared to those who are not. This determination is based on current demographic distributions and projected changes in climate hazards under future levels of warming and sea level rise. For a more detailed discussion of the conceptual framework, please refer to Appendix B.

INTRODUCTION

Figure 1.1 – Climate Change Risk Framework

People are at risk of experiencing climate change impacts when they are both **exposed** and **vulnerable** to **climate hazards.**

This report focuses on whether those who are **socially vulnerable** are **disproportionately exposed** to projected **climate hazards.**

Interpreting the Results

The analyses presented in this report are part of the Climate Change Impacts and Risk Analysis (CIRA) project, a multi-model framework using consistent inputs to enable comparison of impacts across time and space.[11] The data and methods used in the analyses have been peer-reviewed and published in the scientific literature; the corresponding research papers are cited throughout this report and in the technical appendix.

This report is intended to provide insights about disproportionate risks to socially vulnerable groups across multiple impacts and levels of global warming, with consideration of important sources of uncertainty involved with projecting risks in the future. None of the estimates should be interpreted as definitive predictions of future impacts at a particular time or place. Instead, the intention is to produce estimates using the best available data and methods, which can be revisited and updated as science and modeling capabilities continue to advance.

This report analyzes impacts that are well established in the scientific literature and that pose substantial public health and/or economic risks across the U.S.[12] However, there are many impacts of climate change that are not explored in this report. Therefore, the results capture only a portion of the potential disproportionate risks to socially vulnerable populations.

The report considers four categories of social vulnerability based on income, education, age, and race and ethnicity. Additional dimensions of social vulnerability (e.g., linguistic isolation, gender, single parent household, religion, disability, and others) are not included and warrant additional analysis. There are also many ways in which the measures of social vulnerability analyzed could contribute to adverse health outcomes, both independently and jointly, and not all of these pathways and interactions are explored in this report.

Similarly, there are many reasons why socially vulnerable populations may be more likely to currently live in areas where impacts from climate change are projected to be highest. The purpose of this report is to estimate the degree to which the four socially vulnerable populations are disproportionately at risk in the six categories of impacts analyzed. However, investigating the reasons why a particular group is found to be more or less likely to live in a high-impact area is outside the scope of the report.

Importantly, the CIRA analyses do not evaluate or assume specific greenhouse gas (GHG) mitigation or adaptation policies in the U.S. or in other world regions. Therefore, the results should not be interpreted as supporting any particular domestic or global mitigation policy or target. In addition, the costs of reducing GHG emissions, including how these costs are distributed across U.S. populations, as well as the health benefits associated with co-reductions in other air pollutants are beyond the scope of this report.

CHAPTER 2
APPROACH

This chapter describes the four-step approach employed in each of the six analyses presented in this report. Figure 2.1 summarizes the four steps, which are described in detail in the following sections. For more information, please refer to Appendix C.

Step 1: Project Changes in Climate Across the U.S.

Temperature

The analyses presented in this report quantify the impacts of climate change associated with different levels of global temperature change. Instead of estimating impacts for a specific time period under a particular scenario of future GHG emissions, the analyses evaluate impacts that are projected to occur if global average temperature increases by 1°C, 2°C, 3°C, 4°C, and 5°C (1.8°F, 3.6°F, 5.4°F, 7.2°F, and 9°F) above the 1986 to 2005 average.[1] Figure 2.2 shows the estimated timing for these global temperature increases under three GHG emissions scenarios commonly used in the research literature: higher (RCP8.5), lower (RCP4.5), and even lower (RCP2.6).[2] The figure shows both the average estimated "arrival time" for each level of warming (i.e., the estimated year in which each global average temperature

Figure 2.1 – The Four-Step Approach Used in the Analyses

STEP 1 | Project changes in climate hazards across the contiguous United States.

STEP 2 | Estimate human health and economic impacts.

STEP 3 | Identify the areas where the estimated impacts are highest.

STEP 4 | Estimate the likelihood that those who are socially vulnerable currently live in the high-impact areas compared to those who are not.

Figure 2.2 – Projected Timing for Global Average Temperature Changes

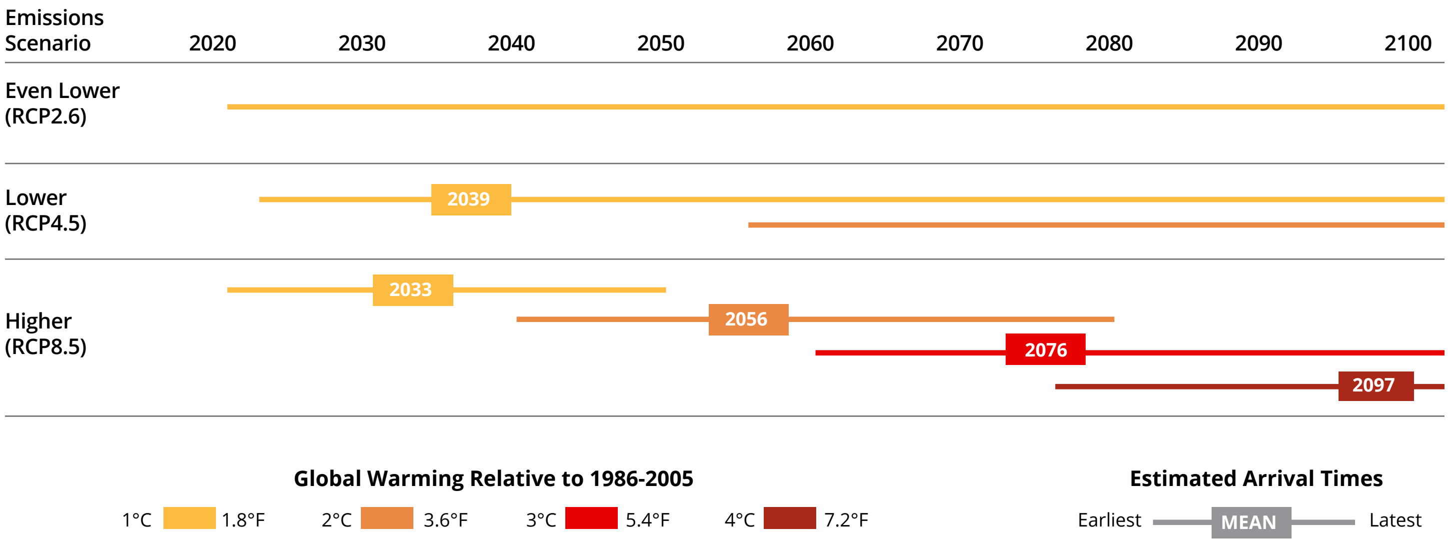
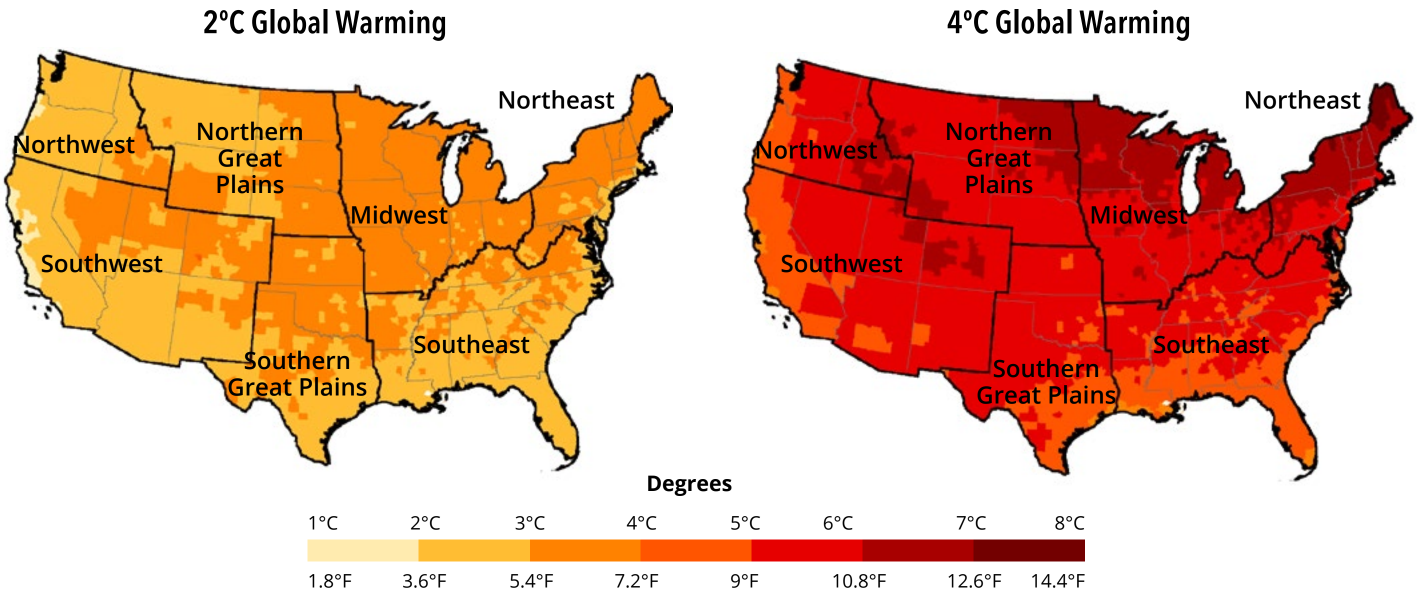


Figure 2.3 – Projected Changes in Average Annual Temperatures Across the U.S. Associated with Global Warming of 2°C and 4°C

Maps show county-level average annual temperature changes associated with global average temperature changes of 2°C and 4°C, relative to the 1986 to 2005 baseline period.



increase is projected occur), as well as the estimated range (i.e., the earliest and latest years in which each global average increase is projected to occur). In the higher emissions scenario, the estimated arrival time for experiencing a global average temperature increase of 1°C of warming ranges from 2020 to 2050, with an average estimate of 2033. The estimated arrival time for experiencing a global average temperature increase of 4°C in this scenario is estimated to occur as early as 2074, with an average estimated arrival time of 2097. In the "even lower" emissions scenario, however, global warming above 1°C is not projected to occur before the end of the century.[3]

Temperature change is not uniform across the globe, and the projected global average temperature changes shown in Figure 2.2 manifest differently in the U.S. Figure 2.3 shows the projected county-level temperature changes that correspond to global warming of 2°C and 4°C. As shown, changes in global temperatures generally result in higher changes in average annual temperatures in the U.S. With 2°C of global warming, large areas of the Southwest, Northern Great Plains, Southern Great Plains, Midwest, and Northeast are projected to experience average annual temperature increases of between 3°C and 4°C (5.4°F and 7.2°F). With 4°C of global warming, the majority of the contiguous U.S. is projected to experience average temperature increases of between 5°C and 6°C (9°F and 10.8°F), with many areas of the Northern Great Plains, Midwest, and Northeast experiencing average annual increases of between 6°C and 7°C (10.8°F and 12.6°F).

To estimate the human health and environmental impacts of climate change, the analyses in this report draw on the rich array of climate data provided in general circulation models (GCMs) to project future climate hazards associated with changes in temperature and precipitation. Specifically, the analyses use six GCMs to project changes in climate variables such as high-temperature days and extreme rainfall.[4] The analyses also derive information from the GCMs about the timing of global mean temperature increases, and then use the GCM results from those time periods to project specific climate hazards (e.g., high-temperature days) needed for each sectoral analysis.

CHAPTER 2

APPROACH

Future Warming In Context

Throughout this report, global mean temperature changes (over land and water) are defined as changes from baseline period from 1986 to 2005. This period is used in the published literature upon which the analyses rely.[5] Other studies, including those by the United Nations' Intergovernmental Panel on Climate Change (IPCC), use a "pre-industrial" baseline period, approximated by IPCC as 1850 to 1900.[6,7] The pre-industrial period is also the reference point for temperature targets established as part of the 21st Conference of the Parties (COP21), also known as the Paris Agreement.[8]

Pre-industrial temperatures were about 0.45°C lower than temperatures observed in the period from 1986 to 2005. Therefore, increases in global mean temperature from the pre-industrial baseline are approximately 0.45°C higher than the projections of global warming presented in this report. For example, global warming of 2°C from the 1986 to 2005 base period used in this report corresponds roughly to an increase of 2.45°C relative to pre-industrial levels.

APPROACH

Sea Level Rise

The Coastal Flooding and Property and Coastal Flooding and Traffic analyses evaluate impacts associated with global average sea level rise of 25 cm (0.8 ft) to 150 cm (4.9 ft) relative to the year 2000 baseline. Changes in global sea levels over this century will depend on the response of the climate system to warming, as well as on future emissions of GHGs and other pollutants from human activities. The NCA4 found that global average sea level has risen by about 16 to 21 cm (7 to 8 in) since 1900. It projects that global average sea level is likely to rise by 9 to 18 cm (0.3 to 0.6 ft) by 2030 (relative to the year 2000), 15 to 38 cm (0.5 to 1.2 ft) by 2050, and 30 to 130 cm (1 to 4 ft) by 2100.[9]

As with temperature, the projected changes in global average sea level generally correspond to higher changes in sea level in the U.S. Table 2.1 shows the projected, relative sea level rise for the 10 most populous U.S. coastal cities that correspond to 50 and 100 cm (1.6 and 3.3 ft) of global average sea level rise. Local sea level rise in the U.S. may be more than 50% greater than global sea level rise, particularly in the Northeast, Southeast, and Southern Great Plains[10] where land levels are falling as sea levels rise.[11] The Coastal Flooding and Property analysis also incorporates the effects of sea level rise on the height of storm surges associated with hurricanes and other coastal storms.

Table 2.1 – Projected Sea Level Rise for the Ten Most Populous Coastal Cities in the U.S. with Global Average Sea Level Rise of 50 cm and 100 cm

COASTAL CITY*	50CM (1.6 FT)	100 CM (3.3 FT)
New York	84 cm (2.8 ft)	154 cm (5.1 ft)
Los Angeles	59 cm (1.9 ft)	122 cm (4.0 ft)
Houston	87 cm (2.9 ft)	158 cm (5.2 ft)
Philadelphia	80 cm (2.6 ft)	148 cm (4.9 ft)
San Diego	61 cm (2.0 ft)	125 cm (4.1 ft)
San Jose	58 cm (1.9 ft)	121 cm (4.0 ft)
Jacksonville	70 cm (2.3 ft)	135 cm (4.4 ft)
San Francisco	59 cm (1.9 ft)	123 cm (4.0 ft)
Seattle	53 cm (1.7 ft)	112 cm (3.7 ft)
Washington, DC	80 cm (2.6 ft)	148 cm (4.9 ft)

**Cities listed in descending order of total population[12]*

Treatment of Adaptation

The approaches for projecting the six impacts differ in their evaluation of how adaptation may reduce overall risk. The Coastal Flooding and Property and Coastal Flooding and Traffic analyses rely on simulation models that explicitly estimate impacts both with and without adaptation to future sea level rise. These estimates include the likelihood that socially vulnerable populations live in areas that might be excluded from adaptation if adaptation investments are made solely based on comparison of economic costs and benefits.

The Air Quality and Health, Extreme Temperature and Health, and Extreme Temperature and Labor analyses use empirical relationships between climate changes and human responses (i.e., premature mortality, allocation of labor hours). To the extent that populations have adapted to past climatic changes and weather variations, these analyses capture these forms of adaptation. Due to data constraints, the Inland Flooding and Property analysis does not consider how adaptation may affect risks to socially vulnerable populations. See each chapter and the accompanying appendices for more detail on the treatment of adaptation.

Step 2: Estimate Human Health and Economic Impacts

Each of the six analyses model the following human health and/or economic impacts stemming from the changes in climate hazards projected in Step 1:

- **Air Quality and Health:** New asthma diagnoses in children age 0 to 17 due to particulate air pollution, and premature deaths in adults ages 65 and older due to particulate air pollution.[13]
- **Extreme Temperature and Health:** Deaths due to extreme temperatures.
- **Extreme Temperature and Labor:** Labor hours lost by weather-exposed workers due to high-temperature days.
- **Coastal Flooding and Traffic:** Traffic delays due to high-tide flooding and extreme temperature and precipitation.[14]
- **Coastal Flooding and Property:** Property inundation due to sea level rise, and exclusion from protective adaptation measures.
- **Inland Flooding and Property:** Property damage or loss due to inland flooding.

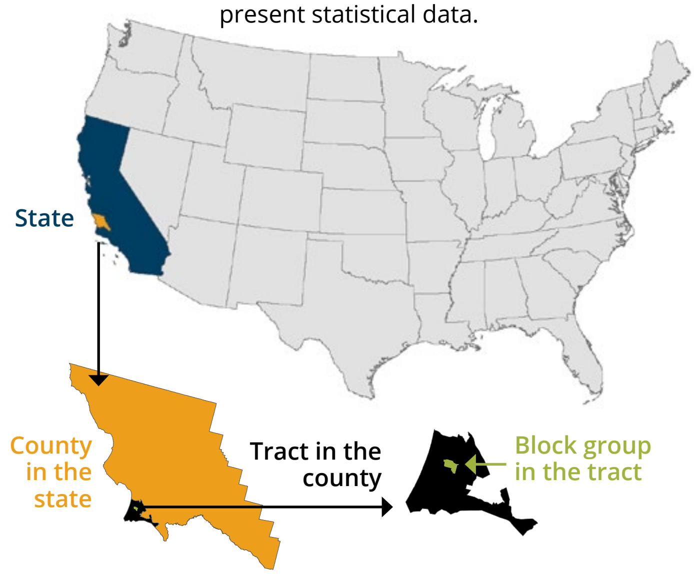
The following chapters include summaries of the modeling approaches used in each analysis and the appendices provide more detailed technical information, as well as additional results.

Step 3: Identify the Areas Where the Estimated Impacts Are Highest

After modeling health and/or economic impacts that result from projected climate hazards, the analyses identify the areas with the highest impacts, which are defined as those with the highest third of impacts.[15] These areas are identified for both the contiguous U.S. and at the regional level; the subsequent chapters present results corresponding to both spatial scales.[16] Note that the spatial resolution of each analysis varies; some results are calculated at the county level while others are calculated at the Census tract or Census block group level.

What is a Census tract and Census block group?

This report often presents information and results at the Census tract and Census block group levels. These geographic areas are standard subdivisions used by the Census to present statistical data.



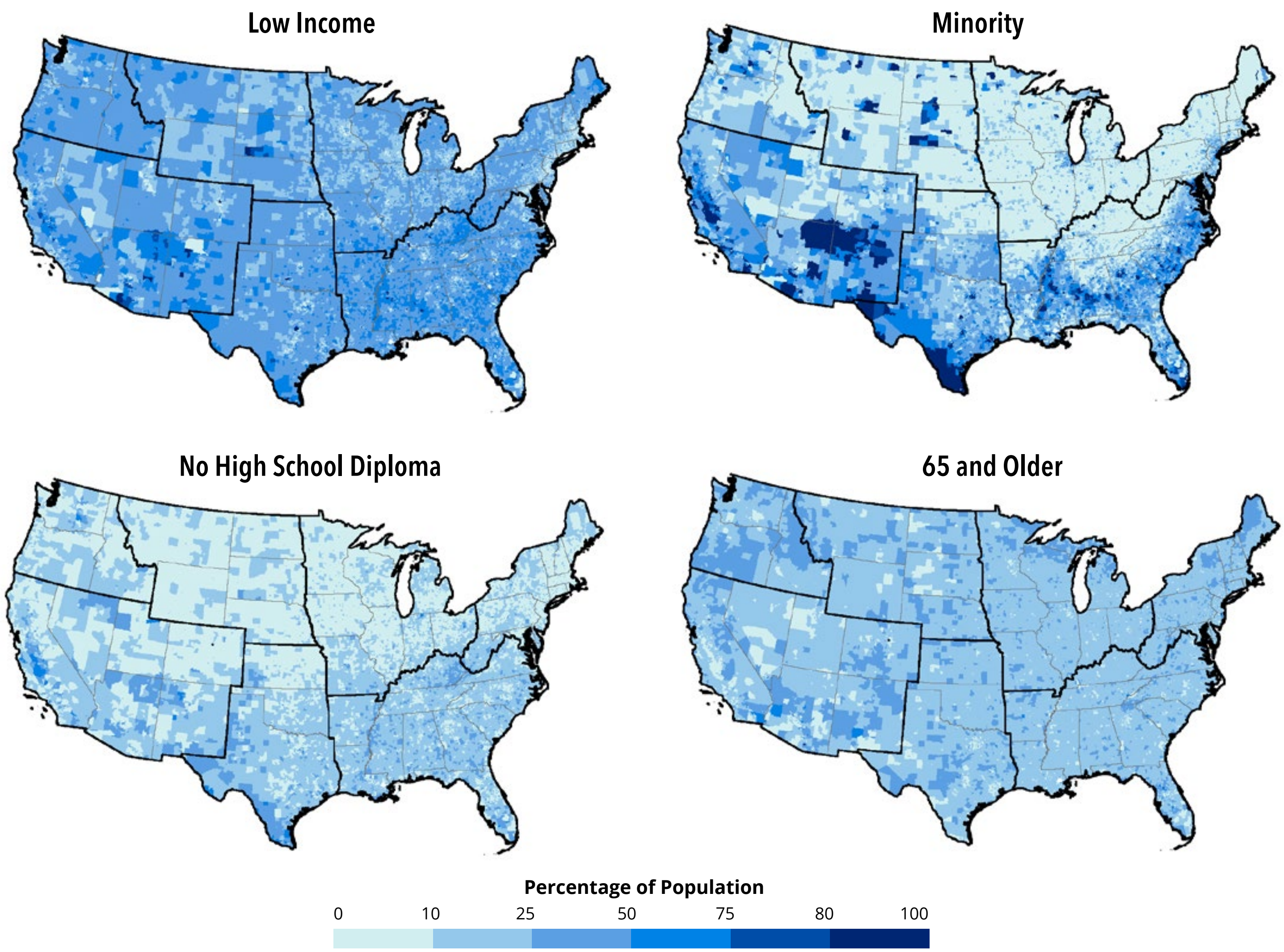
Step 4: Analyze Comparative Risks to Socially Vulnerable Groups

After identifying the areas with the highest projected impacts, the analyses quantify the number of people in each socially vulnerable group who currently live these areas, as well as the number of people in each of the reference populations (i.e., people not included in each socially vulnerable group). The analyses then calculate the likelihood that those who are socially vulnerable live in the high impact areas compared to those who are not, based on current demographic data from the U.S. Census.[17] Figure 2.4 presents the current distribution of each of the four socially vulnerable populations in the U.S. by Census tract.

Table 2.2 provides definitions for each of the four socially vulnerable groups analyzed as well as their reference populations. There are additional dimensions of social vulnerability which are not considered in this report and which warrant further analysis. Further, additional disproportionate risks may be present when evaluating the interconnections between social vulnerability measures, connections that are not explored in this report.

Figure 2.4 – Current Distribution of Socially Vulnerable Populations by Census Tract

Data from the U.S. Census Bureau's 2014-2018 American Community Survey.



Use of the Term "Minority"

This report adopts the term "minority" for the sake of consistency with Executive Order 12898 and other government publications and datasets pertaining to environmental justice and climate change. However, we note that minorities are increasingly being referred to as "people of color." There are important differences in the social vulnerability of the individual communities which are included under the "minority" and "people of color" umbrellas, and that not all non-White communities are comparable. The chapters and appendices of this report therefore include, where possible, results for individual racial and ethnic groups. In addition, we recognize that because of historical systems of discrimination and oppression, Black, Indigenous, and other communities in the United States are often particularly vulnerable to environmental hazards, including the effects of climate change.

Table 2.3 provides sample calculations for calculating risks to a socially vulnerable population (ages 65 and older) in the Coastal Flooding and Traffic analysis.

Sources of Uncertainty

This section reviews some of the key sources of uncertainty that are important to consider when interpreting the results of the analyses presented in this report. For more detailed information on these limitations, please refer to Appendix C. For more information on uncertainties and limitations specific to each of the six analyses, please refer to the relevant chapters and appendices.

- **Projections of Future Changes in Climate:** As described under Step 1 above, the analyses in this report rely on climate projections from six GCMs. While the six models were chosen to capture a wide range of the variability observed across the entire ensemble of GCMs, they are not representative of the full range of variability. However, even the full set of GCMs is unlikely to capture the entire range of potential physical responses of the climate system to changes in the concentration of atmospheric GHGs.[18,19]

- **Socioeconomic and Demographic Change:** This report estimates climate change impacts to socially vulnerable populations based on current demographic distributions, as long-term and robust projections for local changes in demographics are currently unavailable. However, the country's demographics will change in the future. National-scale demographic projections from the U.S. Census suggest the U.S. population will grow older and more diverse in the coming decades. Depending on the impact, socially vulnerable groups may be more or less able to migrate away from adverse climate effects. Therefore, the results of this report should be interpreted with this limitation in mind, as actual impacts could be larger or smaller based on future changes in U.S. demographics.

Table 2.2 – Definitions for the Four Socially Vulnerable Groups and their Reference Populations

CATEGORY	DEFINITION
Low Income	Individuals living in households with income that is 200% of the poverty level or lower.[20] *Reference population: Individuals living in households with income greater than 200% of the poverty level.*
Minority	Individuals identifying as one or more of the following: Black or African American; American Indian and Alaska Native; Asian; Native Hawaiian and Other Pacific Islander; Other; and Hispanic or Latino.[21] *Reference population: Individuals identifying as White and/or non-Hispanic.*
No High School Diploma	Individuals age 25 or older with maximum educational attainment of less than a high school diploma or equivalent.[22] *Reference population: Individuals age 25 or older with educational attainment of a high school diploma (or equivalent) or higher.*
65 and Older	Individuals ages 65 and older.[23] *Reference population: Individuals under age 65.*

Data Source: U.S. Census, American Community Survey 2014-2018

APPROACH

Key Concepts

Social Vulnerability: This report analyzes risks to four specific groups: those with low income, minorities, those with no high school diploma, and people ages 65 and older. These groups have been identified in the literature as socially vulnerable due to a range of social, economic, historical and political factors that reduce their capacity to prepare for, cope with, and recover from climate change impacts. For more information, please see Appendix B.

Risks to Socially Vulnerable Populations: The analyses begin by projecting impacts of climate change and identifying the areas where the highest impacts are projected to occur (defined as areas where impacts are in the highest tercile). Next, the analyses calculate the likelihood that individuals in each of the four socially vulnerable groups currently live in these high-impact areas, relative to individuals in the reference populations (see definition below). The resulting values are measures of the potential risks to these populations of being exposed to future impacts of climate change. For more information, please refer to Appendix C.

Reference Populations: The reference populations for each socially vulnerable group are defined as all individuals who do not possess the defining demographic characteristics of that group. For example, the low income group is defined as those with incomes at or below 200% of the poverty level. The corresponding reference population includes all individuals with incomes above 200% of the poverty level.

- **Coverage of Impacts:** The six impacts analyzed in this report were selected due to the availability of robust methods and data, the demonstrated economic importance of these impacts, and the potential for disproportionate risks to socially vulnerable populations. However, there are many other human health and economic impacts of climate change that will disproportionately affect socially vulnerable populations. Therefore, this report provides only partial insight into the effects of climate change on socially vulnerable populations. Importantly, this report does not assume that socially vulnerable populations will always face disproportionately higher risks from climate change. In fact, there are results presented throughout the report that suggest that risks to reference populations may be higher in some cases compared to socially vulnerable populations.

- **Impacts Modeling:** Each analysis was developed using a single impact model. These models are complex analytical tools, and choices regarding their structure and parameter values can influence the results.[24] The use of additional models would improve the understanding of potential impacts. In addition, the analyses were developed independently and, as a result, the estimated impacts may omit important interactive or correlative effects.[25]

- **Individual Exposure:** The analyses of this report are not designed to project impacts or risks for specific individuals and are instead intended to explore disproportionate risks based on current demographic distributions in areas with higher projected impacts. As a result, the analyses assume uniform and equal exposure to risks by everybody living in these tracts.

- **Treatment of Adaptation:** Populations will adapt to climate change in many ways, with some actions reducing impacts, and others potentially exacerbating impacts. The timeliness and effectiveness of adaption efforts depend on a variety of factors, including socioeconomic status, the condition and accessibility of infrastructure, the accessibility of health care, specific demographic characteristics, and other institutional resources.[26] As described previously, the Coastal Flooding and Property and Coastal Flooding and Traffic analyses directly model the implications of potential adaptation responses.[27] The Air Quality and Health, Extreme Temperature and Labor and Extreme Temperature and Health analyses implicitly incorporate historical adaptation to climate hazards.[28] The general adaptation scenarios or responses considered in the analyses of this report do not capture the complex issues that drive adaptation decision-making at regional and local scales. As such, the adaptation scenarios and estimates presented in all sections of this report should not be construed as recommending any specific policy or adaptive action and do not explicitly address the potential inequities in future adaptation responses.

- **Geographic Coverage:** Due to data and modeling constraints, the analyses presented in this report do not assess impacts of climate change that occur outside of the contiguous U.S., such as those in Hawai'i, Alaska, and the U.S. territories, or the rest of the world. In addition, the Temperature Mortality analysis quantifies impacts in a limited set of major U.S. cities. Incorporation of additional locales would provide a more comprehensive understanding of likely effects on socially vulnerable populations.

Table 2.3 – Demonstration of the Approach for Estimating Disproportionate Risks to Socially Vulnerable Populations

The below steps demonstrate the process for estimating risks to individuals ages 65 and older in the Coastal Flooding and Traffic analysis.

STEPS	EXAMPLE CALCULATIONS
Step 4a. In the area where climate change impacts are projected to occur, count the number of individuals included in the population of individuals ages 65 and older, as well as those in the reference population (see definitions in Table 2).	Individuals ages 65 and older: 49 million Individuals under age 65: 272 million
Step 4b. In the areas where climate change impacts are projected to be the highest (i.e. where impacts are in the top third), count the number of individuals ages 65 and older, as well as those in the reference population.	Individuals ages 65 and older: 17 million Individuals under age 65: 86 million
Step 4c. Calculate the likelihood that an individual age 65 or older currently lives in the high-impact area. Then calculate the likelihood that an individual under age 65 lives in the high-impact area.	Likelihood for individual age 65 or older: 17/49 = 0.35 Likelihood for individual under 65: 86/272 = 0.32
Step 4d. Compare the two likelihoods calculated in Step 4c. The resulting value is the estimated likelihood that those ages 65 and older live in the high-impact areas compared to those under age 65.[29]	Result: Those ages 65 and older have an estimated 9% higher likelihood of living in areas with the highest impacts in the Coastal Flooding and Property analysis.

CHAPTER 3
AIR QUALITY AND HEALTH

Background

Climate change will alter chemical and physical interactions that create, remove, and transport air pollution.[1] The resulting changes in air pollution, including fine particulate matter ($PM_{2.5}$)[2] and ground-level ozone,[3] are likely to have significant respiratory and cardiovascular health effects.[4] Changes in climate, including temperature, humidity, precipitation, and other meteorological factors, can change concentrations of $PM_{2.5}$ and ozone, broadening the distribution of human exposures to these pollutants.[5,6] In addition, climate-driven increases in the intensity and duration of warm seasons are projected to increase the number of days with poor air quality. Furthermore, climate change-driven increases in wildfires and windblown dust events also result in higher $PM_{2.5}$ concentrations.[7]

This analysis estimates changes in the numbers of premature deaths for individuals ages 65 and older and new childhood asthma diagnoses associated with climate change-driven increases in $PM_{2.5}$. The approach considers adaptation responses implemented in recent history, but not new advancements in technology or behavior, or increased access for those who are socially vulnerable. It then estimates the risks that socially vulnerable populations currently live in areas where these impacts are projected to be highest. The next section describes why socially vulnerable populations in the U.S. may be particularly at risk of experiencing air quality impacts.

AIR QUALITY AND HEALTH

Social Vulnerability and Air Quality

The relationship between social vulnerability and exposure to air pollution is well established in the literature.[8,9,10] Recent research indicates that although the average concentrations of $PM_{2.5}$ have fallen over time, the spatial distribution remains disproportionate across the population.[11,12] Table 3.1 summarizes findings from the literature on the ways in which the socially vulnerable populations examined in this analysis may be more vulnerable to air pollution. As described in the table, studies have found that minorities, individuals with lower income, and individuals with lower educational attainment are at increased risk of ambient air pollution exposure and health effects related to that exposure.[13] Race, in particular, plays a significant role in determining one's risk of exposure to air pollution, even after controlling for other socioeconomic and demographic factors.[14,15] EPA's most recent Particulate Matter Integrated Science Assessment (ISA) concludes that race and ethnicity are important factors in determining $PM_{2.5}$ related risk, and that Black individuals, in particular, are at increased risk for health effects, in part due to disparities in exposure.[16,17]

Table 3.1 – Social Vulnerability and Air Quality

CATEGORY	DEFINITION
Low Income	Neighborhoods with higher poverty rates have been found to have higher exposures to $PM_{2.5}$ and ozone.[18] Low income communities tend to have greater sources of environmental risk, including higher ambient air pollution concentrations.[19]
Minority*	Studies have found higher exposures to $PM_{2.5}$ and ozone in neighborhoods with more racial minorities[20,21,22] and higher incidence of childhood asthma.[23] One study found that a large portion of non-Hispanic Black individuals reside in communities with the poorest air quality.[24]
No High School Diploma	Studies have found significant differences in educational attainment between areas with air pollution sources and those without,[25,26] though there are complex cause and effect drivers involved with these disproportionate risks.
65 and Older	Air pollution can exacerbate chronic obstructive pulmonary disorder and increase the risk of heart attack in older adults, especially those who are also diabetic or obese.[27] Because the analysis of premature mortality focuses on the population of individuals ages 65 and older, the results do not include separate estimates of disproportionate risks to this group.

METHODS

The steps below outline the general approach to the analysis. For more detailed information, please refer to Appendix D.

STEP 1 | Project changes in $PM_{2.5}$ concentrations in scenarios with 2°C and 4°C of global warming using air quality estimation techniques described in Fann et al. (2021).[28]

STEP 2 | Estimate changes in premature mortality associated with $PM_{2.5}$ for individuals ages 65 and older. Estimate changes in the number of asthma diagnoses associated with $PM_{2.5}$ for individuals ages 0 to 17. The analysis uses methods described in Fann et al. (2021), including the U.S. EPA's Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE).

STEP 3 | For each impact category (premature mortality and asthma diagnoses), identify the Census tracts where impacts are projected to be highest (defined as those in the highest tercile).

STEP 4 | Calculate the likelihood that individuals who are socially vulnerable currently live in these high-impact areas relative to those who are not.[29]

AIR QUALITY AND HEALTH

Key Findings on $PM_{2.5}$ Related Premature Mortality

With 2°C of global warming, climate-driven changes in $PM_{2.5}$ are projected to result in an annual increase of 2,100 premature deaths nationwide among those 65 and older. With 4°C, this estimate increases to 5,800 annual deaths. The Southeast is projected to experience the highest increases in premature deaths, while some Northern and Midwestern areas are projected to experience decreases due to higher numbers of rainy days, which generally reduce $PM_{2.5}$ concentrations and associated health effects.

Climate change is projected to increase annual premature deaths associated with $PM_{2.5}$ across large areas of the country. Figure 3.1 shows the projected changes in annual premature deaths among people ages 65 and older, by Census tract, due to climate-driven changes in $PM_{2.5}$. Table 3.2 shows the projected changes in the number of premature deaths by region. For information on baseline rates, please see Appendix D.

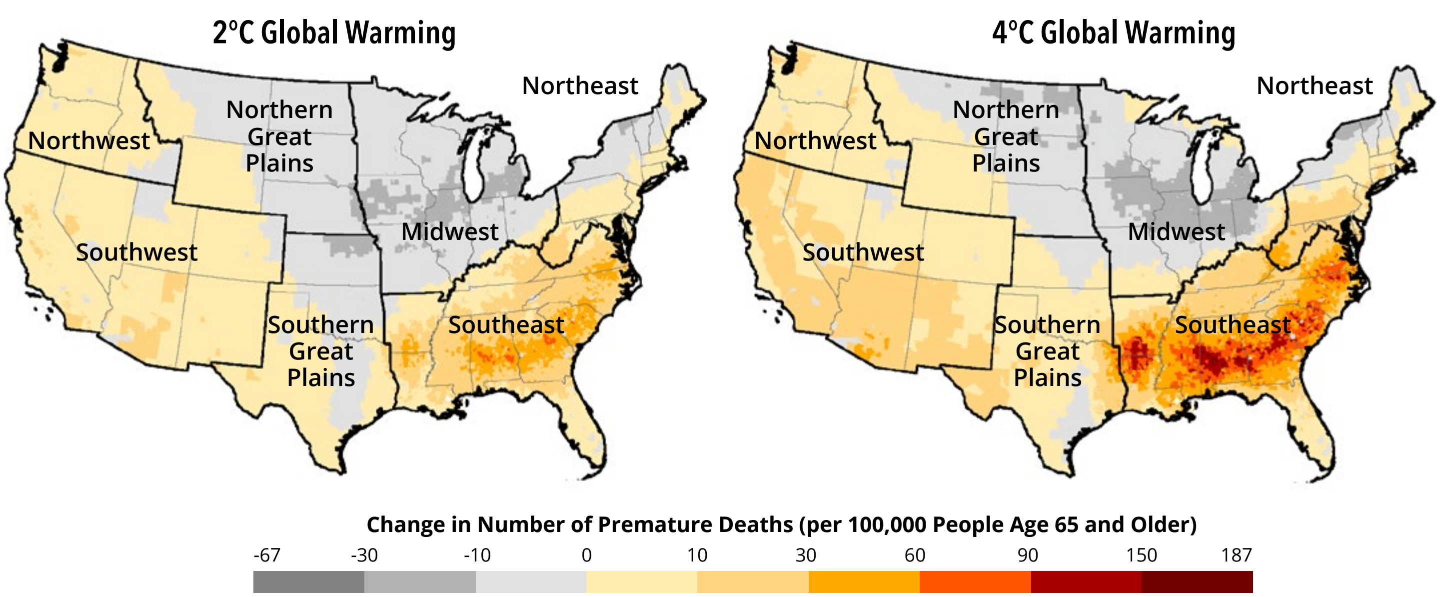
With 2°C of global warming, the Southeast is projected to experience an annual increase of 1,900 premature deaths from climate-driven changes in $PM_{2.5}$. With 4°C of global warming, this estimate increases to 3,900 annual deaths. The Northeast and Southwest are projected to experience annual increases of

Table 3.2 – Projected Regional Changes in Annual Premature Deaths Among People Ages 65 and Older due to Climate-Driven Effects on $PM_{2.5}$

REGION	GLOBAL WARMING (RELATIVE TO 1986-2005) 2°C	4°C
Midwest	-850	-900
Northeast	400	1,200
Northern Great Plains	-43	-29
Northwest	79	180
Southeast	1,900	3,900
Southern Great Plains	-3	290
Southwest	610	1,200
National Total	**2,100**	**5,800**

Figure 3.1 – Projected Changes in Annual Premature Deaths due to Climate-Driven Effects on $PM_{2.5}$

The analysis estimates changes in premature deaths among people ages 65 and older at the Census tract level. Levels of global warming are relative to the 1986-2005 average.



CHAPTER 3

AIR QUALITY AND HEALTH

1,200 premature deaths with 4°C of global warming. Areas of the Midwest, Northern and Southern Great Plains, and parts of the Northeast, however, are projected to experience decreases in annual premature deaths from climate-driven changes in $PM_{2.5}$. This is due to the projected increase in the number of rainy days in these areas, which reduces $PM_{2.5}$ concentrations and corresponding health effects.

Note, the analysis also evaluated changes in the numbers of premature deaths for individuals ages 65 and older associated with climate change-driven increases in ozone. Projected changes in premature mortality were not shown to have large disproportionate risks to socially vulnerable populations, and are therefore summarized in Appendix D.

Actions to reduce pollutants that form $PM_{2.5}$ have been highly successful over the past several decades; since 2000, national average concentrations of $PM_{2.5}$ have been reduced by 41%. However, climate change can hinder these improvements by altering weather patterns and increasing the prevalence of conditions that lead to poor air quality.[30]

AIR QUALITY AND HEALTH

Key Findings on $PM_{2.5}$ Related Premature Mortality and Social Vulnerability

Black and African American individuals ages 65 and older have the most disproportionate risk, relative to their reference population, of currently living in areas with the highest projected increases in premature mortality from climate-driven changes in $PM_{2.5}$. Specifically, with 4°C of global warming, Black and African American individuals are 60% more likely than non-Black and non-African American individuals to currently reside in high-impact areas.

Using the data presented in Figure 3.1, the analysis identifies the Census tracts with the highest increases in premature mortality among those 65 and older from climate-driven changes in $PM_{2.5}$. The high-impact areas are defined as Census tracts where impacts are in the highest tercile. On average, high-impact Census tracts across the contiguous U.S. are projected to experience increases of 7 to 90 annual premature deaths per 100,000 individuals ages 65 and older with 2°C of global warming, and 15 to 187 annual premature deaths with 4°C of global warming.[31] Following the steps outlined in the Approach chapter, the analysis then estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not.

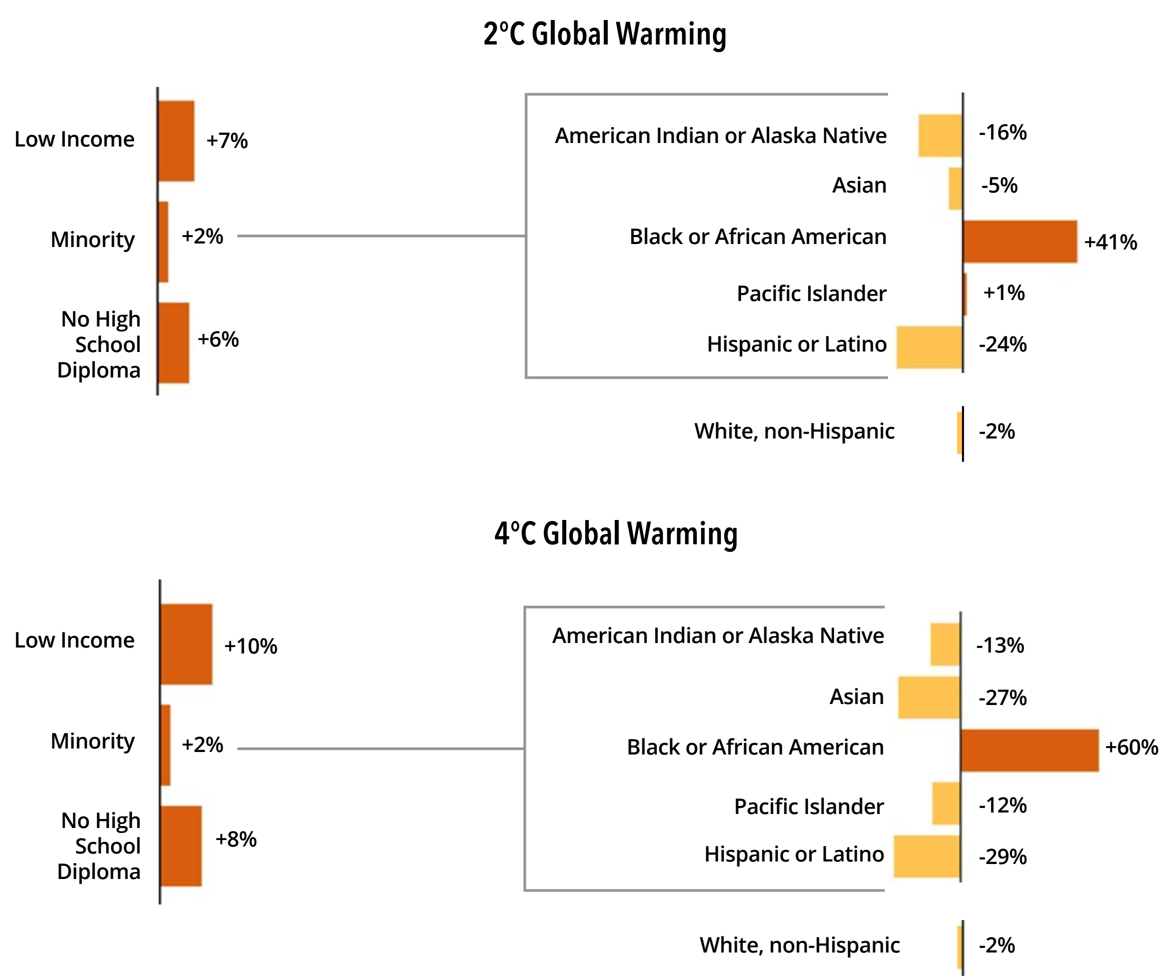
Figure 3.2 presents the relative likelihood that socially vulnerable individuals ages 65 and older currently live in areas with the highest projected increases in premature mortality from climate-driven changes in $PM_{2.5}$, compared to individuals in the reference populations. The analysis finds that Black and African American individuals are 41-60% more likely than non-Black and non-African American

Key Findings on $PM_{2.5}$ Related Premature Mortality and Social Vulnerability (continued)

individuals to currently live in areas with the highest projected increases in premature mortality from climate-driven changes in $PM_{2.5}$. Hispanic and Latino individuals are 24-29% less likely to live in high-impact areas compared to non-Hispanic and non-Latino individuals; this is partially driven by the lower projected impacts in Texas and southern Florida (as shown in Figure 3.1), where there are larger Hispanic and Latino populations. Importantly, this finding does not suggest that Hispanic and Latino individuals will not experience negative impacts from climate-driven changes in $PM_{2.5}$; rather, it refers to the degree to which the estimated impacts on this group are projected to differ from impacts on non-Hispanic and non-Latino individuals.

Figure 3.2 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Projected Increases in Annual Premature Deaths from Climate-Driven Effects on $PM_{2.5}$

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected increases in premature deaths among those 65 and older relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global warming are relative to the 1986-2005 average.



AIR QUALITY AND HEALTH

Key Findings on $PM_{2.5}$ Related Childhood Asthma

With 2°C of global warming, climate-driven changes in $PM_{2.5}$ are projected to result in an annual increase of 2,500 childhood asthma diagnoses nationwide. With 4°C, this estimate increases to 7,000 annual diagnoses. Southern regions are projected to experience the highest increases in childhood asthma diagnoses, while some Northern and Midwestern areas are projected to experience decreases due to higher numbers of rainy days, which reduce $PM_{2.5}$ concentrations and associated health effects.

Climate change is projected to increase the annual number of asthma diagnoses in children ages 0 to 17 in many regions of the U.S., particularly the Southwest and Southeast. Figure 3.3 shows the projected changes in childhood asthma diagnoses each year, by Census tract, due to climate-driven changes in $PM_{2.5}$.[32] Table 3.3 shows the projected changes at the regional level. For information on baseline rates, please see Appendix D.

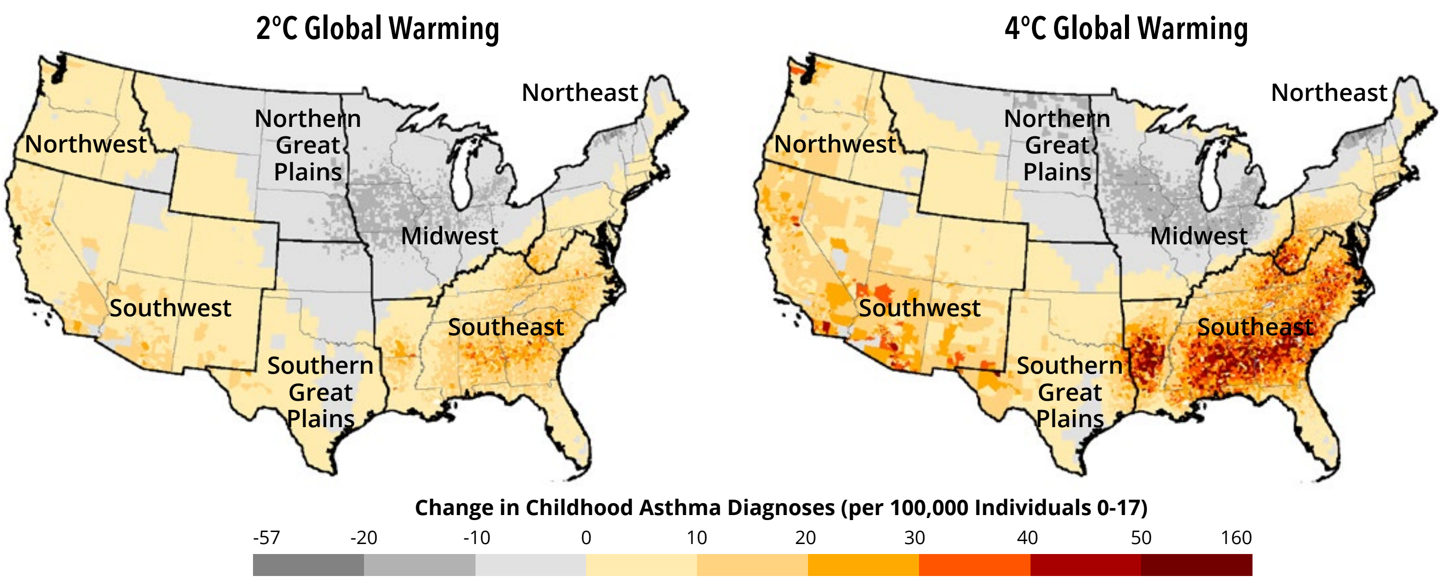
The Southeast is projected to experience an annual increase of 2,000 childhood asthma diagnoses due to climate-driven changes in $PM_{2.5}$ with 2°C of global warming, and an annual increase 4,000 diagnoses with 4°C of global warming. Areas of the Southwest are also projected to experience relatively high impacts. As shown in Figure 3.3, areas of the Midwest, Northern and Southern Great Plains, and parts of the Northeast are projected to experience decreases in the annual number of childhood asthma diagnoses due to the projected increase in the number of rainy days in these areas, which reduces $PM_{2.5}$ concentrations and corresponding health effects.

Table 3.3 – Projected Regional Changes in Annual Childhood Asthma Diagnoses Due to Climate-Driven Effects on $PM_{2.5}$

	GLOBAL WARMING (RELATIVE TO 1986-2005)	
REGION	**2°C**	**4°C**
Midwest	-1,100	-1,200
Northeast	450	1,400
Northern Great Plains	-75	-52
Northwest	130	310
Southeast	2,000	4,000
Southern Great Plains	36	490
Southwest	1,000	2,000
National Total	**2,500**	**7,000**

Figure 3.3 – Projected Changes in Annual Childhood Asthma Diagnoses Due to Climate Change-Driven Effects on $PM_{2.5}$

Levels of global warming are relative to the 1986-2005 average. Results are calculated at the Census tract level.



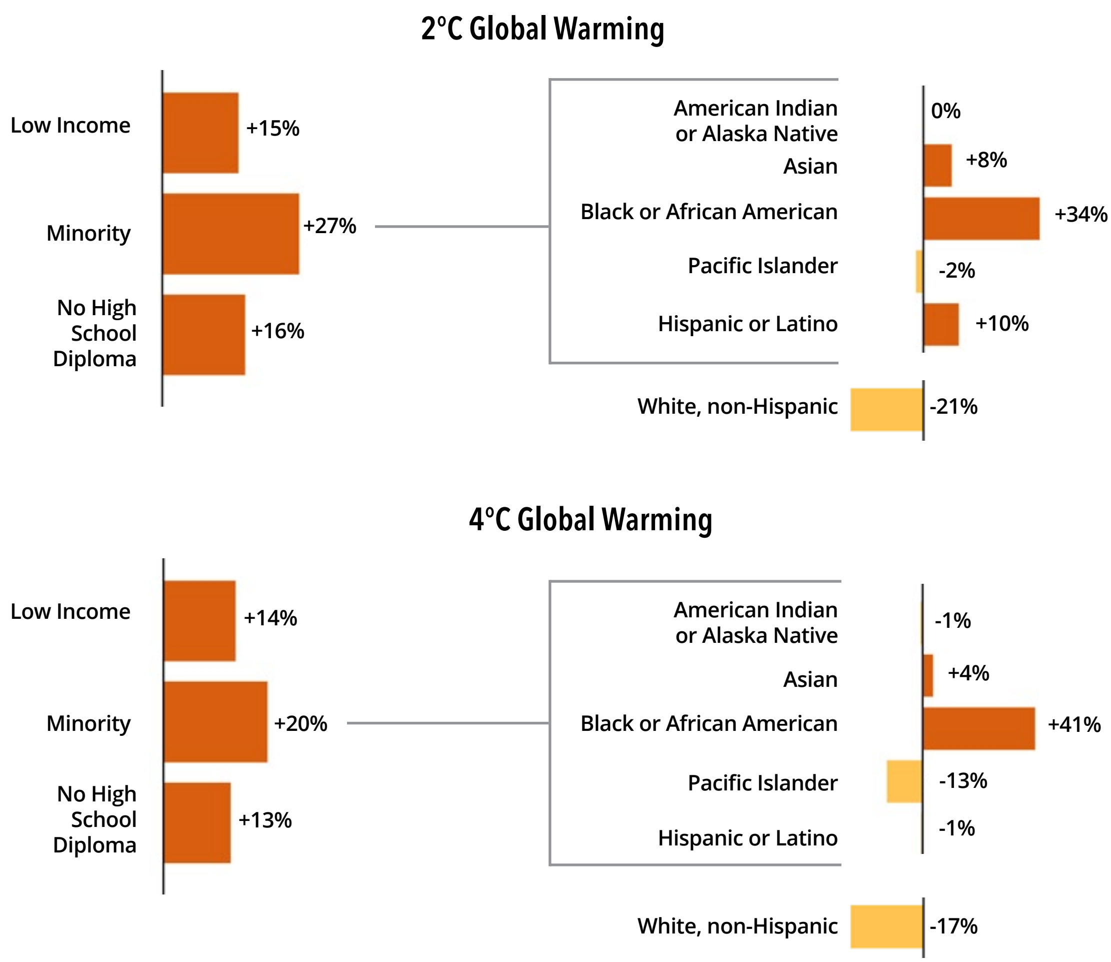
AIR QUALITY AND HEALTH

Key Findings on Social Vulnerability and $PM_{2.5}$ Related Childhood Asthma Cases

Black and African American children ages 0 to 17 have the most disproportionately high risk, relative to their reference population, of currently living in areas with the highest projected increases in asthma diagnoses due to climate-driven changes in $PM_{2.5}$. Specifically, with 4°C of global warming, Black and African American children are 41% more likely than non-Black and non-African American children to currently reside in areas with the highest projected impacts.

Figure 3.4 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Projected Increases in Annual Childhood Asthma Diagnoses due to Climate-Driven Effects on $PM_{2.5}$

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected increases in asthma diagnoses in children ages 0 to 17 relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global warming are relative to the 1986-2005 average.



AIR QUALITY AND HEALTH

Using the data presented in Figure 3.3, the analysis identifies the Census tracts with the highest increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$. The high-impact areas are defined as Census tracts where impacts are in the highest tercile. On average, high-impact tracts across the contiguous U.S. are projected to experience increases of 6 to 65 annual diagnoses per 100,000 individuals ages 0 to 17 with 2°C of global warming and 13 to 160 annual diagnoses with 4°C of global warming.[33] Following the steps outlined in the Approach chapter, the analysis then estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not.

Figure 3.4 presents the relative likelihood that socially vulnerable individuals ages 0 to 17 currently live in areas with the highest projected increases in childhood asthma diagnoses due to climate-driven changes in $PM_{2.5}$, compared to individuals in the reference populations. The analysis finds that minority children are 20-27% more likely than non-minority children to currently live in areas with the highest projected increases in childhood asthma diagnoses due to climate-driven changes in $PM_{2.5}$, compared to individuals in the reference populations. Black and African American children are 34% more likely than non-Black and non-African American children to currently live in high-impact areas with 2°C global warming and 41% more likely to currently live in high-impact areas with 4°C of global warming. White, non-Hispanic children are 17-21% less likely to live in high-impact areas; this is likely due to the lower projected impacts in the Midwest and other areas of the country (as shown in Figure 3.3) with larger White, non-Hispanic populations. Importantly, this finding does not suggest that White, non-Hispanic children will not experience negative impacts from climate change driven changes in $PM_{2.5}$; rather, it refers to the degree to which the estimated impacts on this group are projected to differ from impacts on minorities.

The analysis also evaluated changes in the numbers of asthma-related emergency department (ED) visits among children ages 0 to 18 associated with climate change-driven increases in $PM_{2.5}$. Projected changes are presented in Appendix D. The analysis finds that minorities have an estimated 53-58% higher likelihood of living in areas with the highest projected increases in childhood asthma ED visits, relative to non-minorities. The magnitude of this effect is tied to the availability of race-stratified estimates for this impact metric; it is possible that the incorporation of race-stratified data for the analysis of impacts on childhood asthma diagnoses may yield even more disproportionate impacts than the results presented in Figure 3.3.[34]

AIR QUALITY AND HEALTH

Key Findings on Regional Impacts for Childhood Asthma

In nearly all regions of the U.S., children in low income households are more likely than those in higher income households to currently live in areas with the highest projected increases in childhood asthma diagnoses due to climate-driven changes in $PM_{2.5}$ In the Southern Great Plains, minority children are 77% more likely than non-minority children to currently live in high-impact areas.

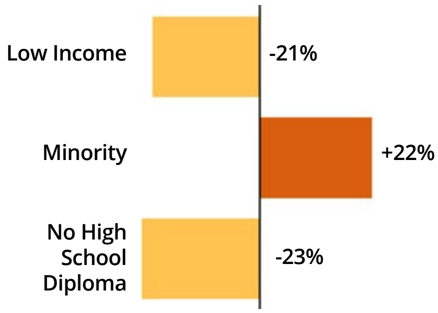
The regional analysis follows the same approach as the national-level analysis, first identifying the areas within each region that are projected to experience the highest impacts of climate change (see Section 4 of Appendix D) and then estimating the likelihood that those who are socially vulnerable currently live in these areas compared to those who are not. For each region, the charts show the likelihood that children in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected increases childhood asthma diagnoses due to climate-driven changes in $PM_{2.5}$, relative to children in the reference groups (e.g., non-low income).

The results are for a scenario with global warming of 2°C relative to 1986 to 2005. Please refer to Appendix D for results in the scenario with 4°C of warming, as well as for regional findings of the premature mortality analysis. As described in the Approach chapter, a finding that a socially vulnerable group is less likely to experience risks does not suggest that they will not experience negative impacts; rather, such findings refer to the degree to which the estimated impacts are projected to be disproportionate relative to the reference population.

AIR QUALITY AND HEALTH

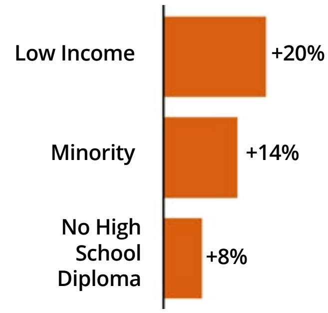
Key Findings on Regional Impacts for Childhood Asthma (continued)

NORTHWEST
2°C Global Warming



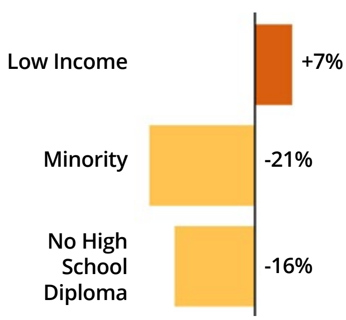
- In the Northwest, minority children are 22% more likely than non-minority children to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$.
- In the Northwest, children in households with low income or no high school diploma are over 20% *less* likely to currently live in high-impact areas, relative to their reference populations.

SOUTHWEST
2°C Global Warming



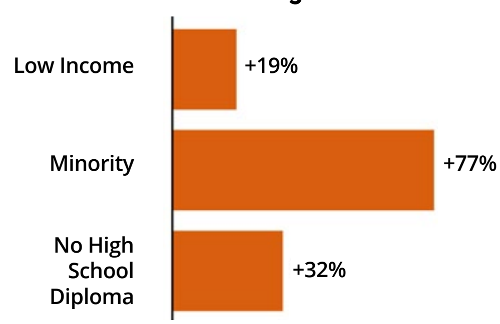
- In the Southwest, children in households with low income are 20% more likely than those with higher income to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$.
- In the Southwest, minority children are 14% more likely than non-minority children to currently live in high-impact areas.

NORTHERN GREAT PLAINS
2°C Global Warming



- In the Northern Great Plains, children in households with low income are 7% more likely than those with higher income to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$.
- In the Northern Great Plains, minority children and those living in households with no high school diploma are *less* likely than their reference populations to currently live in high-impact areas.

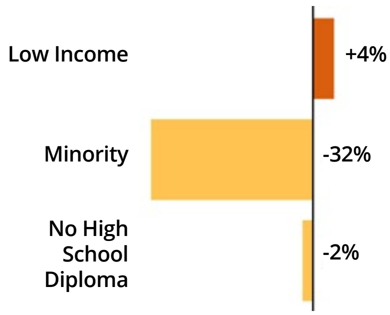
SOUTHERN GREAT PLAINS
2°C Global Warming



- In the Southern Great Plains, minority children are 77% more likely than non-minority children to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$.
- Children in households with low income or no high school diploma are 19% and 32% more likely, respectively, to currently live in high-impact areas, relative to their reference populations.

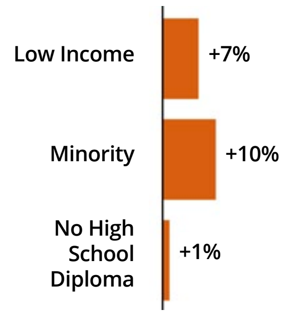
Key Findings on Regional Impacts for Childhood Asthma (continued)

MIDWEST
2°C Global Warming



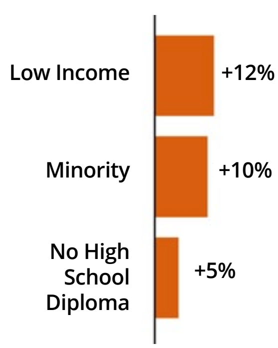
- In the Midwest, children in households with low income are slightly more likely than those with higher income to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$. Minorities are 32% *less* likely to live in high impact areas relative to non-minorities.
- Overall, individuals in the Midwest region are projected to experience a decrease in childhood asthma cases due to an increase in the number of rainy days, which results in lower $PM_{2.5}$ concentrations.

NORTHEAST
2°C Global Warming



- In the Northeast, minority children are 10% more likely than non-minority children to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$.
- Children in households with low income are 7% more likely than those with higher income to currently live in high-impact areas.

SOUTHEAST
2°C Global Warming



- In the Southeast, children in households with low income are 12% more likely than those with higher income to currently live in areas with the highest projected increases in childhood asthma diagnoses from climate-driven changes in $PM_{2.5}$.
- In the Southeast, minority children are 10% more likely than non-minority children to currently live in high-impact areas.

CHAPTER 4
EXTREME TEMPERATURE AND HEALTH

Background

Rising temperatures resulting from climate change will lead to an increase in heat-related illnesses and deaths.[1] Extreme temperature days, or days that are substantially hotter than the average seasonal temperature in summer or substantially colder than the average seasonal temperature in winter, cause increases in illnesses and death by compromising the body's ability to regulate its temperature.[2] Exposure to extreme temperature may result in more severe health responses or death because it exacerbates pre-existing conditions, including cerebral, respiratory, and cardiovascular diseases, and because it has greater impact on those who are taking prescribed or other drugs that may already change their circulatory system, and thus their body's ability to regulate its temperature.[3] Studies that have analyzed future temperature mortality related to climate change over the past two decades provide consistent evidence higher temperatures will increase the risk of heat-related illness and death, in the absence of additional societal adaptation.[4] The relationship between exposure to extreme temperatures and socially vulnerable populations has also been examined around the world, across hundreds of studies, reports, and guidance documents.[5]

This analysis estimates changes in the numbers of premature deaths associated with climate-driven changes in extremely hot and extremely cold days across the contiguous U.S. The approach considers adaptation responses implemented in recent history, such as air conditioning, but not new advancements in technology or behavior, or increased access for those who are socially vulnerable. It then estimates the risks to socially vulnerable populations of living in areas where these impacts are projected to be highest. The next section describes why socially vulnerable populations in the U.S. may be particularly at risk of experiencing health impacts from extreme temperatures.

Social Vulnerability and Temperature Mortality

Table 4.1 summarizes findings from the literature on the ways in which the four socially vulnerable populations examined in this analysis may experience higher impacts from exposure to extreme temperatures. Most frequently, the relevant studies analyze impacts on those ages 65 and older and on children under age five.[6] Older individuals tend to experience worse health outcomes due to cardiac strain created by exposure to heat, and young children sweat less, which limits their body's ability to naturally cool.[7] Studies also examine the relationship between extreme temperature mortality and race, poverty, residence in an urban environment, homelessness, social isolation, and working outdoors.[8,9] Access to air conditioning can mitigate one's risk of health impacts from extreme heat, but may be limited depending on income, location, and other factors.[10,11] Similarly, in colder climates, heating can mitigate adverse health effects from extreme cold, but access may be limited for certain socially vulnerable groups.[12]

EXTREME TEMPERATURE AND HEALTH

Table 4.1 – Social Vulnerability and Temperature Mortality

CATEGORY	DEFINITION
Low Income	Neighborhoods in the U.S. and Canada where poverty rates are relatively higher have been found to experience elevated temperature mortality impacts.[13] Individuals without health insurance—a condition which may be more common for low-income populations—have also been found to experience higher rates of temperature mortality impacts.[14]
Minority	Studies have found higher temperature mortality rates among many minority populations, including Black and Hispanic populations.[15]
No High School Diploma	There is a paucity of research on the relationship between one's education and impacts from exposure to extreme temperatures. However, one study found higher temperature mortality among individuals working in outdoor occupations (agriculture and resource extraction),[16] industries where some workers may be more likely to lack a high school diploma.
65 and Older	Older individuals have higher baseline mortality rates and are more susceptible to the negative health consequences of heat exposure, in part due to the exacerbation of heat stress on pre-existing cardiac conditions.[17]

Figure 4.1 – Cities Included in the Temperature Mortality Analysis

Due to the underlying method, the analysis focuses on the 49 cities shown below. Many additional U.S. locations are vulnerable to impacts from climate change-driven increases in extreme temperatures, which are not estimated in this analysis.

METHODS

The analysis quantifies the impact of climate change on mortality from both extreme heat and extreme cold in 49 large cities across the U.S. (Figure 4.1).[18] The steps below outline the general approach to this analysis. For more detailed information, please refer to Appendix E.

STEP 1 | For each of the 49 U.S. cities analyzed, project changes in daily temperature patterns in scenarios with 2°C and 4°C of global warming.

STEP 2 | Estimate changes in mortality in urban areas associated with extreme temperature using U.S. EPA's Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE) and methods described in Mills et al. (2014), updated for U.S. EPA (2017).[19]

STEP 3 | Identify the Census tracts where the change in mortality rates are projected to be highest (defined as those in the highest tercile).

STEP 4 | Calculate the likelihood that individuals who are socially vulnerable currently live in these high-impact areas relative to those who are not.[20]

CHAPTER 4

EXTREME TEMPERATURE AND HEALTH

Key Findings on Temperature Mortality

Climate-driven changes in extreme temperatures—particularly increases in high-temperature days—are projected to result in an annual increase in the number of premature deaths in the 49 cities studied. The projected increases are highest in the cities located in the Midwest, Southeast, and Northeast.

Figure 4.2 shows the estimated changes in combined heat and cold mortality rates per 100,000 people due to climate-driven changes in extreme temperatures in the 49 cities included in the analysis. Although global warming is projected to result in fewer deaths from extremely cold days, these reductions are outweighed by higher mortality rates from increases in extremely hot days. As shown in Figure 4.2, some of the highest projected increases in mortality rates occur in cities in Ohio and Pennsylvania, likely because these cities are not as heat-adapted as many warmer-climate locales (see Appendix E for more details, including baseline mortality rates for these cities).[21,22] Cities in Louisiana and Florida are also projected to experience relatively high increases in mortality rates. To place these rates in context, the combined age-adjusted mortality rates for influenza and pneumonia in 2018 were 14.9 per 100,000.[23]

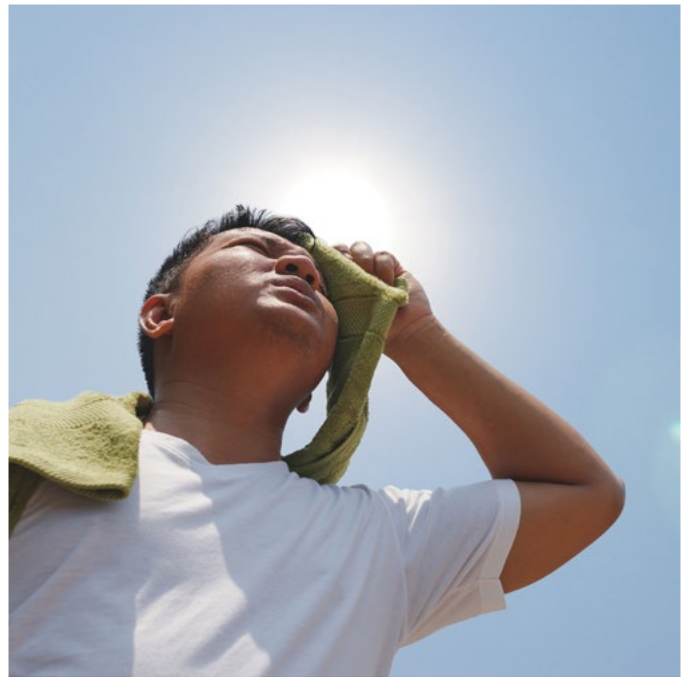
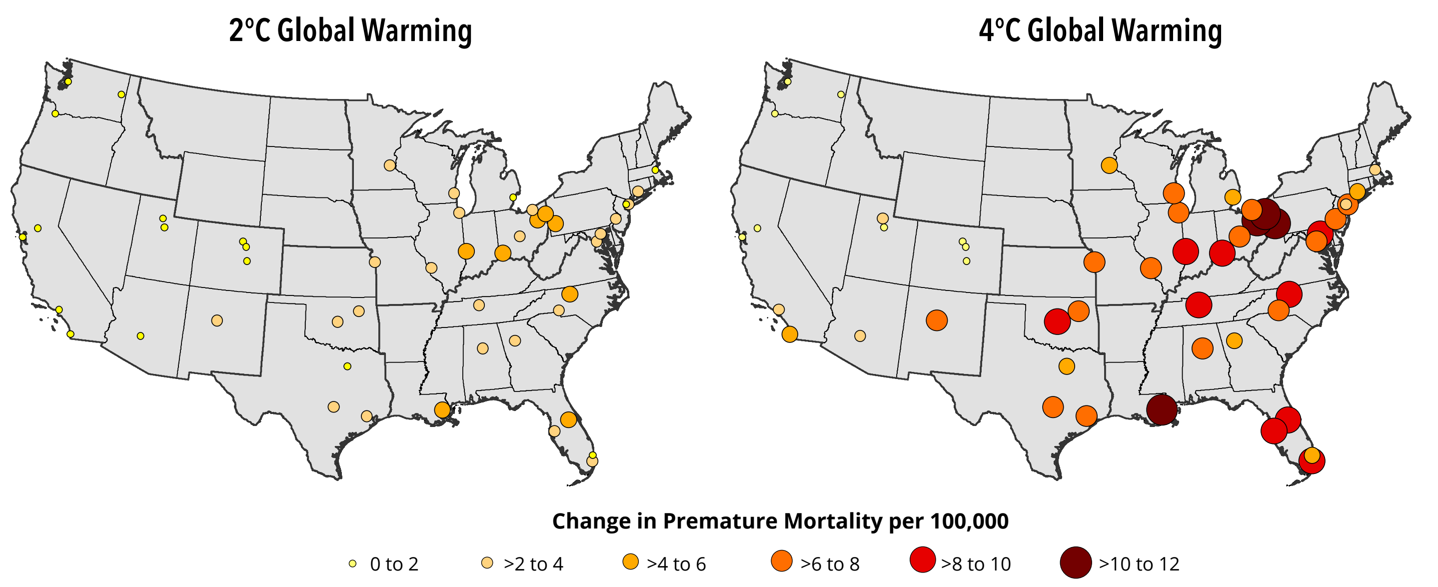


Figure 4.2 – Projected Increase in Annual Premature Mortality Rates due to Extreme Temperatures

Levels of global warming are relative to the 1986-2005 average. Results are calculated for each of the 49 cities included in the analysis (see Figure 4.1). Importantly, cities that are not included in the analysis may still experience significant temperature mortality impacts from climate change.



EXTREME TEMPERATURE AND HEALTH

Key Findings on Social Vulnerability and Temperature Mortality

In the cities analyzed, minorities and those with low income are more likely than non-minorities and those with higher income to currently live in areas with the highest projected increases in temperature mortality from climate-driven changes in extreme temperatures. Black and African American individuals are 40-59% more likely than non-Black and non-African American individuals to currently live in high-impact areas.

Increases in extreme temperature-related premature mortality are projected to occur in many U.S. cities, but the largest increases are expected in areas with larger shares of low income and minority populations. This finding is consistent with the results of prior literature on social vulnerability and temperature mortality.[24] Figure 4.3 presents the likelihoods for each socially vulnerable group at the national level, relative to their reference populations.[25]

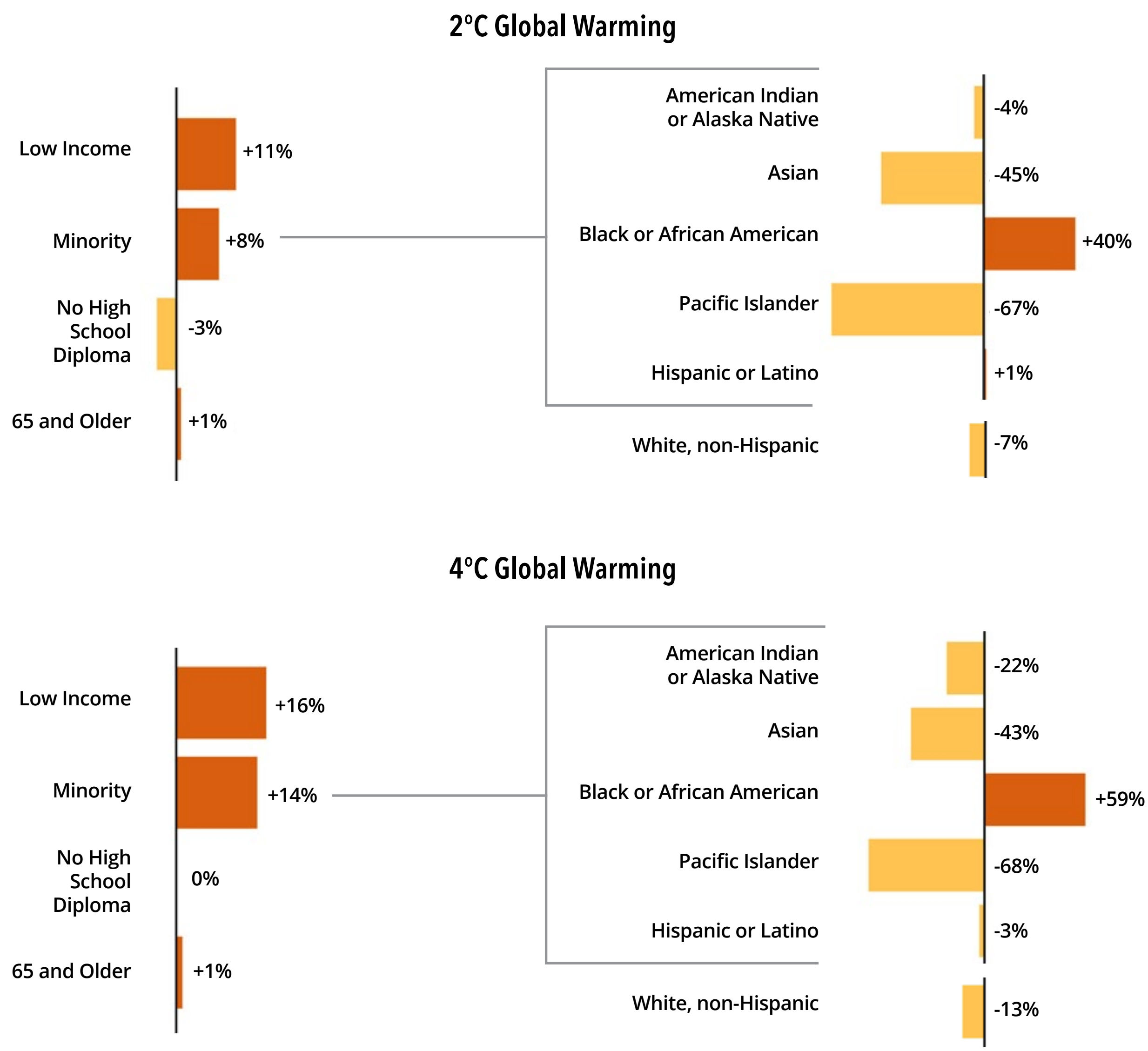
Heat waves are occurring more often than they used to in major cities across the U.S. Their frequency has increased steadily, from an average of two heat waves per year during the 1960s to six per year during the 2010s. For more information, see EPA's Climate Change Indicators website.

In the cities analyzed, Black and African American individuals are 40% more likely than non-Black and non-African American individuals to live in areas with the highest projected increases in extreme temperature related mortality with 2°C of global warming. With 4°C of global warming, this estimate increases to 59%. In contrast, Asian individuals and Pacific Islanders are 43% and 68% less likely to live in high-impact areas with 4°C of global warming. For more information, please refer to Appendix E; note that the chapter and appendix do not present regional results due to the limited spatial domain of the analysis.

Key Findings on Social Vulnerability and Temperature Mortality (continued)

Figure 4.3 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Projected Increases in Premature Mortality due to Climate-Driven Changes in Extreme Temperatures

Results are for the 49 cities included in the analysis (Figure 4.1). The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected increases in mortality relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global warming are relative to the 1986-2005 average.



CHAPTER 5
EXTREME TEMPERATURE AND LABOR

Background

Climate-driven changes in the frequency and intensity of extreme temperatures are expected to result in disruptions in labor sectors where people work outdoors or in indoor environments without air conditioning.[1,2] When temperatures are high, people are at risk of experiencing health and cognitive effects that prevent them from working at optimal levels. As a result, they may spend less time working on hot days, or may not be able to work at all.[3] This results in a shift in the allocation of time to labor, with potentially significant economic implications.

This analysis estimates changes in labor hours in weather-exposed industries associated with climate-driven effects on high-temperature days. Although climate change can also result in fewer extremely cold days, with potential benefits for certain labor sectors in winter months, such benefits were not found in empirical data upon which this analysis is based.[4] In addition, this analysis does not evaluate changes in labor hours that may result from other climate-driven weather events that may affect labor, such as thunderstorms, rain events, and snow.

The analysis focuses on the following weather-exposed industries: agriculture, forestry, fishing, and hunting; mining; construction; manufacturing; and transportation and utilities.[5] The approach considers adaptation responses implemented in recent history, but not new advancements in technology or behavior, or increased access for those who are socially vulnerable. It then estimates the risks that socially vulnerable populations currently live in areas where the estimated labor hour losses are projected to be highest. The next section describes why socially vulnerable populations in the U.S. may be particularly at risk of experiencing labor impacts.

Social Vulnerability and Labor

Table 5.1 summarizes findings from the scientific literature on the ways in which socially vulnerable groups may experience greater reductions in labor hours from climate-driven changes in extreme temperature. Workers in weather-exposed industries tend to be lower-income individuals who are particularly reliant on their income for meeting basic needs.[6] For example, the average construction worker earns 25% less than the median worker in the U.S., and laborers in the farming, fishing and forestry sectors earn an average of 48% less.[7] These individuals are therefore very sensitive to any decrease in pay associated with reduced labor hours resulting from high-temperature days. As a result, some workers may opt to work during high-temperature days, if given the choice, thereby putting their health at risk. Or, in some cases, employers might pressure employees to work on extremely hot days. Since having low income may also be associated with a lack of access to quality healthcare, these individuals may be more vulnerable to health risks from heat exposure.[8]

Table 5.1 – Social Vulnerability and Labor

CATEGORY	DESCRIPTION
Low Income	Workers with low income levels may experience more hardship associated with reduced pay from lost labor hours.[9] Low income may also be associated with lack of access to insurance or healthcare, making these individuals more vulnerable to the potential health effects of heat exposure.
Minority	There is a lack of research on the link between minority status and labor impacts from extreme temperatures. However, individual racial and ethnic identity has been strongly associated with heat-associated morbidity and mortality in the U.S.[10]
No High School Diploma	There is a lack of comprehensive literature on the link between educational attainment and labor impacts from extreme temperature. However, as described in Appendix E, those with no high school diploma make up significant percentages of workers in the agriculture sector (31%) and construction sector (19%).
65 and Older	Older individuals are more susceptible to the negative health consequences of heat exposure.[11,12]

METHODS

The steps below outline the general approach to the analysis. For more detailed information, please refer to Appendix E.

STEP 1 | Estimate the change in the number of "degree days" over 90°F for each Census tract in scenarios 2°C and 4°C of global warming.[13]

STEP 2 | Estimate the labor hours lost per weather-exposed worker due to high-temperature days using the approach presented in Neidell et al. (2021).[14]

STEP 3 | Identify the Census tracts with the highest rates of labor hour losses per weather-exposed worker (defined as those in the highest tercile).

STEP 4 | Calculate the likelihood that individuals who are socially vulnerable currently live in these high-impact areas relative to those who are not.[15]

CHAPTER 5

EXTREME TEMPERATURE AND LABOR

Key Findings on Lost Labor Hours

With 2°C of global warming, climate-driven increases in high-temperature days are projected to result in 14 lost labor hours per year, on average, for weather-exposed workers in the U.S. With 4°C of global warming, the average number of hours lost per weather-exposed worker increases to 34 hours per year.

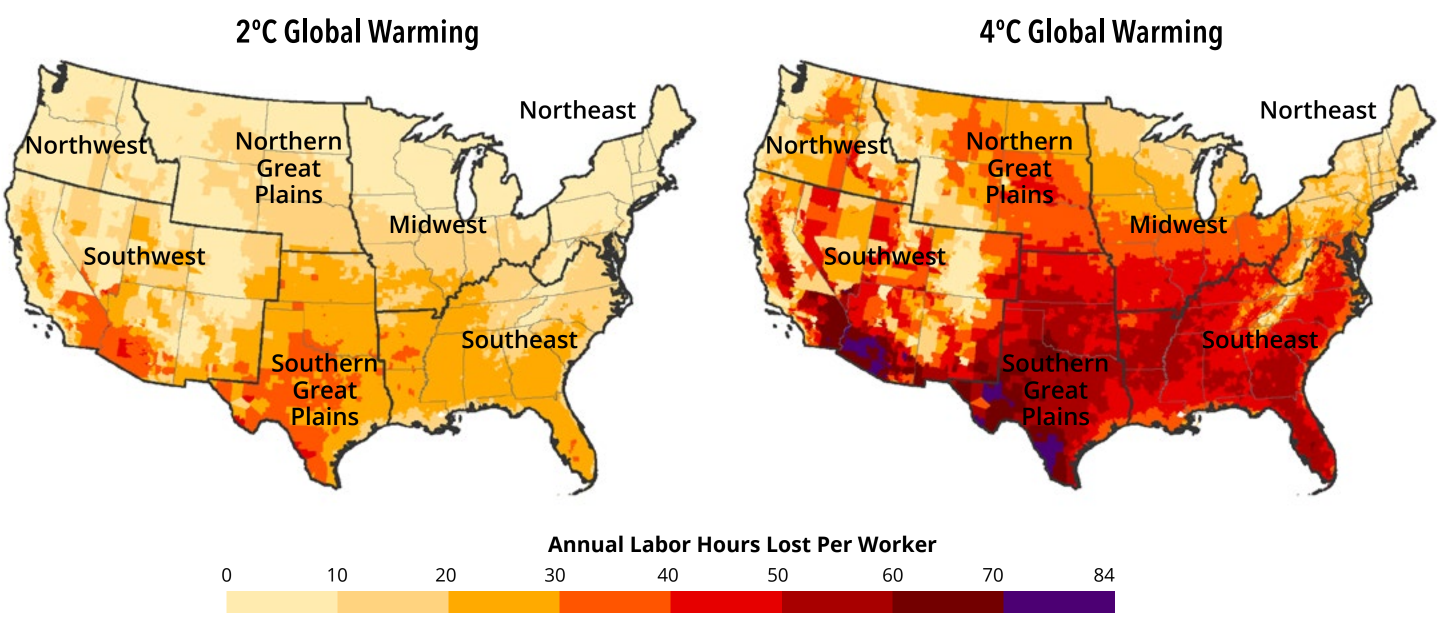
Climate change is projected to result in a significant increase in the number of days above 90°F across the country, resulting in reductions in labor hours for weather-exposed workers.[16] Figure 5.1 shows the projected labor hours lost per weather-exposed worker by Census tract, and Table 5.2 summarizes the average, per-worker hours lost at the national and regional levels. With 2°C of global warming, the average weather-exposed worker in the Southern Great Plains is projected to lose 26 hours of labor per year, and this increases to 50 hours with 4°C of global warming. With 4°C of global warming, weather-exposed workers in some Census tracts located in the Southwest and Southern Great Plains are projected to lose up to 84 hours per worker per year.

Table 5.2 – Projected Average Annual Labor Hours Lost per Weather-Exposed Worker due to Climate-Driven Effects on High-Temperature Days

	GLOBAL WARMING (RELATIVE TO 1986-2005)	
REGION	**2°C**	**4°C**
Midwest	11	30
Northeast	7	24
Northern Great Plains	11	30
Northwest	5	15
Southeast	20	44
Southern Great Plains	26	50
Southwest	17	34
National Total	**14**	**34**

Figure 5.1 – Projected Labor Hours Lost Each Year due to Climate Change

Levels of global warming are relative to the 1986-2005 average. Results are calculated at the Census tract level.



EXTREME TEMPERATURE AND LABOR

Key Findings on Social Vulnerability in the Labor Sector

With 2°C of global warming, minorities are 35% more likely than non-minorities to currently live in areas with the highest projected labor hours losses due to climate-driven increases in high-temperature days. Hispanic and Latino individuals are 43% more likely than non-Hispanic and non-Latino individuals to live in these high-impact areas. In addition, those with low income or no high school diploma are approximately 25% more likely than individuals in their reference populations to live in high-impact areas.

Using the data presented in Figure 5.1, the analysis identifies the Census tracts with the highest labor hour losses due to climate-driven increases in high-temperature days. The high-impact areas are defined as Census tracts where impacts are in the highest tercile. On average, high-impact Census tracts across the contiguous U.S. are projected to experience increases of 19 to 49 lost labor hours per worker with 2°C of global warming, and 42 to 84 lost labor hours per worker with 4°C of global warming.[17] Following the steps outlined in the Approach chapter, the analysis then estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not.

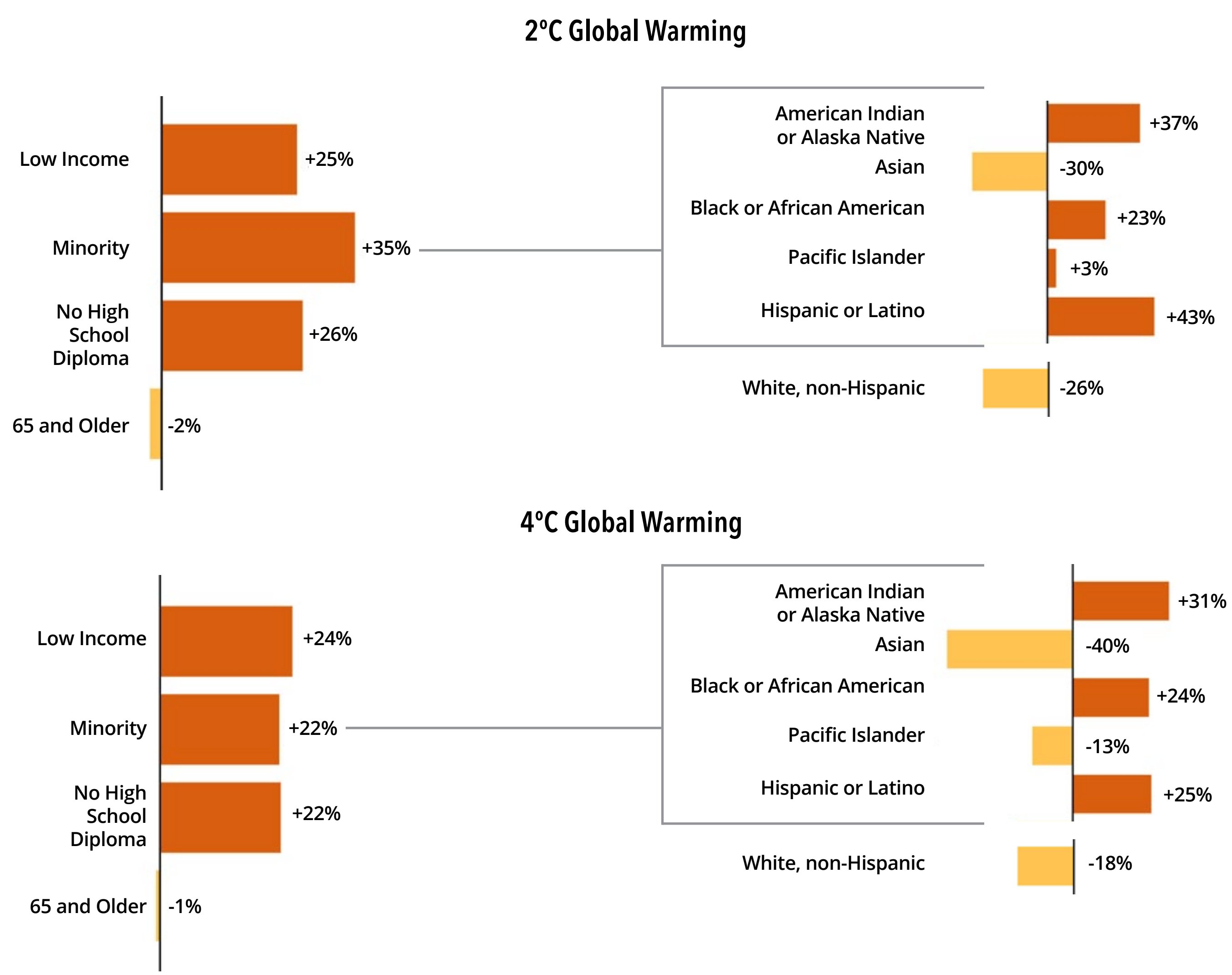
Figure 5.2 presents the likelihood that individuals from each socially vulnerable group examined in this report currently live in areas that are projected to have the highest losses in labor hours due to climate-driven increases in high-temperature days, relative to individuals from their reference populations.[18] The analysis finds that three of the four socially vulnerable populations (minorities, those with low income, and those without a high school diploma) have a higher likelihood compared to their reference populations of living in high-impact areas.[19]

At both levels of future warming, minorities, those with low income, and those without a high school diploma are all estimated to be over 20% more likely than individuals in the reference populations to currently live in areas that are projected to have the greatest labor hour losses due to climate change. Minorities, in particular, are 35% more likely than non-minorities to currently live in areas that are projected to have the highest labor hour losses with 2°C of global warming. Of all the individual racial and ethnic groups that comprise the minority category, Hispanic and Latino individuals are found to have the highest comparative risk (43% higher than non-Hispanic and non-Latino individuals) of living in high-impact areas. Individuals ages 65 and older are not expected to experience impacts that are significantly different from those experienced by younger individuals.

Key Findings on Social Vulnerability in the Labor Sector (continued)

Figure 5.2 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Projected Labor Hour Losses Due to Climate-Driven Increases in High-Temperature Days

The bar charts present the relative likelihood that weather-exposed workers in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected labor hour losses relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global warming are relative to the 1986-2005 average.



EXTREME TEMPERATURE AND LABOR

Key Findings on Regional Impacts

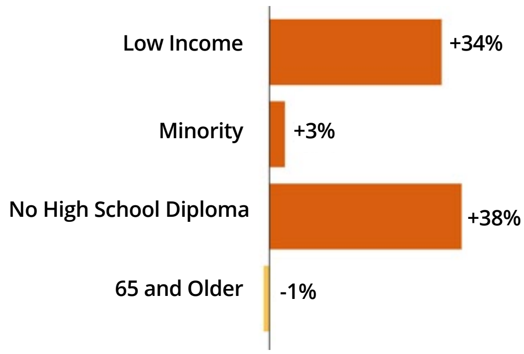
In all regions except the Midwest, minorities are found to have a higher risk than non-minorities of currently living in areas with the highest projected losses in labor hours due to climate-driven increases in high-temperature days. In all regions except the Northeast, those with low income or no high school diploma are found to have a higher risk relative to individuals in their reference populations of currently living in high-impact areas.

The regional analysis follows the same approach as the national-level analysis, first identifying the areas within each region that are projected to experience the highest impacts of climate change (see Appendix F) and then estimating the likelihood that those who are socially vulnerable currently live in these areas compared to those who are not. For each region, the charts show the likelihood that weather-exposed workers in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected labor hour losses due to climate-driven increases in high-temperature days, relative to weather-exposed workers in the reference groups (e.g., non-low income).

The results shown are for a scenario with global warming of 2°C relative to 1986 to 2005. Please refer to Appendix F for results in the scenario with 4°C of warming. As described in the Approach chapter, a finding that a socially vulnerable group is less likely to experience risks does not suggest that they will not experience negative impacts; rather, such findings refer to the degree to which the estimated impacts are projected to be disproportionate relative to the reference population.

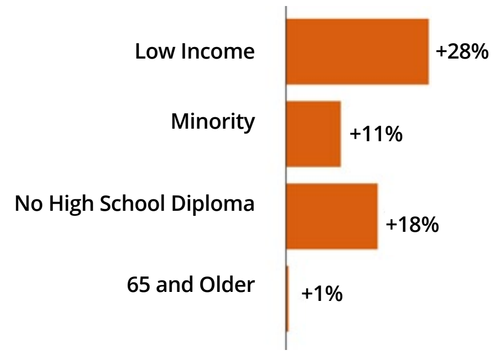
Key Findings on Regional Impacts (continued)

NORTHWEST
2°C Global Warming



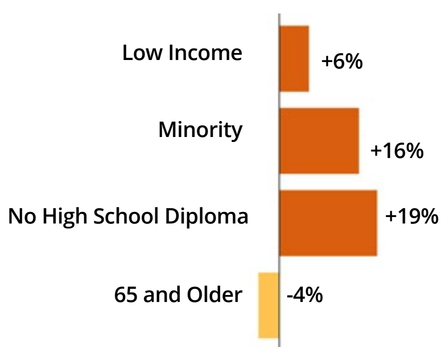
- In the Northwest, individuals without a high school diploma are 38% more likely than those with a high school diploma to currently live in areas with the highest projected losses of labor hours due to climate-driven increases in high-temperature days.
- In the Northwest, low income workers are 34% more likely than those with higher income to currently live in high-impact areas.

SOUTHWEST
2°C Global Warming



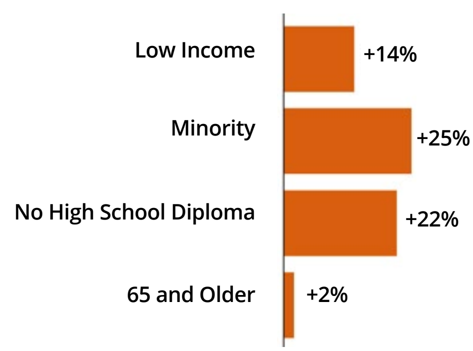
- In the Southwest, low income individuals are 28% more likely than those with higher income to currently live in areas with the highest projected losses of labor hours due to climate-driven increases in high-temperature days.
- In the Southwest, individuals without a high school diploma are 18% more likely than those with a high school diploma to currently live in high-impact areas.

NORTHERN GREAT PLAINS
2°C Global Warming



- In the Northern Great Plains, individuals without a high school diploma are 19% more likely than those with a high school diploma to currently live in areas with the highest projected losses of labor hours due to climate-driven increases in high-temperature days.
- In the Northern Great Plains, minorities are 16% more likely than non-minorities to currently live in high-impact areas.

SOUTHERN GREAT PLAINS
2°C Global Warming

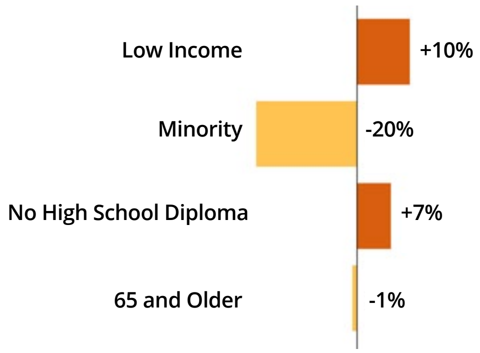


- In the Southern Great Plains, minorities are 25% more likely than non-minorities to currently live in areas with the highest projected losses of labor hours due to climate-driven increases in high-temperature days.
- In the Southern Great Plains, individuals without a high school diploma are 22% more likely than those with a high school diploma to currently live in high-impact areas.

Key Findings on Regional Impacts (continued)

MIDWEST

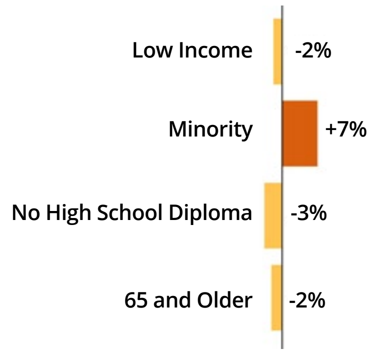
2°C Global Warming



- In the Midwest, those with low income are 10% more likely than those with higher income to currently live in areas with the highest projected losses of labor hours due to climate-driven increases in high-temperature days.
- In the Midwest, minorities are about 20% *less* likely than non-minorities to live in high-impact areas. This is likely because the areas in the Midwest that are projected to experience more substantial increases in high-temperature days are less racially and ethnically diverse areas.

NORTHEAST

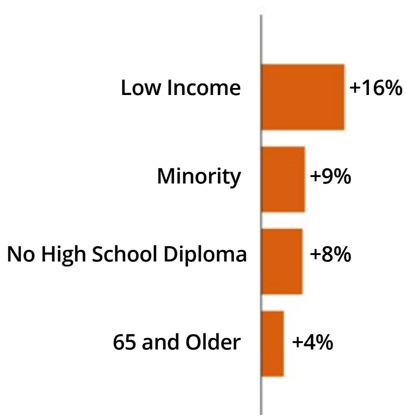
2°C Global Warming



- Compared to other regions, the Northeast is an area where higher losses of labor hours due to climate change are projected to affect socially vulnerable and non-socially vulnerable populations more equally.
- Minorities have a slightly higher likelihood (7%) relative to non-minorities of currently living in areas with the highest projected losses in labor hours.

SOUTHEAST

2°C Global Warming



- In the Southeast, low income individuals are 16% more likely than those with higher income to currently live in areas with the highest projected losses of labor hours due to climate-driven increases in high-temperature days.
- In the Southwest, minorities are 9% more likely than non-minorities to currently live in high-impact areas.

CHAPTER 6
COASTAL FLOODING AND TRAFFIC

Background

Roads represent the primary mode of transportation in the U.S. and are a crucial element of the U.S. economy, facilitating the movement of an ever-growing number of people and goods. According to the latest National Household Travel Survey, the average American takes 1,500 trips per year and the average driver spends almost an hour a day behind the wheel.[1] Already, drivers face weather-related delays across the country, and these delays are projected to worsen under climate change. Specifically, increasing temperatures are likely to cause accelerated aging of road binder materials and rutting of asphalt. Heavy precipitation is likely to cause cracking and erosion. High-tide flooding, also known as "tidal flooding" or "nuisance flooding," is becoming increasingly common as sea levels rise. All these climate hazards can cause traffic delays for drivers as they navigate damaged road surfaces or are forced to take longer routes to avoid roads that are closed for maintenance or repair.

This analysis estimates traffic delays in coastal areas resulting from climate change-driven increases in high-tide flooding. Impacts to socially vulnerable populations are analyzed based on current demographics in the areas most affected by delays from high-tide flooding. In addition, the analysis examines disproportionate impacts associated with potential decisions about which roads should receive protective adaptation that could mitigate these delays. A separate analysis, presented in Appendix G, examines the potential impacts of extreme temperature and precipitation on roads and resulting traffic delays. This analysis finds that although the delays associated with temperature and precipitation are likely to be significant in many areas across the contiguous U.S., there are fewer disproportionate impacts to socially vulnerable populations; as a result, this chapter focuses on the analysis of delays associated with high-tide flooding.

COASTAL FLOODING AND TRAFFIC

Social Vulnerability and Traffic Delays from High-Tide Flooding

Table 6.1 summarizes findings from the scientific literature on the ways in which traffic delays caused by high-tide flooding could disproportionately affect socially vulnerable populations. In general, to the extent that traffic hinders mobility, it is likely to have more significant impacts on those who require reliable transportation for employment, social engagement, and access to health care. As described in Table 6.1, limits on mobility presented by traffic delays have been shown in multiple studies to disproportionately affect socially vulnerable populations through effects on income, employment security, and health status.[2]

Coastal road networks and the communities they support are increasingly at risk of impacts from sea level rise and intensifying coastal flood events.

Table 6.1 – Social Vulnerability and Traffic Delays

CATEGORY	DESCRIPTION
Low Income	Low income workers are more likely to get paid on an hourly basis and work in jobs with fixed hours.[3] As a result, they may be more vulnerable to consequences of unexpected traffic delays.
Minority	Increased travel times may reduce the accessibility of employment or social engagement, exacerbating trends of reduced proximity to job opportunities experienced by minority populations.[4]
No High School Diploma	There is a lack of comprehensive research on the association between educational attainment and vulnerability to traffic delay-related impacts. However, to the extent that those with lower educational attainment have lower job security, road delays could further exacerbate this vulnerability.[5]
65 and Older	Limited access to transportation among older adults has been shown to cause missed or delayed medical care appointments,[6] and more, generally, to limit access to health care.[7] Traffic delays associated with climate change may further exacerbate this vulnerability.

METHODS

The steps below outline the general approach to the analysis. For more detailed information, please refer to Appendix G.

STEP 1 | Project extent and duration of high-tide flooding resulting from SLR using data from Sweet et al. (2018).[8]

STEP 2 | Using the methods of Fant et al. (2021),[9] identify coastal roads that are vulnerable to inundation from high-tide flooding with 50 cm and 100 cm of global SLR. Estimate traffic delays by Census tract using location-specific daily traffic data adjusted for the projected duration of high-tide flooding and the availability of alternative routes. Identify which roads could be excluded from protective adaptation measures, if adaptation decisions were made using a benefit-cost test in which the cost of the adaptation measures is compared to the value of the avoided delays.[10,11]

STEP 3 | Identify the Census tracts with the highest hours of annual traffic delays per person (defined as those in the highest tercile). Identify the Census tracts where the highest percentage of at-risk roads could be excluded from protective adaptation measures that could reduce traffic delays.

STEP 4 | Calculate the likelihood that individuals who are socially vulnerable currently live in these high-impact areas relative to those who are not.[12]

CHAPTER 6

COASTAL FLOODING AND TRAFFIC

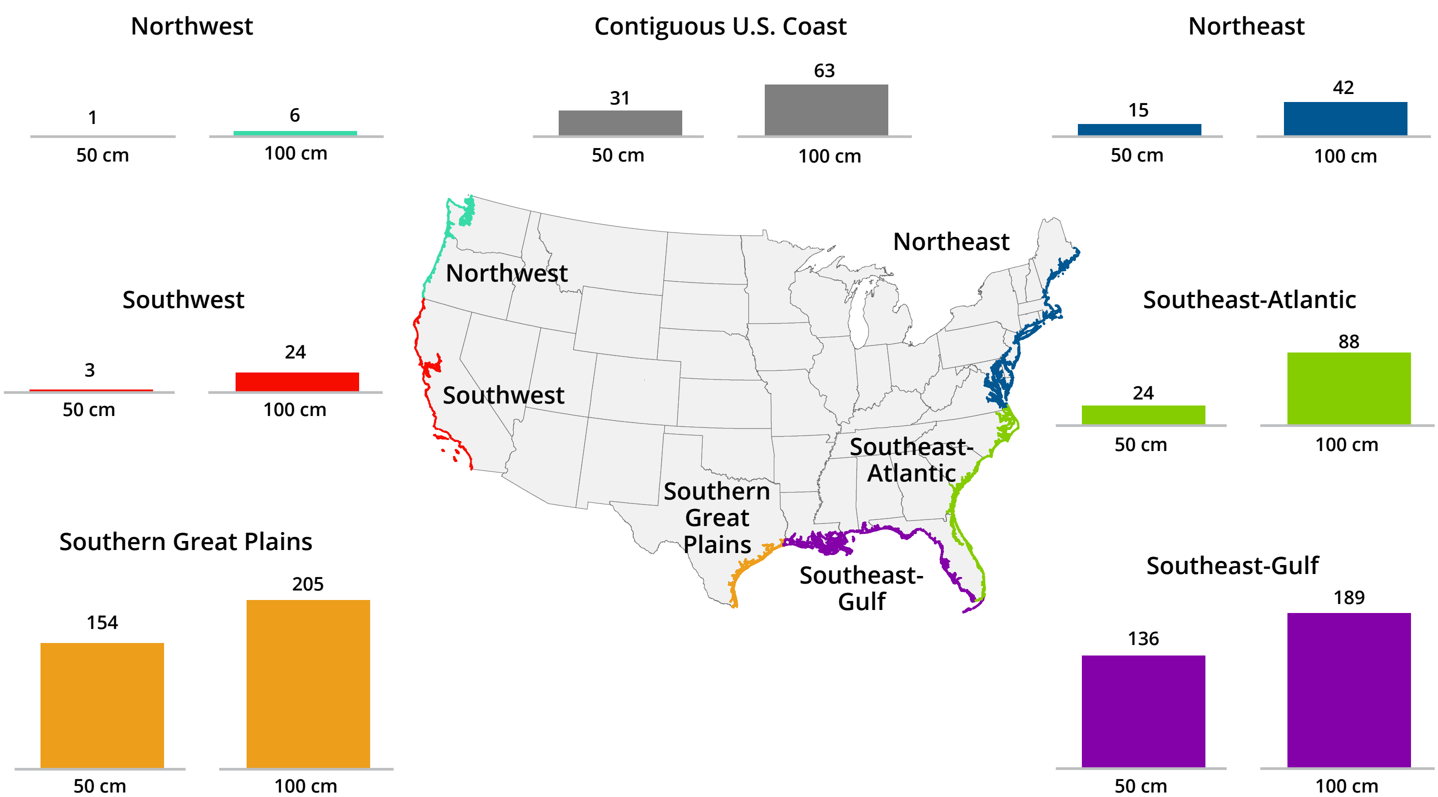
Key Findings on Traffic Delays from High-Tide Flooding

With 100 cm of global mean SLR, coastal traffic delays associated with climate-driven changes in high-tide flooding are projected to increase by an average of 63 hours per person annually. The projected impacts are highest in the Southern Great Plains and Southeast-Gulf regions, where per-person traffic delays are estimated at 205 and 189 hours, respectively, annually.

Figure 6.1 shows the average, annual traffic delays by region and nationwide with 50 cm and 100 cm of global SLR (relative to the year 2000), focusing on the Census tracts with the greatest traffic delays in each geographic area. At 100 cm, projected average traffic delays are highest in the Southern Great Plains and Southeast-Gulf, reaching 205 and 189 hours per person per year, respectively.[13] Although projected traffic delays are relatively low in the western regions, on average, there are some Census tracts that have significant projected delays, especially with global sea level rise of 100 cm or more.

Figure 6.1 – Projected Traffic Delays from High-Tide Flooding in Coastal Areas (Hours Per Person Per Year)

Levels of global sea level rise are relative to the year 2000. The map shows the coastal regions included in the analysis, but does not show the specific areas projected to experience high-tide flooding traffic delays.



COASTAL FLOODING AND TRAFFIC

Key Findings on Social Vulnerability and Traffic Delays from High-Tide Flooding

Traffic delays from high-tide flooding are projected to disproportionately affect those with low income, minorities, and those without a high school diploma. In addition, some racial and ethnic groups–American Indian and Alaska Native individuals, Asian individuals, and Pacific Islanders, in particular–are projected to be disproportionately at risk of living in areas excluded from adaptation measures that could mitigate the impacts of high-tide flooding delays.

Using the data presented in Figure 6.1, the analysis identifies the Census tracts with the highest traffic delays from climate-driven changes in high-tide flooding. The high-impact areas are defined as Census tracts where impacts are in the highest tercile. On average, high-impact Census tracts are projected to experience annual, per-person traffic delays of 101 hours with 50 cm of global SLR, and 324 hours with 100 cm of global SLR. Following the steps outlined in the Approach chapter, the analysis then estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not.

Figure 6.2 presents the likelihoods that individuals from each socially vulnerable group currently live in areas with the highest projected traffic delays from climate-driven high-tide flooding, relative to individuals in their reference populations.[14] With 50 cm of global SLR, minorities are 41% more likely than non-minorities to currently live in areas with the highest projected traffic delays due to climate-driven changes in high-tide flooding. With 100 cm of global SLR, this risk increases to 52%.

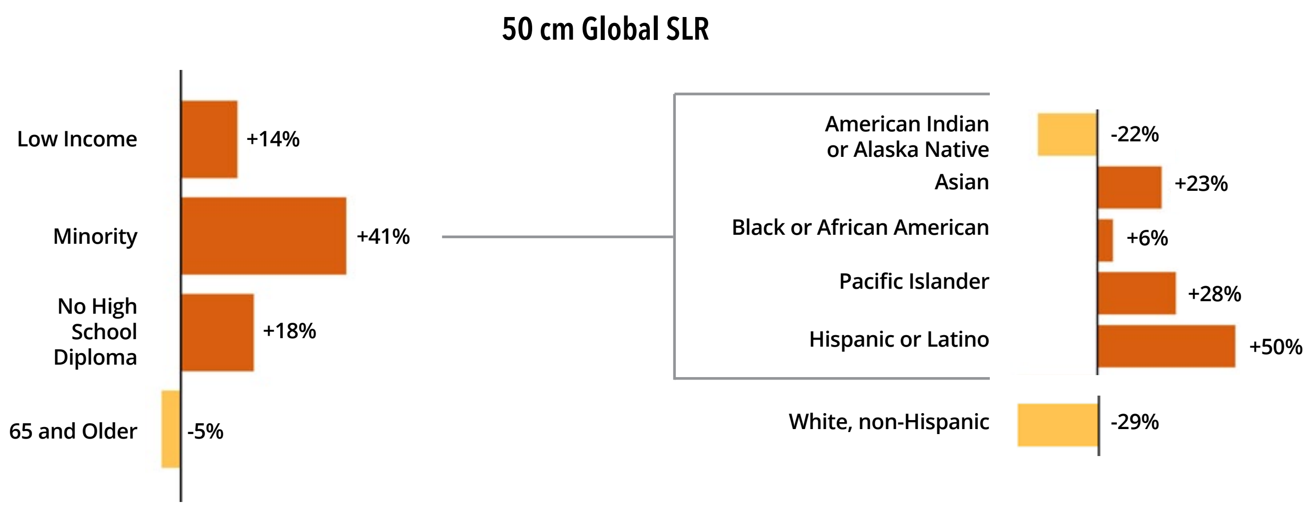
Of the racial and ethnic groups comprising the minority population, Hispanic and Latino individuals, Asian individuals, and Pacific Islanders have the highest risks relative to their reference populations (50%, 23%, and 28%, respectively, with 50 cm of global SLR; and 52%, 60%, and 74%, respectively, with 100 cm of global SLR).

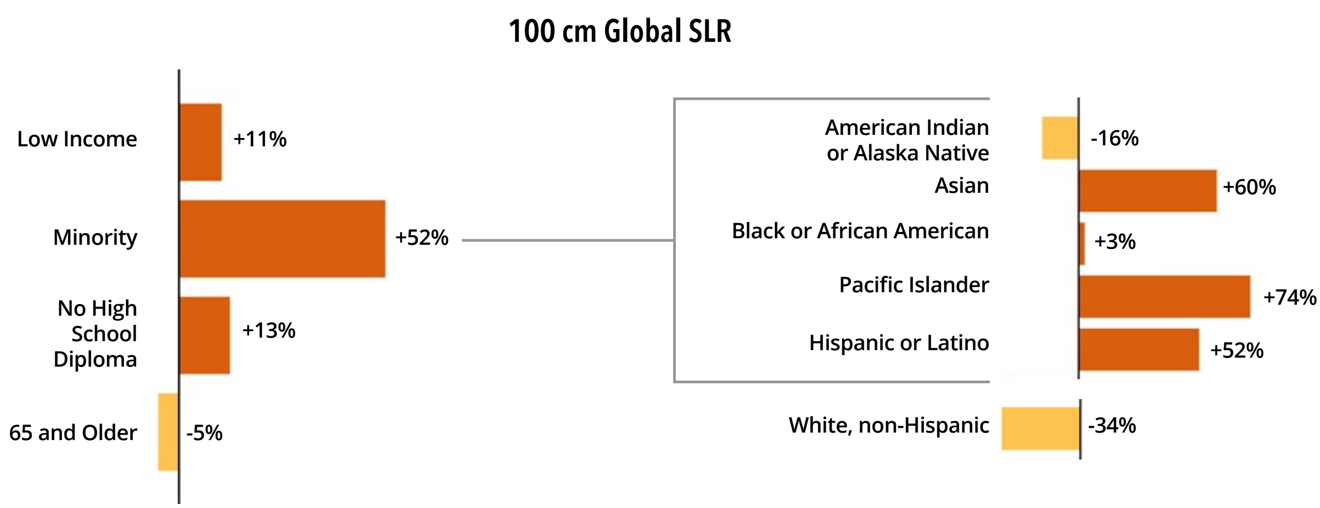
COASTAL FLOODING AND TRAFFIC

Key Findings on Social Vulnerability and Traffic Delays from High-Tide Flooding (continued)

Figure 6.2 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Projected Traffic Delays Due to Climate-Driven Changes in High-Tide Flooding

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected traffic delays relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global SLR are relative to the year 2000.





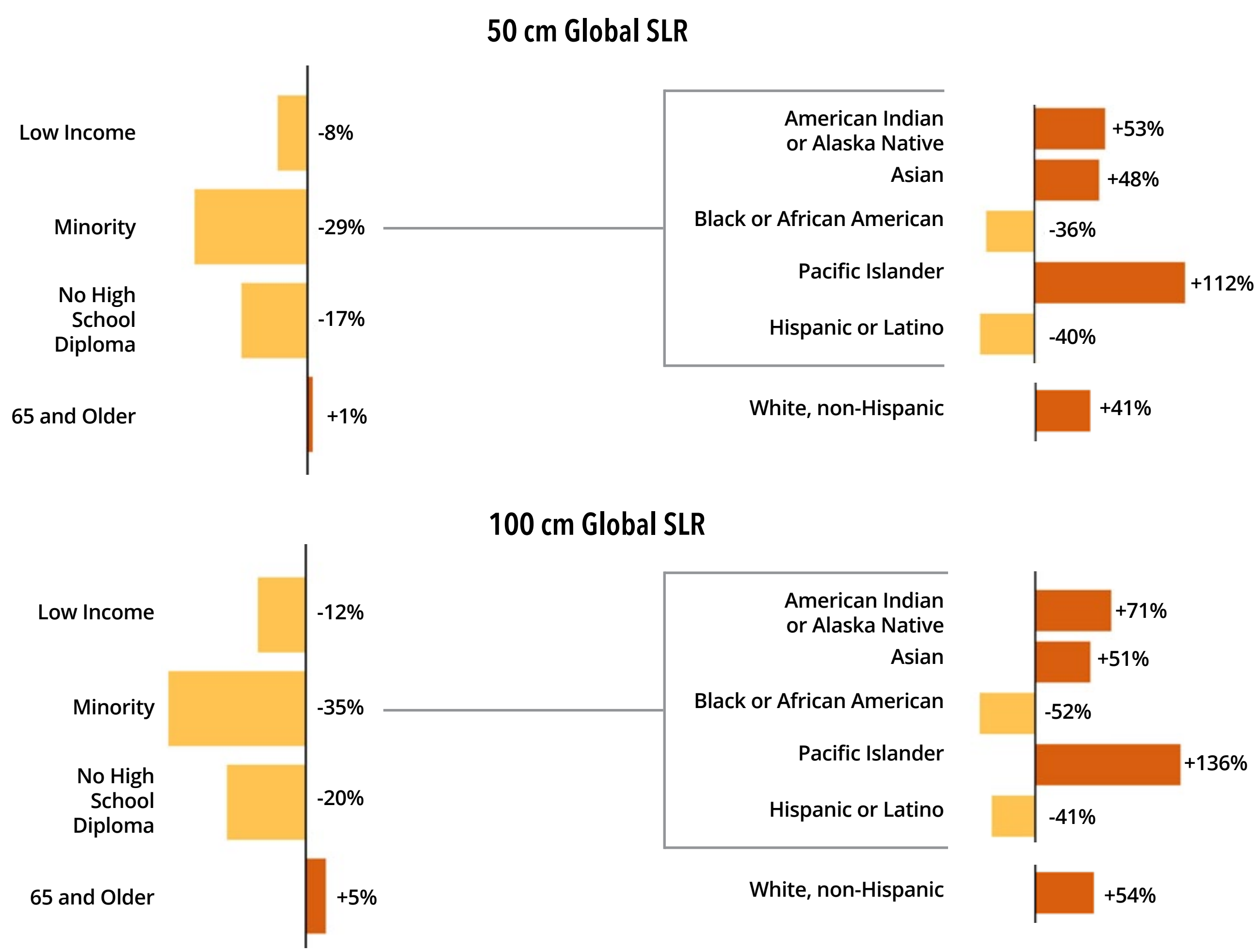
COASTAL FLOODING AND TRAFFIC

Key Findings on Social Vulnerability and Traffic Delays from High-Tide Flooding (continued)

The analysis also estimates the risks to socially vulnerable populations of living in areas that could be excluded from adaptation, using a benefit-cost test in which the cost of the adaptation measures is compared to the value of the avoided delays. As shown in Figure 6.3, this analysis finds that individuals in several racial and ethnic groups are significantly more likely than individuals in their reference populations to currently live in areas where the highest percentage of at-risk roads could be excluded from protective adaptation measures that could reduce flooding delays. Pacific Islanders, in particular, have a 112% higher risk of living in these areas, relative to non-Pacific Islanders, with 50 cm of global SLR.

Figure 6.3 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas Where the Highest Percentage of At-Risk Roads Could be Excluded from Adaptation

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas where the highest percentage of at-risk roads could be excluded from adaptation, relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global SLR are relative to the year 2000.



CHAPTER 6

COASTAL FLOODING AND TRAFFIC

Key Findings on Regional Impacts

In the Northwest, Northeast, Southeast-Atlantic, and Southeast-Gulf, those with no high school diploma are significantly more likely than those with a high school diploma to currently live in areas with the highest projected traffic delays due to high-tide flooding. In many regions, the socially vulnerable groups analyzed are not projected to experience disproportionately higher risks of exclusion from adaptation, and in some cases they are projected to experience lower risks. However, in the Southern Great Plains, those with low income are 18% more likely than those with higher income to live in areas excluded from adaptation.

The regional analysis follows a similar approach as the national-level analysis. First, it identifies the areas within each region that are projected to experience the highest impacts of high-tide flooding and areas where the highest percentage of roads could be excluded from adaptation. Next, it estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not. For each region, the charts show the likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected traffic delays due to increases in high-tide flooding (or the highest percentage of at-risk roads that could be excluded from adaptation) relative to individuals in the reference groups (e.g., non-low income).

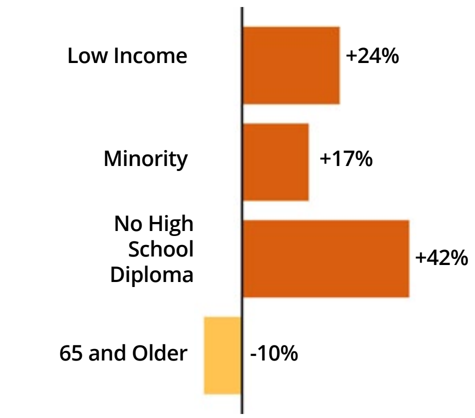
The results shown are for a scenario with global SLR of 50 cm relative to 2000. Please refer to Appendix G for results in the scenario with 100 cm of global SLR. As described in the Approach chapter, a finding that a socially vulnerable group is *less* likely to experience risks does not suggest that they will not experience negative impacts; rather, such findings refer to the degree to which the estimated impacts are projected to be disproportionate relative to the reference population.

Key Findings on Regional Impacts (continued)

NORTHWEST

Higher Traffic Delays

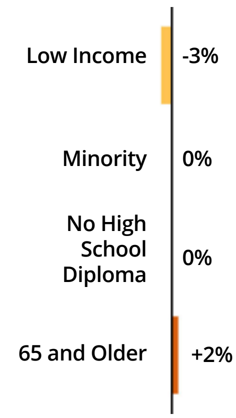
50 cm Global SLR



- In the Northwest, those with no high school diploma are 42% more likely than those with a high school diploma to currently live in areas with the highest projected traffic delays from climate-driven changes in high-tide flooding.

Exclusion from Adaptation

50 cm Global SLR

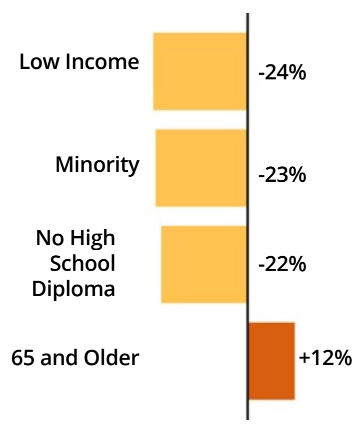


- In the Northwest, the socially vulnerable groups analyzed are not projected to be disproportionately at risk of currently living in areas where the highest percentage of roads could be excluded from adaptation.

SOUTHWEST

Higher Traffic Delays

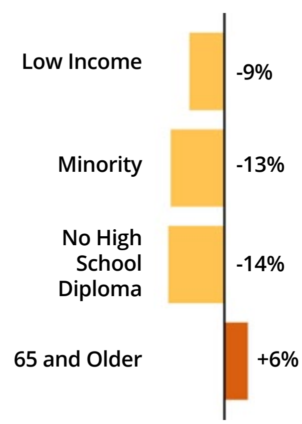
50 cm Global SLR



- In the Southwest, those ages 65 and older are 12% more likely than younger individuals to currently live in areas with the highest projected traffic delays from climate-driven changes in high-tide flooding. However, the other three socially vulnerable groups are 22-24% *less* likely.

Exclusion from Adaptation

50 cm Global SLR



- In the Southwest, the socially vulnerable groups analyzed are projected to be equally or less at risk of exclusion from adaptation relative to their reference populations with 50 cm of global SLR. With 100 cm of global SLR (not shown), those ages 65 and older are projected to be 20% more at risk than younger individuals.

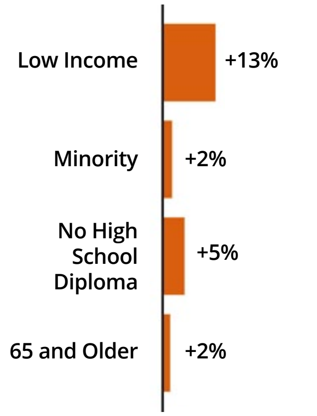
COASTAL FLOODING AND TRAFFIC

Key Findings on Regional Impacts (continued)

SOUTHERN GREAT PLAINS

Higher Traffic Delays

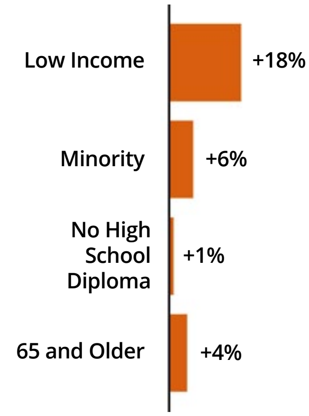
50 cm Global SLR



- In the Southern Great Plains, those with low income are 13% more likely than those with higher income to currently live in areas with the highest projected traffic delays from climate-driven changes in high-tide flooding.

Exclusion from Adaptation

50 cm Global SLR

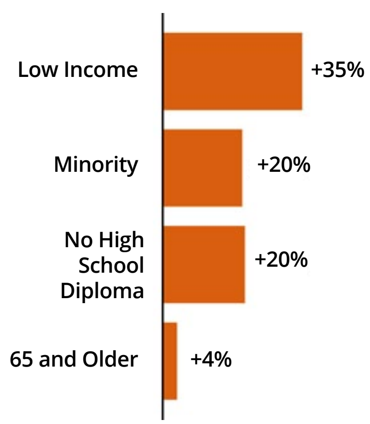


- In the Southern Great Plains, those with low income are 18% more likely than those with higher income to currently live in areas where the highest percentage of at-risk roads could be excluded from adaptation that could reduce traffic delays.

NORTHEAST

Higher Traffic Delays

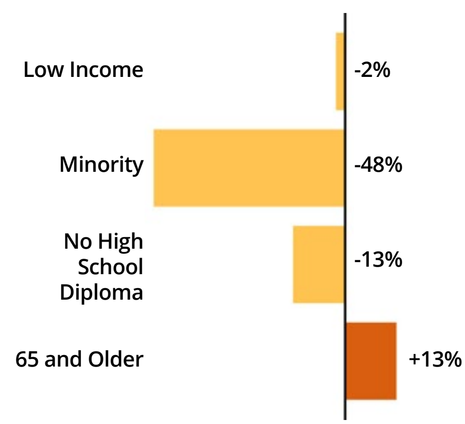
50 cm Global SLR



- In the Northeast, those with low income are 35% more likely than those with higher income to currently live in areas with the highest projected traffic delays from climate-driven changes in high-tide flooding.

Exclusion from Adaptation

50 cm Global SLR

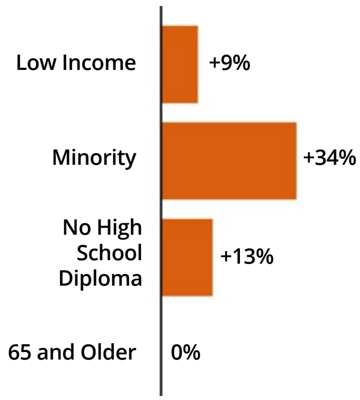


- In the Northeast, those ages 65 and older are 13% more likely than younger individuals to currently live in areas where the highest percentage of at-risk roads could be excluded from adaptation. Minorities are 48% *less* likely than White, non-Hispanic individuals with 50 cm of global SLR.

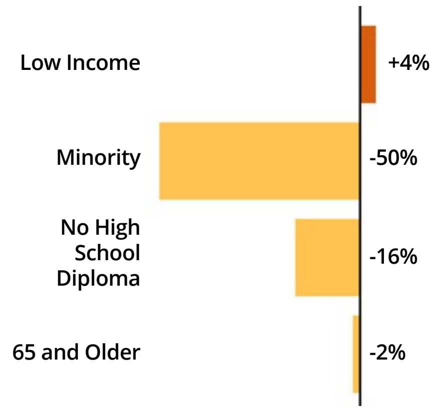
Key Findings on Regional Impacts (continued)

SOUTHEAST-ATLANTIC

Higher Traffic Delays
50 cm Global SLR



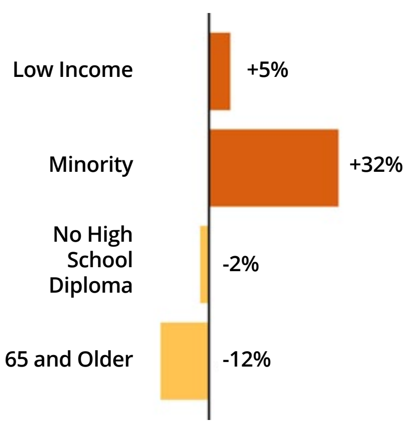
Exclusion from Adaptation
50 cm Global SLR



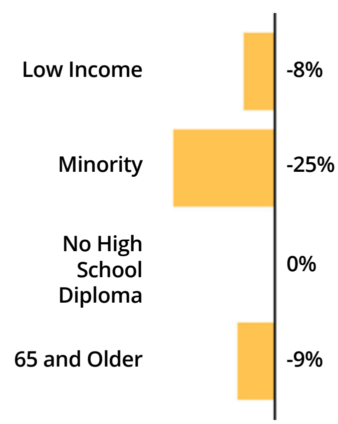
- In the Southeast-Atlantic, minorities are 34% more likely than non-minorities to currently live in areas with the highest projected traffic delays from climate-driven changes in high-tide flooding.
- In the Southeast-Atlantic, the socially vulnerable groups analyzed are projected to be equally or less at risk of exclusion from adaptation relative to their reference populations with 50 cm of global SLR. Minorities are 50% less likely than White, non-Hispanic individuals.

SOUTHEAST-GULF

Higher Traffic Delays
50 cm Global SLR



Exclusion from Adaptation
50 cm Global SLR



- In the Southeast-Gulf, minorities are 32% more likely than non-minorities to currently live in areas with the highest projected traffic delays from climate-driven changes in high-tide flooding.
- In the Southeast-Gulf, the socially vulnerable groups analyzed are projected to be equally or less at risk of exclusion from adaptation relative to their reference populations with 50 cm of global SLR. With 100 cm of global SLR (not shown), however, all groups except for those ages 65 and older are found to be more at risk than their reference populations.

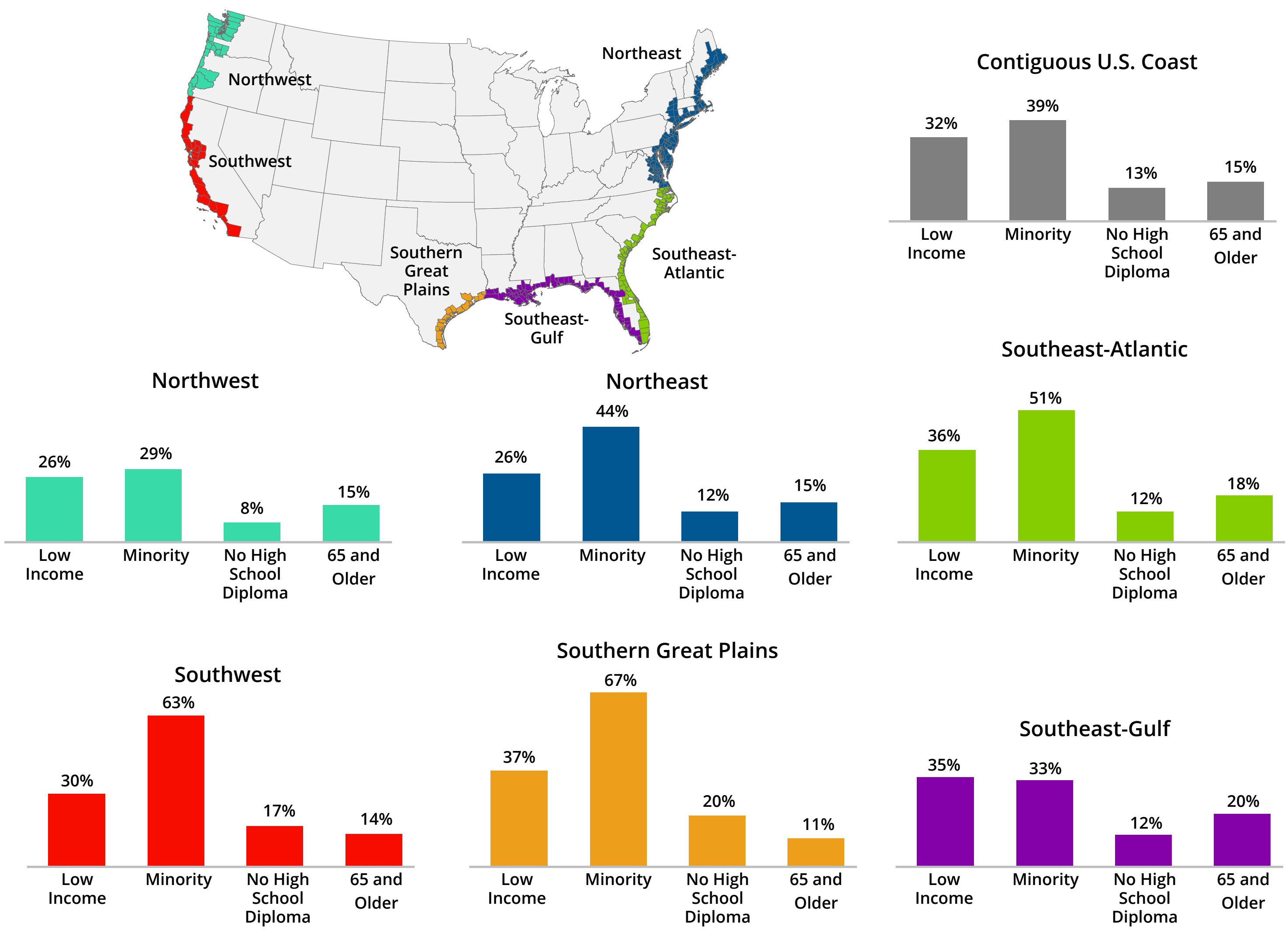
CHAPTER 7
COASTAL FLOODING AND PROPERTY

Background

Coastal counties in the U.S. are home to over 127 million people, or nearly 40% of the nation's total population.[1,2] The coast is a critical component of the U.S. economy; if the U.S. coastal counties were an individual country, it would rank third in the world in gross domestic product, surpassed only by the U.S. and China.[3] Due to climate change, America's coastal properties, infrastructure, and ecosystems—and the economies they support—face increasing threats from ongoing SLR, high tide flooding, storm surge, erosion, ocean acidification, harmful algal blooms, and other hazards.[4]

This analysis estimates the changes in SLR and storm surge resulting from climate change. It then identifies the low-lying properties that are susceptible to these climate hazards and estimates the future damages, with and without adaptation. Next, it estimates risks to socially vulnerable populations of currently living in areas where damages are projected to be highest. The next section describes why socially vulnerable groups may be particularly at risk of property damages from climate-driven SLR and storm surge.

Figure 7.1 – Current Distribution of Socially Vulnerable Populations in the Coastal Counties of the Contiguous U.S.



COASTAL FLOODING AND PROPERTY

Social Vulnerability and Coastal Flooding

Climate change, including current and future SLR, is expected to exacerbate many long-standing inequities that affect socially and economically marginalized groups in the coastal zone.[5] Devastating storms in recent years have provided stark examples of the impacts facing these vulnerable coastal residents, and the long-term consequences for these communities remain uncertain.[6] Adaptive measures, such as seawalls, beach nourishment, and other protective measures including green infrastructure, have been shown to be effective in many instances.[7,8] However, questions of which measures to select, finance, and implement, and when and where to implement them, present significant governance challenges and difficult societal choices. In particular, cases where decisions are made based on whether the benefits of protecting vulnerable property outweigh the cost of the adaptation measures can result in the exclusion of areas with lower market values, which is where socially vulnerable communities are more likely to reside.[9]

Table 7.1 summarizes findings from the literature on ways in which socially vulnerable populations may have heightened risk of impacts from coastal flooding. Figure 7.1 presents the distribution of individuals in each of these groups across the coastal counties of the contiguous U.S. As shown, minorities account for 39% of the population in these counties, low income individuals account for 32%, individuals 65 and older account for 15%, and individuals without a high school diploma account for 13%.

Table 7.1 – Social Vulnerability and Coastal Flooding

CATEGORY	DESCRIPTION
Low Income	Residents of low-lying affordable housing in the coastal zone tend to be low income individuals living in old and poor-quality structures, which are especially vulnerable to coastal floods.[10,11] Low income individuals are also more likely to be adversely affected as they have fewer financial resources to protect against and recover from flooding damage or loss of property.
Minority	Racial and ethnic wealth gaps leave many minority groups vulnerable to exclusion from adaptation based on economic factors.[12]
No High School Diploma	There is a lack of research on the link between educational attainment and vulnerability to impacts from SLR and storm surge. However, studies show that socioeconomic and educational factors may impede individuals' ability to prepare for, respond to, and cope with risks of climate change.[13]
65 and Older	Coastal communities are often a preferred retirement destination for older adults, despite the growing risks of SLR and storm surge. The unique physical and psychosocial challenges of the population ages 65 and over may affect their ability to prepare, cope with, and recover from hazardous events.[14]

METHODS

The steps below outline the general approach to the analysis. For more detailed information, please refer to Appendix H.

STEP 1 | Project local SLR associated with global average SLR of 50 cm and 100 cm for 302 coastal counties in the contiguous U.S.[15] Project storm surge heights based on data from local tide gauges.

STEP 2 | Using the National Coastal Property Model (NCPM), identify coastal areas that are projected to be at risk of permanent inundation from SLR. In addition, identify the areas that could be excluded from adaptation, if adaptation decisions are based on a benefit-cost test in which the cost of the adaptation measures is compared to the value of the avoided damages.[16]

STEP 3 | Identify the Census block groups where the highest percentage of land is lost due to inundation from SLR.[17] In addition, identify the Census block groups where the highest percentage of land at risk of inundation is excluded from adaptation in a scenario where adaptation decisions are made using a benefit-cost test.

STEP 4 | Calculate the likelihood that individuals who are socially vulnerable currently live in these high-impact areas relative to those who are not.[18]

COASTAL FLOODING AND PROPERTY

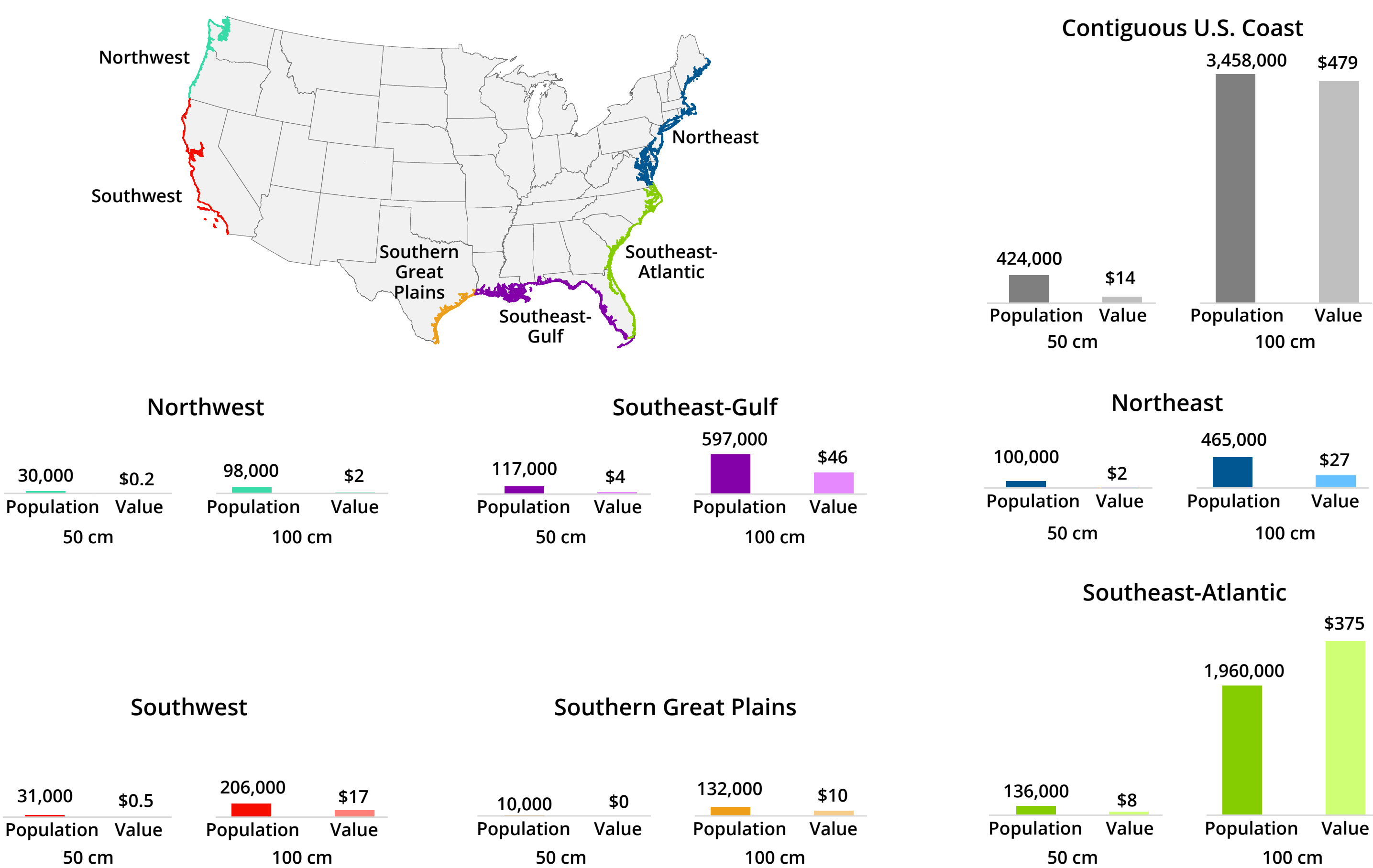
Key Findings on Areas at Risk of Inundation due to Sea Level Rise

With 50 cm of global SLR, coastal areas in the contiguous U.S. that are currently home to over 400,000 people are projected to be at risk of inundation. With 100 cm of global SLR, the number of people living in areas at risk of inundation increases to 3.5 million. The Southeast-Atlantic region is home to the greatest number of people (2.0 million under 100 cm of SLR) who currently reside in areas projected to be vulnerable to inundation, followed by the Southeast-Gulf and Northeast.

For each coastal region of the contiguous U.S., Figure 7.2 identifies the numbers of people and values of properties in areas projected to be at risk of inundation with 50 cm and 100 cm of global SLR.[19] Across all coastal regions, an estimated 424,000 people reside in areas projected to be inundated with 50 cm of global SLR, and this number increases to 3.5 million with 100 cm of SLR.[20] The Southeast-Atlantic is the region with the greatest number of people and highest value of property located in areas vulnerable to inundation: 136,000 people and $8 billion with 50 cm of global SLR, and 2.0 million people and $375 billion with 100 cm of global SLR. As shown in Figure 7.1, 51% of the population in coastal counties of the Southeast-Atlantic identifies as minority, 36% is low income, 18% is 65 and older, and 12% has no high school diploma.

Figure 7.2 – Projected Population and Property Value in Coastal Areas at Risk of Inundation

Levels of global SLR are relative to the year 2000. Value of property shown in billions of $2015. Population data comes from the 2014-2018 American Community Survey of the U.S. Census. Due to uncertainty in future demographic projections, this analysis assumes constant populations along the coast. The map shows the coastal regions included in the analysis but does not show the specific areas at risk of inundation from SLR. Results reflect a scenario with no adaptation.



CHAPTER 7

COASTAL FLOODING AND PROPERTY

Key Findings on Social Vulnerability in Areas at Risk of Inundation due to Sea Level Rise

With 50 cm of global SLR, American Indian and Alaska Native individuals are 48% more likely than non-American Indian and non-Alaska Native individuals to currently live in areas where the highest percentage of land is projected to be inundated. With 100 cm of global SLR, Hispanic and Latino individuals are 47% more likely than non-Hispanic and non-Latino individuals to live in high-impact areas.

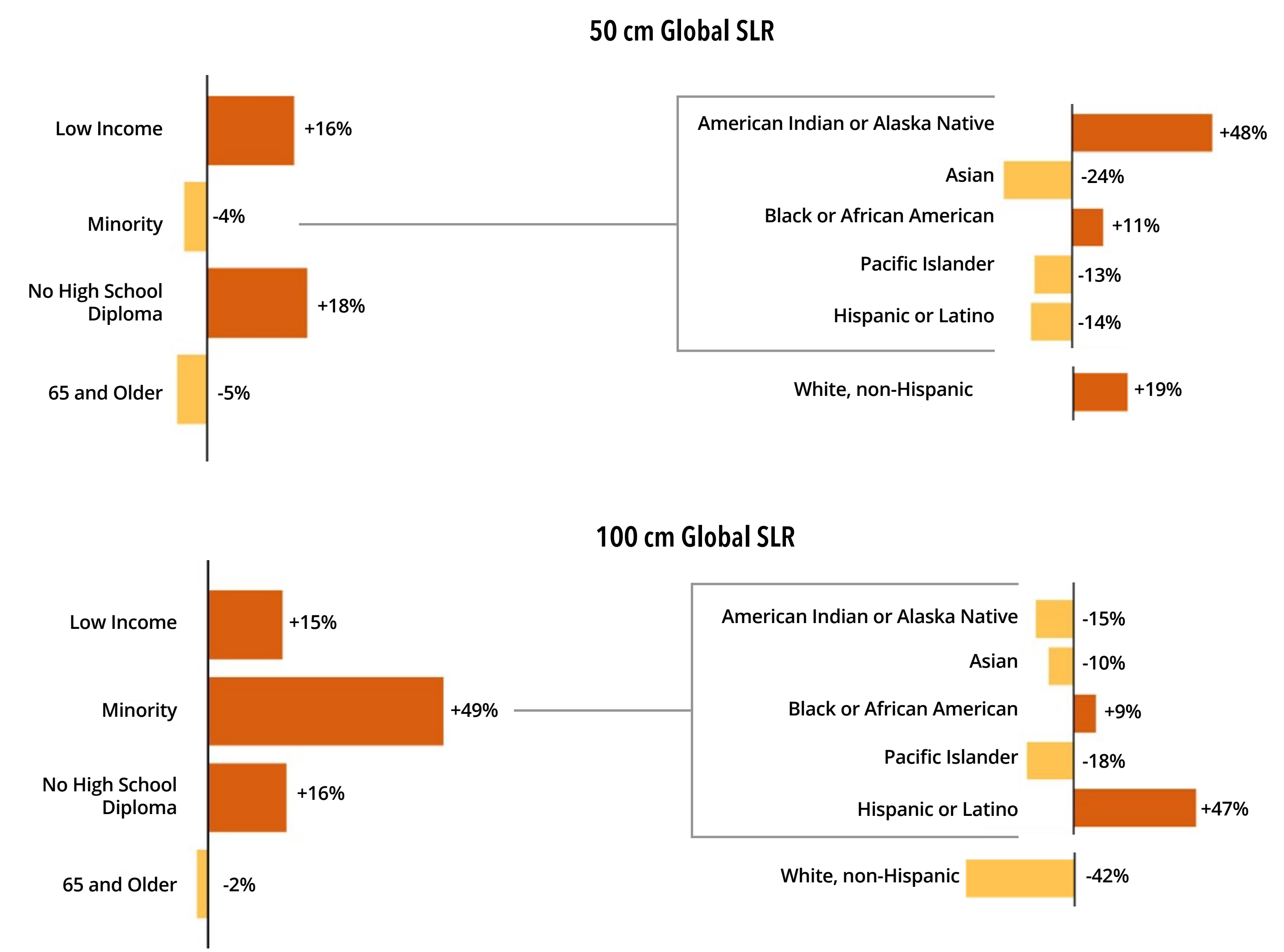
Using the data presented in Figure 7.2, the analysis identifies the Census block groups where the highest percentage of land is projected to be lost to inundation. The high-impact areas are defined as Census tracts where impacts are in the highest tercile. On average, high-impact Census block groups are projected to have between 4% and 90% of land lost with 50 cm of global SLR, and between 20% and 100% of land lost with 100 cm of global SLR. Following the steps outlined in the Approach chapter, the analysis then estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not.

The analysis evaluates the likelihood that individuals in socially vulnerable groups currently live in areas where the highest percentage of land is projected to be lost to inundation from SLR, relative to their reference populations.[21] With 50 cm of global SLR, the analysis finds that American Indian and Alaska Native individuals[22] are 48% more likely than individuals in their reference populations to live in high-impact areas; these groups are particularly at risk in the Southeast regions. Low income individuals, individuals without a high school diploma, and White, non-Hispanic individuals are 16%, 18%, and 19% more at risk, respectively, than their reference populations.[23] With 100 cm of global SLR, Hispanic and Latino individuals are 47% more likely to live in high-impact areas, particularly in the Southeast-Atlantic region. Those who are low income or do not have a high school diploma are 15% and 16% more at risk, respectively, than their reference populations.

Key Findings on Social Vulnerability in Areas at Risk of Inundation due to SLR (continued)

Figure 7.3 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Percentage of Property Lost to Inundation from SLR

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas where the highest percentage of land is projected to be lost to inundation relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global SLR are relative to the year 2000.



COASTAL FLOODING AND PROPERTY

Key Findings on Areas That Could be Excluded from Adaptation

With 50 cm of global SLR, areas that are home to an estimated 640,000 people and have $11 billion of property value could be excluded from adaptation if adaptation decisions are based on a benefit-cost test in which the cost of the adaptation measures is compared to the value of the avoided damages. With 100 cm of global SLR, these values increase to 1.0 million people and $19 billion.

AP Photo/Steven Senne

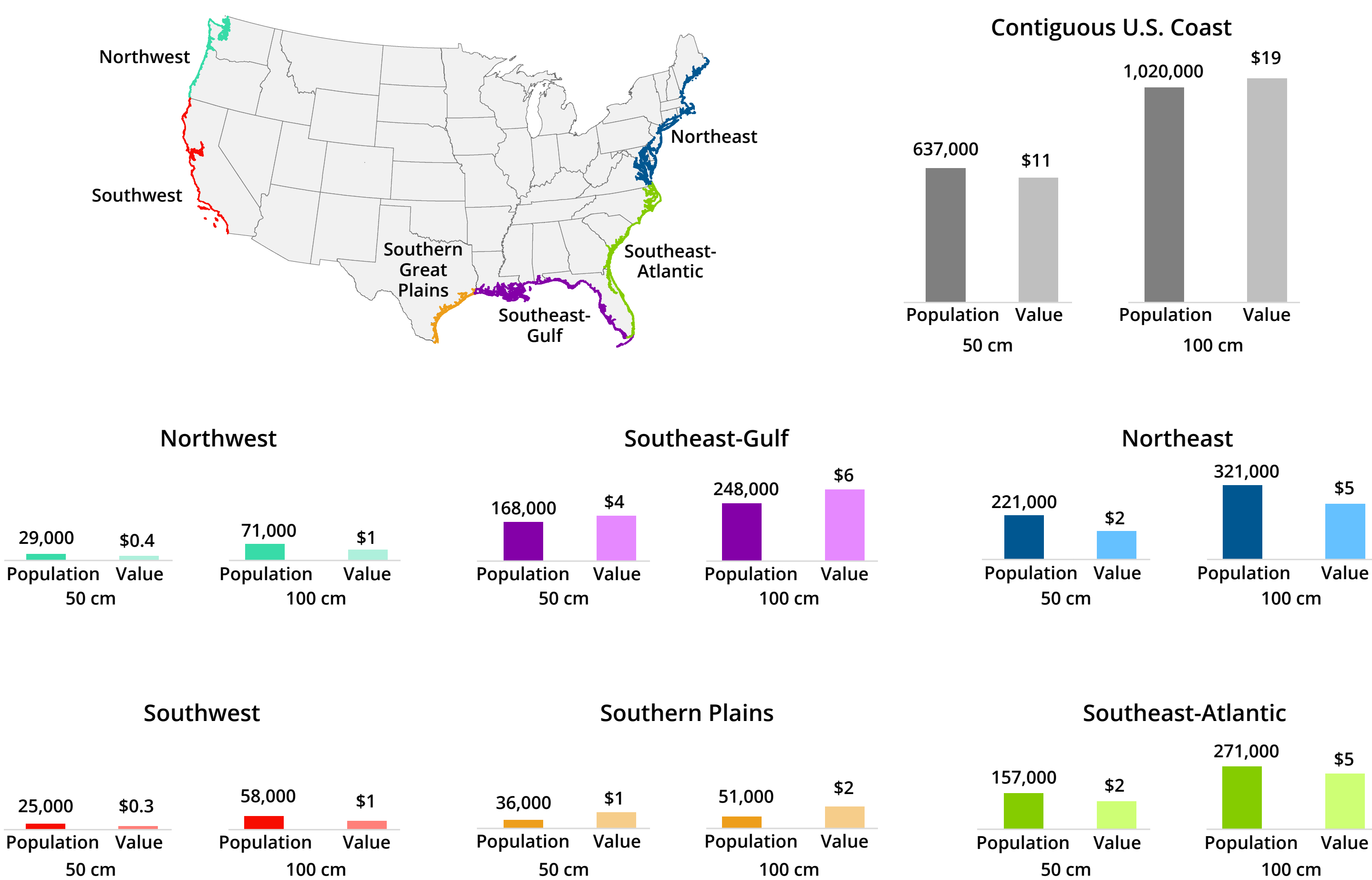
In addition to identifying areas at risk of inundation from SLR, the NCPM estimates which of these areas might receive protective adaptation measures and which might be excluded from adaptation.[24] The model uses a benefit-cost test wherein adaptation measures are implemented in areas where the value of properties outweigh the costs of their protection. In reality, adaptation decisions are made using a complex set of decision criteria that consider more than just property value; however, the NCPM provides a simple decision framework that can be consistently applied for regional and national-scale analysis of the implications of adaptation responses to coastal risks.[25]

Figure 7.4 shows the estimated numbers of people and values of properties in areas that could be excluded from protective adaptation measures based on the benefit-cost decision rule. Across all coastal regions in the contiguous U.S., an estimated 640,000 people and $11 billion worth of property are projected to be excluded from adaptation with 50 cm of global SLR. With 100 cm of global SLR, these values increase to 1.0 million people and $19 billion worth of property. The regions with the highest estimated numbers of people located in areas that are projected to be excluded from adaptation with 100 cm of global SLR are the Northeast (320,000 people excluded) and Southeast-Atlantic (270,000 people excluded).[26] These areas are generally characterized by low population and structure density, which raise technical challenges for cost-effective adaptation (as modeled in this analysis), and/or lower property values.

Key Findings on Areas That Could be Excluded from Adaptation (continued)

Figure 7.4 – Projected Population and Property Value in Coastal Areas That Could be Excluded from Adaptation

Levels of global sea level rise are relative to the year 2000. Value of property shown in billions of $2015. Population data comes from the 2014-2018 American Community Survey of the U.S. Census. Due to uncertainty in future demographic projections, this analysis assumes constant populations along the coast. The map shows the coastal regions included in the analysis but does not show the specific areas at risk of inundation from SLR.



CHAPTER 7

COASTAL FLOODING AND PROPERTY

Key Findings on Social Vulnerability in Areas That Might be Excluded from Adaptation

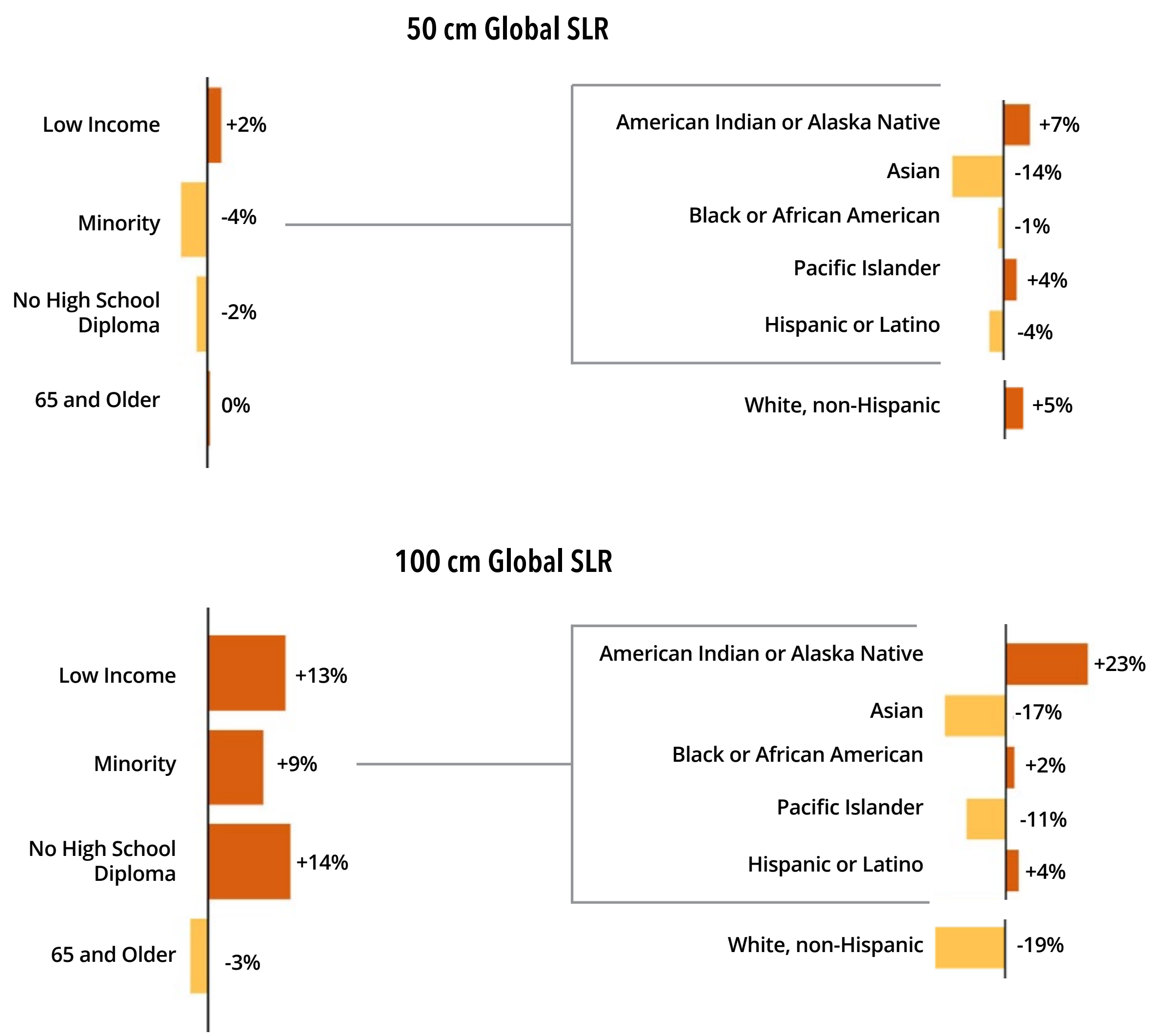
With 100 cm of global SLR, the analysis estimates that American Indian and Alaska Native individuals are 23% more likely to currently live in areas where the highest percentage of at-risk land is projected to be excluded from adaptation. Those with low income and no high school diploma are 13% and 14% more likely than their reference populations to live in these areas.

The analysis quantifies the likelihood that individuals in the four socially vulnerable groups currently live in areas where the highest percentage of at-risk land could be excluded from adaptation in a scenario where adaptation decisions are made using a benefit-cost test. As shown in Figure 7.5, the analysis finds relatively small differences between the risks to the socially vulnerable groups examined and their reference populations in a scenario with 50 cm of global SLR. With 100 cm of global SLR, however, the analysis projects that American Indian and Alaska Native individuals are 23% more likely than non-American Indian and non-Alaska Native individuals to currently live in areas where the highest percentage of at-risk land could be excluded from adaptation in a scenario where adaptation decisions are made using a benefit-cost test. These populations have a higher risk particularly in the Northwest and Southeast-Gulf regions. In addition, those with low income and those without a high school diploma are projected to be more likely than their reference populations (13% and 14%, respectively) to currently live in areas with the highest projected rates of exclusion from adaptation.

Key Findings on Social Vulnerability in Areas That Might be Excluded from Adaptation

Figure 7.5 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas Where the Highest Percentage of At-Risk Land Could be Excluded from Adaptation

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas where the highest percentage of at-risk land could be excluded from adaptation relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global SLR are relative to the year 2000.



CHAPTER 7

COASTAL FLOODING AND PROPERTY

Key Findings on Regional Impacts

Those with no high school diploma living in the Southwest and Southeast-Gulf are 18% and 31% more likely, respectively, to currently live in areas with the highest percentage of land lost to SLR, relative to those with a high school diploma. In the Southwest, those with low income are 25% more likely than those with higher income to currently live in areas where the highest percentage of at-risk land could be excluded from protective adaptation measures.

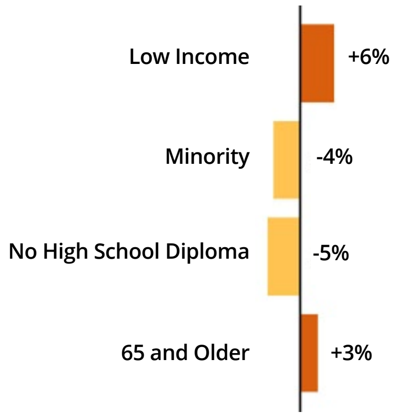
The regional analysis follows a similar approach to the national-level analysis. First, it identifies the areas within each region where the highest percentage of land is projected to be lost to SLR and where the highest percentage of at-risk land could be excluded from adaptation. Next, it estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not. For each region, the charts show the likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in the high-impact areas relative to individuals in the reference groups (e.g., non-low income).

The results shown are for a scenario with global SLR of 50 cm relative to 2000. Please refer to Appendix H for results in the scenario with 100 cm of global SLR. As described in the Approach chapter, a finding that a socially vulnerable group is less likely to experience risks does not suggest that they will not experience negative impacts; rather, such findings refer to the degree to which the estimated impacts are projected to be disproportionate relative to the reference population.

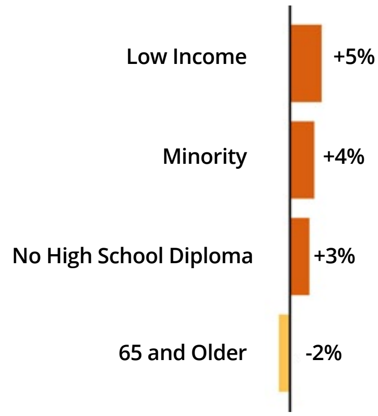
Key Findings on Regional Impacts (continued)

NORTHWEST

Higher Property Loss
50 cm Global SLR



Exclusion from Adaptation
50 cm Global SLR

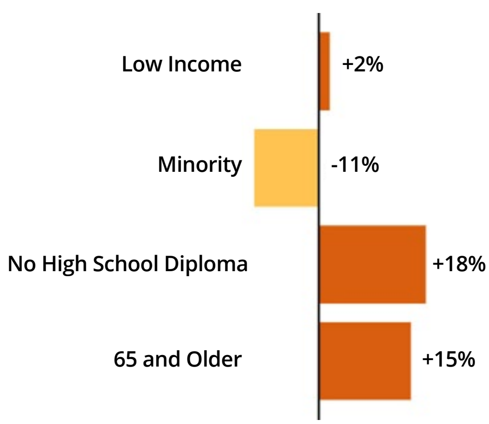


- In the Northwest, individuals in the socially vulnerable groups analyzed are not projected to have significantly disproportionate risks of currently living in areas with the highest projected impacts.

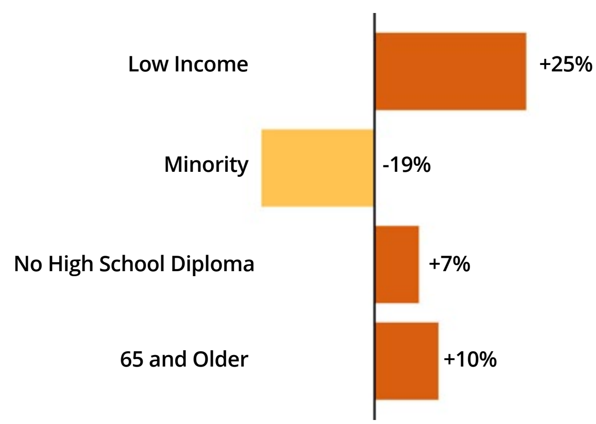
- With 100 cm of global SLR (not shown), low income individuals in the Northwest are estimated to be 11% more likely than higher income individuals to currently live in areas where the highest percentage of at-risk land could be excluded from adaptation.

SOUTHWEST

Higher Property Loss
50 cm Global SLR



Exclusion from Adaptation
50 cm Global SLR



- In the Southwest, those with no high school diploma are 18% more likely than those with a high school diploma to currently live in areas with the highest percentage of land lost to inundation.

- In the Southwest, those with low income are 25% more likely than those with higher income to currently live in areas where the highest percentage of at-risk land could be excluded from protective adaptation measures.

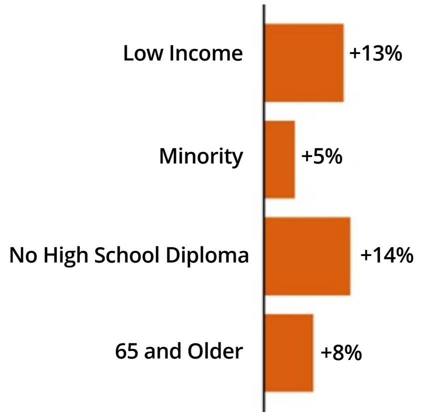
COASTAL FLOODING AND PROPERTY

Key Findings on Regional Impacts (continued)

SOUTHERN GREAT PLAINS

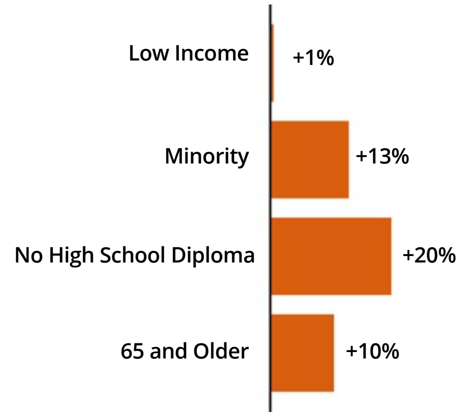
Higher Property Loss

50 cm Global SLR



Exclusion from Adaptation

50 cm Global SLR

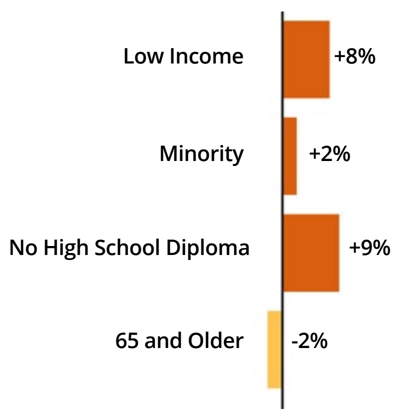


- In the Southern Great Plains, individuals with no high school diploma are 14% more likely than those with a high school diploma to currently live in areas with the highest projected percentage of land lost to inundation.
- In the Southern Great Plains, those with no high school diploma are 20% more likely than those with higher income to currently live in areas where the highest percentage of at-risk land could be excluded from adaptation.

NORTHEAST

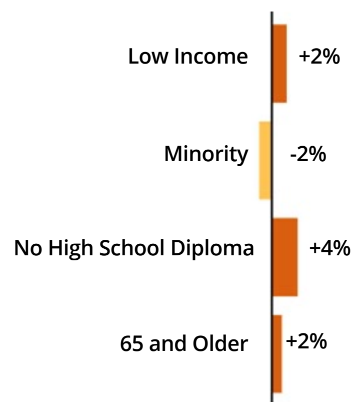
Higher Property Loss

50 cm Global SLR



Exclusion from Adaptation

50 cm Global SLR

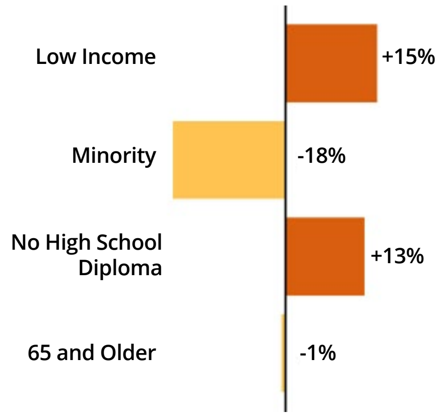


- In the Northeast, individuals in the socially vulnerable groups analyzed are not projected to experience significantly disproportionate impacts relative to their reference groups.
- With 100 cm of global SLR (not shown), individuals with no high school diploma are 11% more likely than those with a high school diploma to currently live in areas where the highest percentage of at-risk land could be excluded from adaptation.

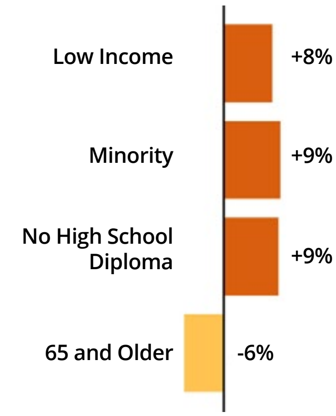
Key Findings on Regional Impacts (continued)

SOUTHEAST-ATLANTIC

Higher Property Loss
50 cm Global SLR



Exclusion from Adaptation
50 cm Global SLR

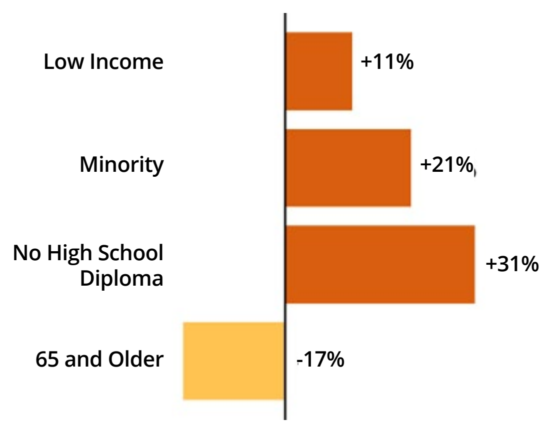


- In the Southeast-Atlantic, individuals with low income are 15% more likely than those with higher income to currently live in areas with the highest projected percentage of land lost to inundation.

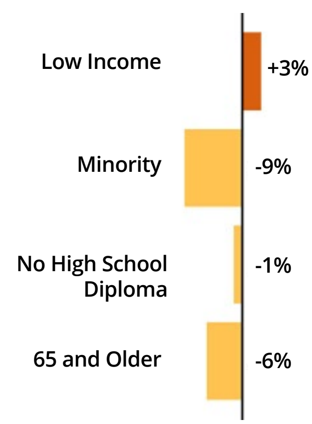
- In the Southeast-Atlantic, all socially vulnerable groups analyzed except for those ages 65 and older have a slightly higher risk of currently living in areas where the highest percentage of at-risk land could be excluded from protective adaptation measures.

SOUTHEAST-GULF

Higher Property Loss
50 cm Global SLR



Exclusion from Adaptation
50 cm Global SLR



- In the Southeast-Gulf, individuals with no high school diploma are 31% more likely than those with a high school diploma to currently live in areas with the highest projected percentage of land lost to inundation.

- In the Southeast-Gulf, individuals in the socially vulnerable groups analyzed are not projected to experience significantly disproportionate risk of exclusion from adaptation relative to their reference groups.

CHAPTER 8
INLAND FLOODING AND PROPERTY

Background

Climate change is expected to cause more frequent and intense precipitation events in many regions of the U.S., increasing the risk of inland flooding and other hazards.[1,2] Inland flooding, also known as riverine flooding, occurs when excessive rainfall collects across a watershed and causes a river to overflow.[3] Heavier downpours can result in more extreme flooding, affecting human health and safety, property, infrastructure, and natural resources.[4] Between 1980 and 2020, inland flooding in the U.S. caused over 600 deaths and nearly $3.7 billion in damages.[5]

This analysis estimates property damage and loss resulting from climate-driven changes in heavy precipitation and associated riverine flooding. It then estimates the risks to socially vulnerable populations of currently living in areas where these impacts are projected to be highest. The next section describes why socially vulnerable populations in the U.S. may be particularly at risk of experiencing negative impacts from inland flooding.

INLAND FLOODING AND PROPERTY

Social Vulnerability and Inland Flooding

In the U.S., minorities, those with low income, people with limited English proficiency, and certain immigrant communities are at increased risk of exposure to flooding given their higher likelihood of living in risk-prone areas and locations with poorly maintained infrastructure.[6,7,8] A 2017 study found that in Houston, TX, and in 20 major metropolitan areas around the country, poorer neighborhoods and those with other socioeconomic indicators of social vulnerability tend to have lower elevations and higher risk of flooding after extreme rainfall.[9] A retrospective analysis of flood events in Texas from 1997-2001 found that lower income communities of color suffered disproportionately high rates of death and injury.[10]

Similarly, a 2021 study found that areas with both high flood exposure and high social vulnerability occur predominantly in rural areas and across the U.S. South.[11]

METHODS

The steps below outline the general approach to the analysis. For more detailed information, please refer to Appendix I.

STEP 1 | Project changes in the frequency of flooding events with an average return period of two to 500 years associated with global warming.[18]

STEP 2 | Using First Street Foundation's flooding risk data and model for the U.S.,[19,20] estimate baseline, average flooding damages at the building level. Project flooding damages with global warming by scaling the per-building baseline damages according to the projected change in frequency of flooding events. Aggregate the results to the Census block group and tract level.[21]

STEP 3 | Identify the Census block groups with the highest projected annual damages relative to the total property value within the area affected by the current 500-year return period flood.

STEP 4 | Calculate the likelihood that individuals who are socially vulnerable currently live in these high-impact areas relative to those who are not.[22]

Table 8.1 – Social Vulnerability and Inland Flooding

CATEGORY	DESCRIPTION
Low Income	Low income and minority residents are more likely to move into high-risk flood zones.[12] In addition, low income populations have been shown to be less likely to evacuate in response to warning systems.[13] Nature-based infrastructure projects, such as those designed to protect against flooding, often exclude socially vulnerable groups and instead end up displacing lower income residents.[14]
Minority	Minorities may have limited access to information and resources designed to prevent or mitigate flooding risk due to language or cultural differences.[15]
No High School Diploma	Those with no high school diploma are more likely to receive lower hourly wages and have less wealth. As a result, they may be forced to live in less desirable areas, such as floodplains.[16]
65 and Older	Since older individuals have lived longer than the younger population, they are more likely to have greater ties to the community or home. Some evidence indicates that those over 65 could see increased riverine flood frequency and magnitude by 2050 because of climate change.[17]

INLAND FLOODING AND PROPERTY

Key Findings on Damages from Inland Flooding

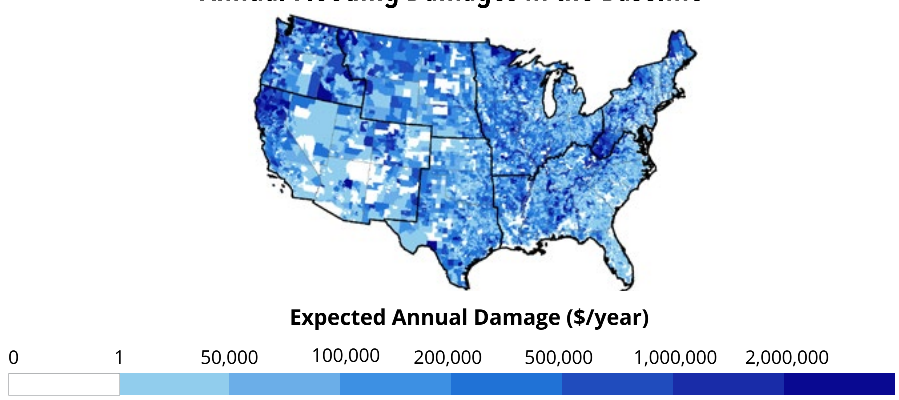
With 2°C of global warming, climate change is projected to increase annual flooding damages throughout the contiguous U.S., but particularly in areas of the Northwest, Southwest, and Northern Great Plains. The areas projected to incur large damages grows substantially with 4°C degrees of warming.

Figure 8.1 shows the estimated annual damages from flooding in the baseline and the change in damages with global warming of 2°C and 4°C.[23] The greatest impacts are projected to occur in the Northern Great Plains and Northwest regions. In addition, the northern areas of the Southwest and Southeast are also estimated to experience high levels of damage. The number of areas with large damages are projected to increase as global warming increases from 2°C to 4°C, especially in parts of the Southwest and Southern Great Plains. The northernmost tracts of the Midwest are projected to experience less damage relative to the baseline, as well as western Arkansas, Louisiana, eastern Oklahoma, and northeast Texas.

Figure 8.1 – Expected Annual Damages from Inland Flooding

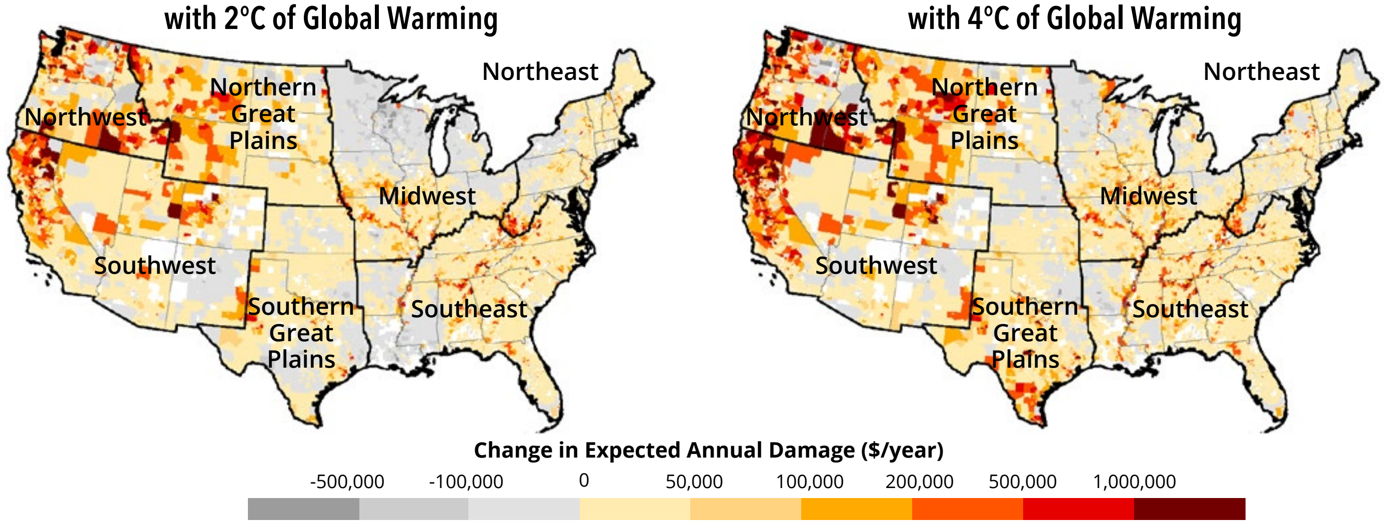
Levels of global warming are relative to the 2001-2020 average.[24] Values represent average damages per year at the Census tract level. Census tracts in white are those that are outside of the 500-year floodplain or in the coastal floodplain and are therefore not included in the analysis. The changes in expected annual damages are relative to the baseline.

Annual Flooding Damages in the Baseline



Projected Change in Annual Flooding Damages with 2°C of Global Warming

Projected Change in Annual Flooding Damages with 4°C of Global Warming



INLAND FLOODING AND PROPERTY

Key Findings on Social Vulnerability and Inland Flooding

In general, the socially vulnerable groups analyzed in this report are not projected to experience disproportionately higher risks of currently living in areas with the highest projected inland flooding damages compared to their reference populations. However, with global warming of 2°C, Black and African American individuals and Pacific Islanders have a 10% higher risk than their reference populations, and with warming of 4°C, Pacific Islanders have a 21% higher risk than their reference population.

Using the data presented in Figure 8.1, the analysis identifies the areas with the highest property damage due to climate-driven changes in inland flooding. The high-impact areas are defined by Census block groups where impacts are in the highest tercile. Following the steps outlined in the Approach chapter, the analysis then estimates the likelihood that those who are socially vulnerable currently live in these high-impact areas compared to those who are not.

Figure 8.2 describes differences in risk to socially vulnerable groups of currently living in areas with the highest projected rates of flood-related property damage with 2°C and 4°C global warming. At a national scale, the analysis finds that the socially vulnerable groups analyzed in this report do not, in general, experience disproportionate risks compared to their reference populations. Individuals ages 65 and older are slightly more likely to live in areas with the worst flooding damages (this is more evident in the regional results, presented in the next section). Overall, minorities are approximately 12% less likely to live in areas with the worst inland flooding damages with 2°C global warming. When examining the risks for individual racial and ethnic groups, the analysis finds that Black and African American individuals and Pacific Islanders are 10% more likely to currently live in areas with the highest projected impacts relative to their reference populations with 2°C global warming. Notably, the likelihood of White, non-Hispanic individuals living in areas with the highest projected inland flooding damages decreases substantially as warming increases: 32% greater likelihood under the 2°C warming scenario and 1% greater likelihood under 4°C.

A Closer Look at the Inland Flooding Results

The highly localized nature of the occurrence of extreme flooding events, and the substantial variation across regions, means that results in Figure 8.2, averaged to the national level, may obscure some of the more informative results at the regional level (presented in the next section). In addition, national results show substantial changes across social vulnerability measures with increases in warming, likely a result driven by changes in the number of socially vulnerable individuals subject to the worst flooding damages as temperatures change.

The underlying data used in this analysis excludes flooding events associated with urban drainage, quantifying only riverine floods instead. The focus on riverine flooding, as a result, may not account for flooding events in cities and other urban areas where large populations of socially vulnerable individuals reside. In addition, the underlying flood risk dataset incorporates the mitigating impact of current flood control structures – these structures are likely to be more common in many densely populated urban areas, which also correlate with the locations of some socially vulnerable populations.

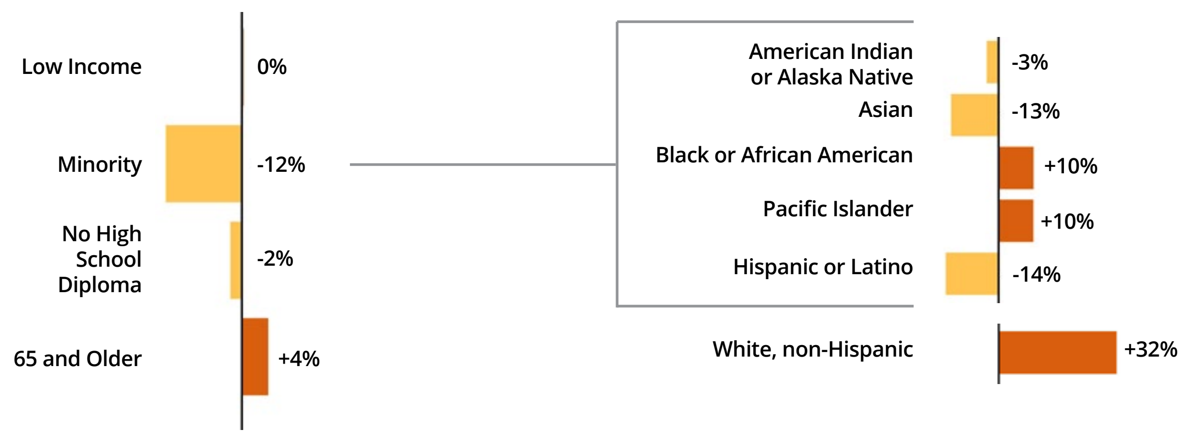
Similarly, this analysis did not evaluate the effectiveness of future adaptation measures in reducing flood risk, nor the likelihood that socially vulnerable populations live in areas excluded from protection. Finally, it is important to note that less vulnerable populations are typically more knowledgeable of their flood risk, and generally have the capital and capacity to prepare adequately. Socially vulnerable populations, on the other hand, are less likely to know their risk and may not be prepared for the damages that their properties could face.[25] See Appendix I for details and supporting figures.

Key Findings on Social Vulnerability and Inland Flooding (continued)

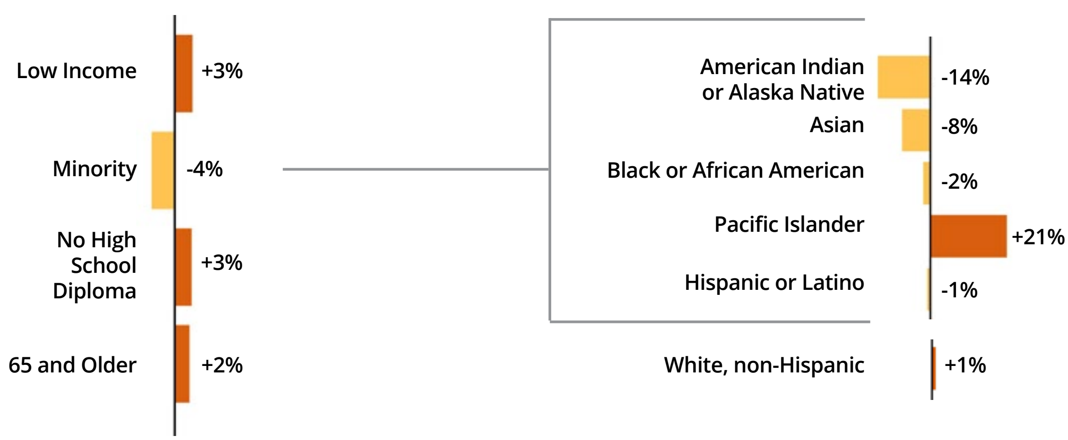
Figure 8.2 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Inland Flooding Damages

The bar charts present the relative likelihood that individuals in each socially vulnerable group (e.g., low income) currently live in areas with the highest projected inland flooding damages relative to their reference populations (e.g., non-low income). Positive percentages indicate higher comparative risk, and negative percentages indicate lower comparative risk. Levels of global warming are relative to the 2001-2020 average.

2°C Global Warming



4°C Global Warming



CHAPTER 8

INLAND FLOODING AND PROPERTY

Key Findings on Regional Impacts

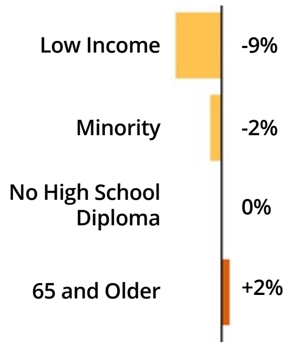
With 2°C of global warming, minorities in the Northeast have a 16% higher risk of currently living in areas with the highest projected inland flooding damages. In the Southwest and Northern Great Plains, individuals ages 65 and older have a 15% higher risk of living in areas with the highest damages.

This section highlights the projected regional differences in risk for the four socially vulnerable groups examined in this report under scenarios with 2°C of global warming (relative to 2001-2020). Please see Appendix I for regional results with 4°C global warming. For each region, the charts show the estimated difference in likelihood that individuals in each socially vulnerable group currently live in areas with the highest projected damages relative to individuals in their reference groups within the same region.

In general, the analysis finds small differences between the risks to the socially vulnerable groups examined and their reference populations at the regional level. Many areas that are projected to experience more substantial damages have lower percentages of socially vulnerable populations, especially low income and minority individuals, which contributes to this pattern. However, some regional results stand out; minorities in the Northeast are approximately 16% more likely to currently live in areas with the highest projected impacts compared to White, non-Hispanic individuals with 2°C of global warming. In addition, individuals ages 65 and older in the Southwest and Northern Great Plains are 15% more likely than younger individuals to live in high-impact areas with 2°C of global warming.

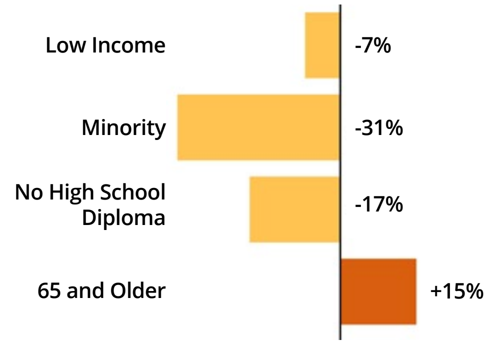
Key Findings on Regional Impacts (continued)

NORTHWEST
2°C Global Warming



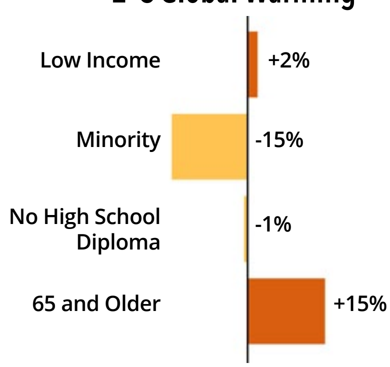
- In the Northwest, socially vulnerable populations are not projected to have a disproportionately higher likelihood of currently living in areas with the highest projected inland flooding damages, relative to their reference groups.
- In the Northwest, low income individuals are 9% *less* likely, relative to those with higher income, to currently live in areas with the highest projected inland flooding impacts.

SOUTHWEST
2°C Global Warming



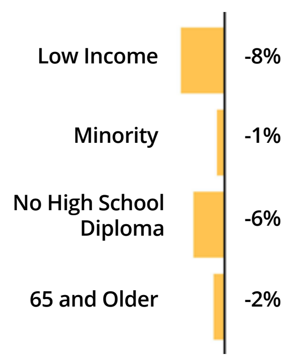
- In the Southwest, individuals ages 65 and older are 15% more likely than younger individuals to currently live in areas with the highest projected inland flooding impacts.
- In the Southwest, minorities are 31% *less* likely than non-minorities to currently live in areas with the highest projected inland flooding impacts.

NORTHERN GREAT PLAINS
2°C Global Warming



- In the Northern Great Plains, individuals ages 65 and older are 15% more likely to currently live in areas projected to have the worst flooding damages, relative to younger populations.
- In the Northern Great Plains, minorities are 15% *less* likely than non-minorities to currently live in areas with the highest projected inland flooding impacts.

SOUTHERN GREAT PLAINS
2°C Global Warming



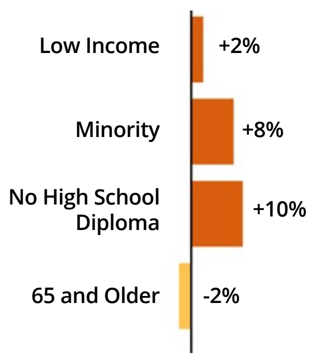
- In the Southern Great Plains, socially vulnerable populations are not projected to have a disproportionately higher likelihood of currently living in areas with the highest projected inland flooding damages, relative to their reference groups.

INLAND FLOODING AND PROPERTY

Key Findings on Regional Impacts (continued)

MIDWEST

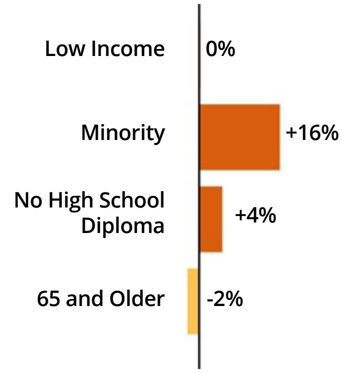
2°C Global Warming



- In the Midwest, those with no high school diploma are 10% more likely to currently live in areas projected to have the worst flooding damages, relative to those with a high school diploma.
- In the Midwest, minorities are 8% more likely than non-minorities to currently live in areas projected to have the worst flooding damages.

NORTHEAST

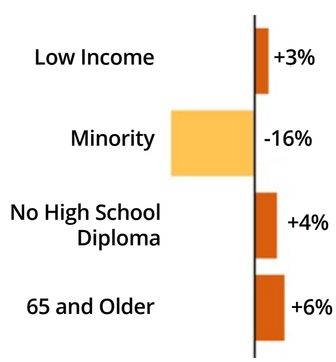
2°C Global Warming



- In the Northeast, minorities are 16% more likely than non-minorities to currently live in areas projected to have the worst flooding damages.
- On average, those with low income, those with no high school diploma, and individuals ages 65 and older are not projected to be disproportionately at risk of currently living in areas with the highest projected inland flooding damages.

SOUTHEAST

2°C Global Warming



- In the Southeast, minorities are 16% *less* likely than non-minorities to currently live in areas projected to have the worst flooding damages.
- On average, those with low income, those with no high school diploma, and individuals ages 65 and older are not projected to be disproportionately at risk of currently living in areas with the highest projected inland flooding damages.

CHAPTER 9
SUMMARY OF NATIONAL RESULTS

This chapter presents a summary of the national-level results from each analysis for each socially vulnerable group analyzed (Low Income, Minority, No High School Diploma, and 65 and Older). In addition, it presents results for each racial and ethnic group included in the Minority category (American Indian and Alaska Native; Asian; Black and African American; Hispanic and Latino; and Pacific Islander), and for the White, non-Hispanic population. The results are presented for scenarios with 2°C of global warming and 50 cm of global sea level rise, as well as for 4°C of global warming and 100 cm of global sea level rise.

Figure 9.1 presents the national-level results for the four socially vulnerable populations. Looking across the results for the four socially vulnerable groups analyzed, minorities are found to be most disproportionately at risk, relative to their reference populations. For example, with 50 cm of global sea level rise, minorities are 41% more likely than non-minorities to currently live in areas with the highest projected increases in traffic delays. By comparison, those with low income are 14% more likely than those with higher income to currently live in these areas, and those with no high school diploma are 18% more likely than those with higher educational attainment to currently live in these areas. In general, those 65 and older are found to have approximately the same levels of risk relative to younger populations for the six impacts analyzed.

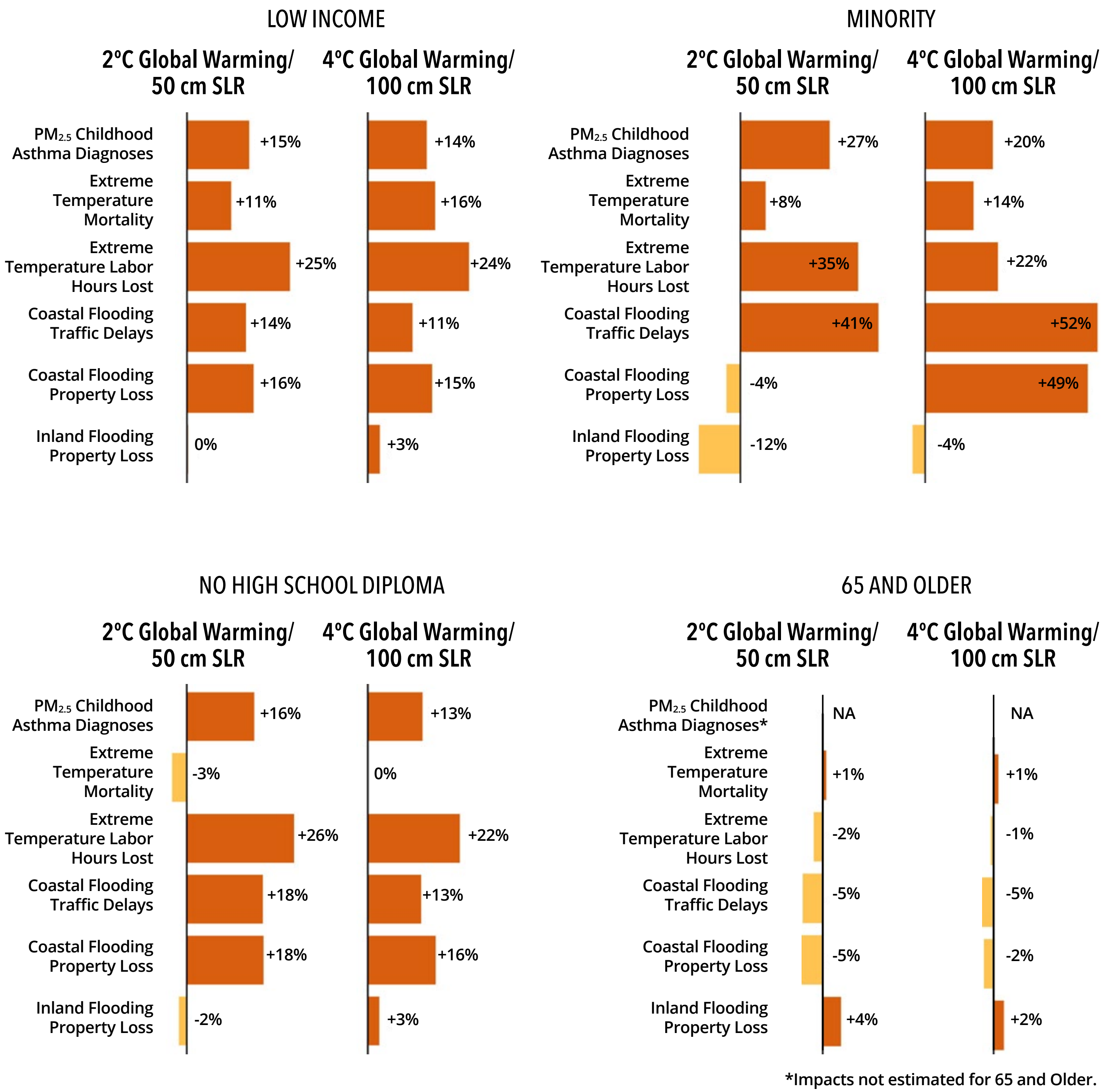
Figure 9.2 presents the results for the individual racial and ethnic groups included in the Minority category, and for White, non-Hispanic individuals. Looking across the results for all the racial and ethnic groups, Black and African American individuals are found to be most disproportionately at risk, relative to non-Black and non-African American individuals. With global warming of 2°C, Black and African American individuals are 40% more likely than non-Black and non-African American individuals to currently live in areas with the highest projected increases in premature mortality from extreme temperatures, and 34% more likely to currently live in areas with the highest projected increases in childhood asthma diagnoses.

Hispanic and Latino individuals are also found to be significantly more likely than non-Hispanic and non-Latino individuals to currently live in areas where impacts are projected to be highest. Specifically, Hispanic and Latino individuals are 43% more likely than their reference population to currently live in areas with the highest projected labor hour losses from extreme temperatures, and they are 50% more likely to currently live in areas with the highest projected traffic delays from coastal flooding. In contrast, White, non-Hispanic individuals are *less* likely than minorities to currently live in areas with the highest projected increases in childhood asthma diagnoses, the highest projected labor hour losses from extreme temperatures, and the highest projected coastal flooding-related traffic delays. White, non-Hispanic individuals are 19% more likely, however, to currently live in areas with the highest projected property damages from coastal flooding and 32% more likely to currently live in areas with the highest projected property damages from inland flooding, relative to their reference population.

SUMMARY OF NATIONAL RESULTS

Figure 9.1 – Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas with the Highest Projected Impacts Relative to their Reference Populations

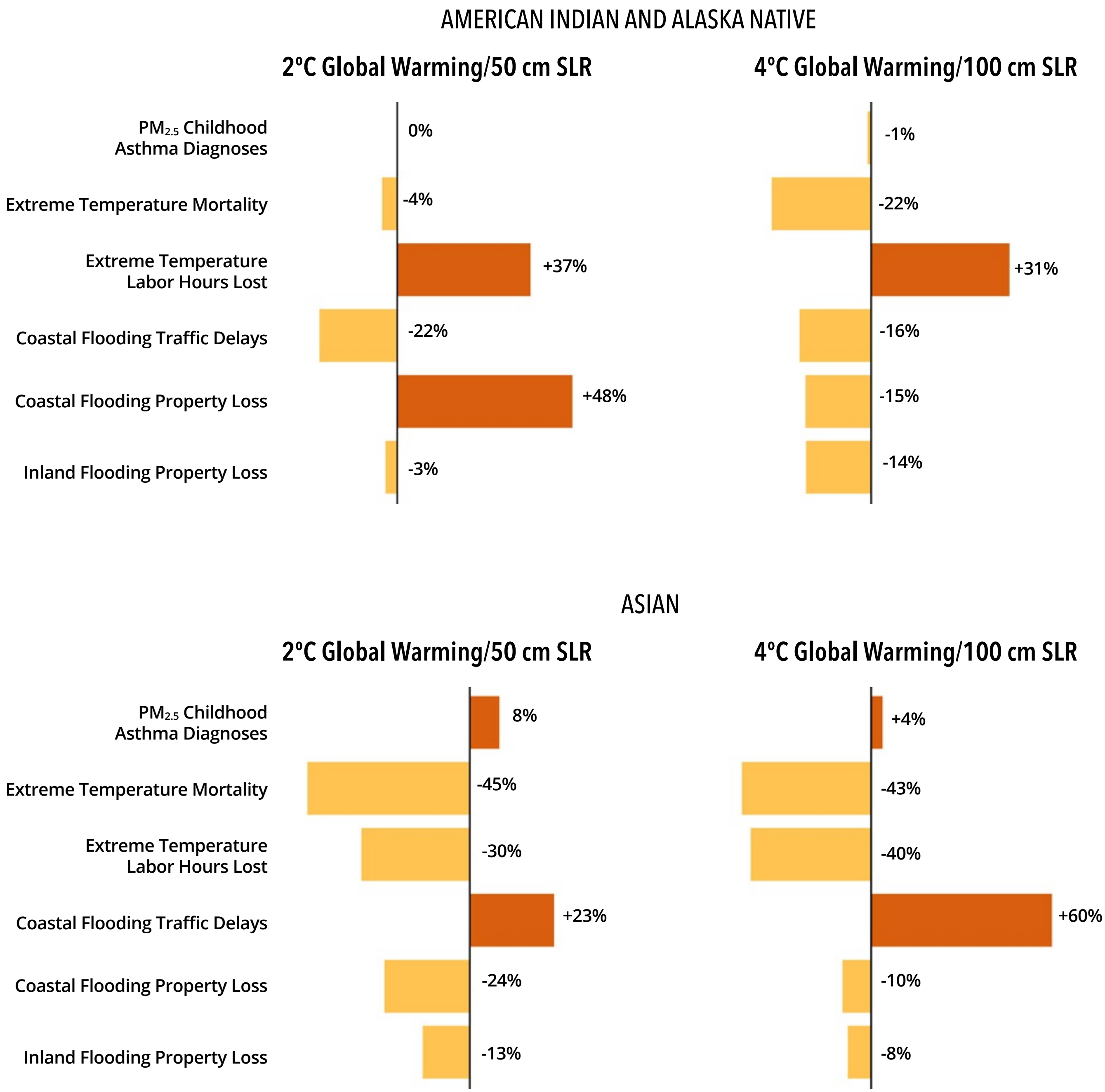
Levels of global warming are relative to the 1986-2005 average (except for the inland flooding analysis, for which the baseline is 2001-2020) and levels of global sea level rise are relative to the year 2000. Positive percentages indicate a higher likelihood that individuals in the socially vulnerable population (e.g., low income) currently live in areas with the highest projected impacts relative to the reference population (e.g., non-low income), and negative percentages indicate lower disproportionate likelihood.



SUMMARY OF NATIONAL RESULTS

Figure 9.2 – Likelihood that Those in Individual Racial and Ethnic Groups Currently Live in Areas with the Highest Projected Impacts Relative to their Reference Populations

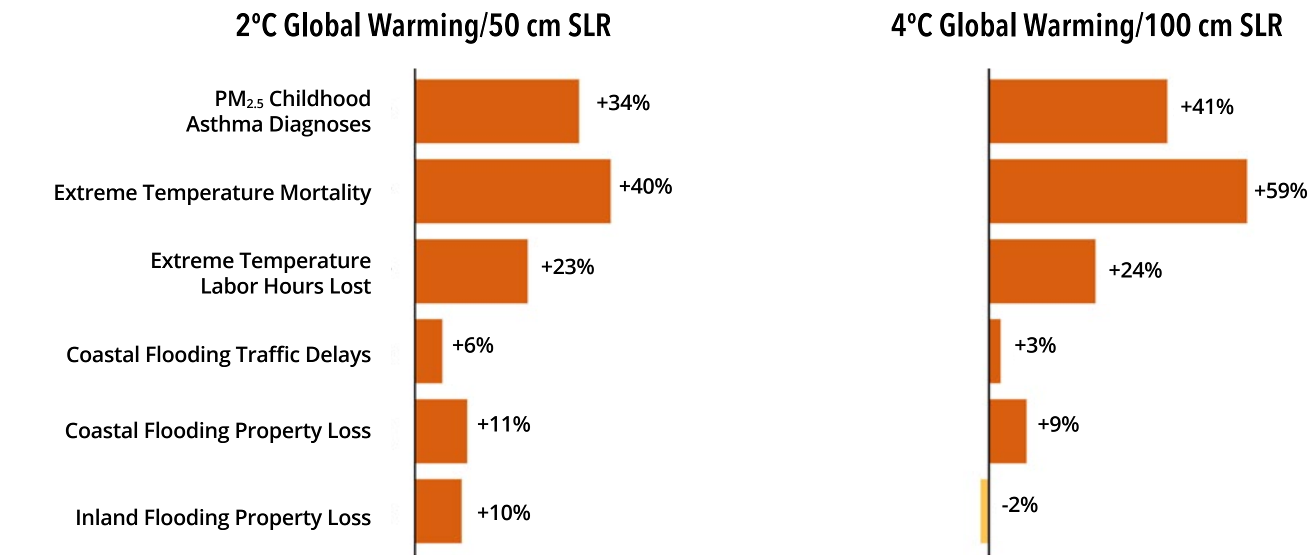
Levels of global warming are relative to the 1986-2005 average (except for the inland flooding analysis, for which the baseline is 2001-2020) and levels of global sea level rise are relative to the year 2000. Positive percentages indicate a higher likelihood that the socially vulnerable population (e.g., low income) currently lives in areas projected to experience the highest impacts relative to the reference population (e.g., non-low income), and negative percentages indicate lower disproportionate likelihood.



SUMMARY OF NATIONAL RESULTS

Figure 9.2 – Continued

BLACK AND AFRICAN AMERICAN



HISPANIC AND LATINO

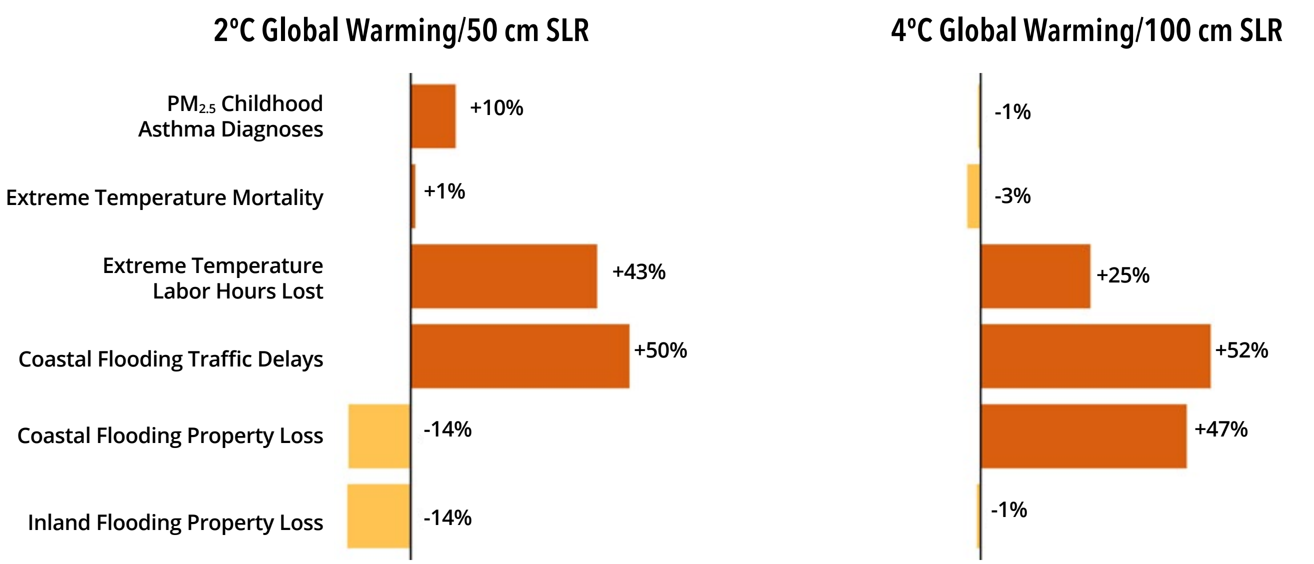
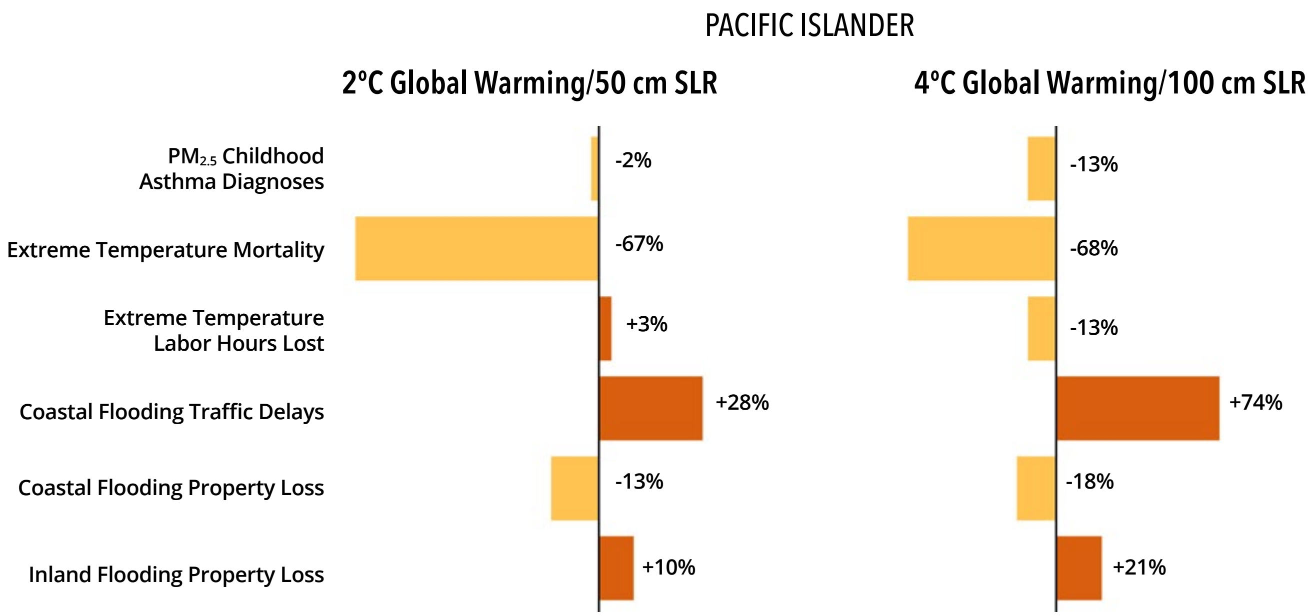
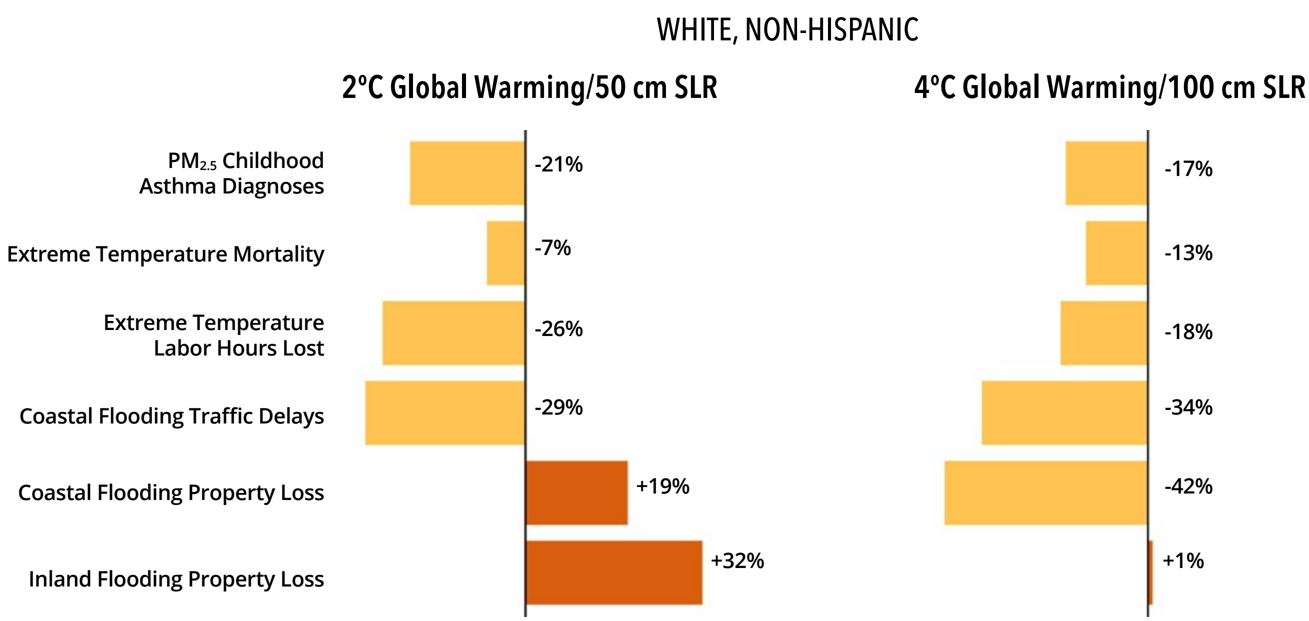


Figure 9.2 – Continued





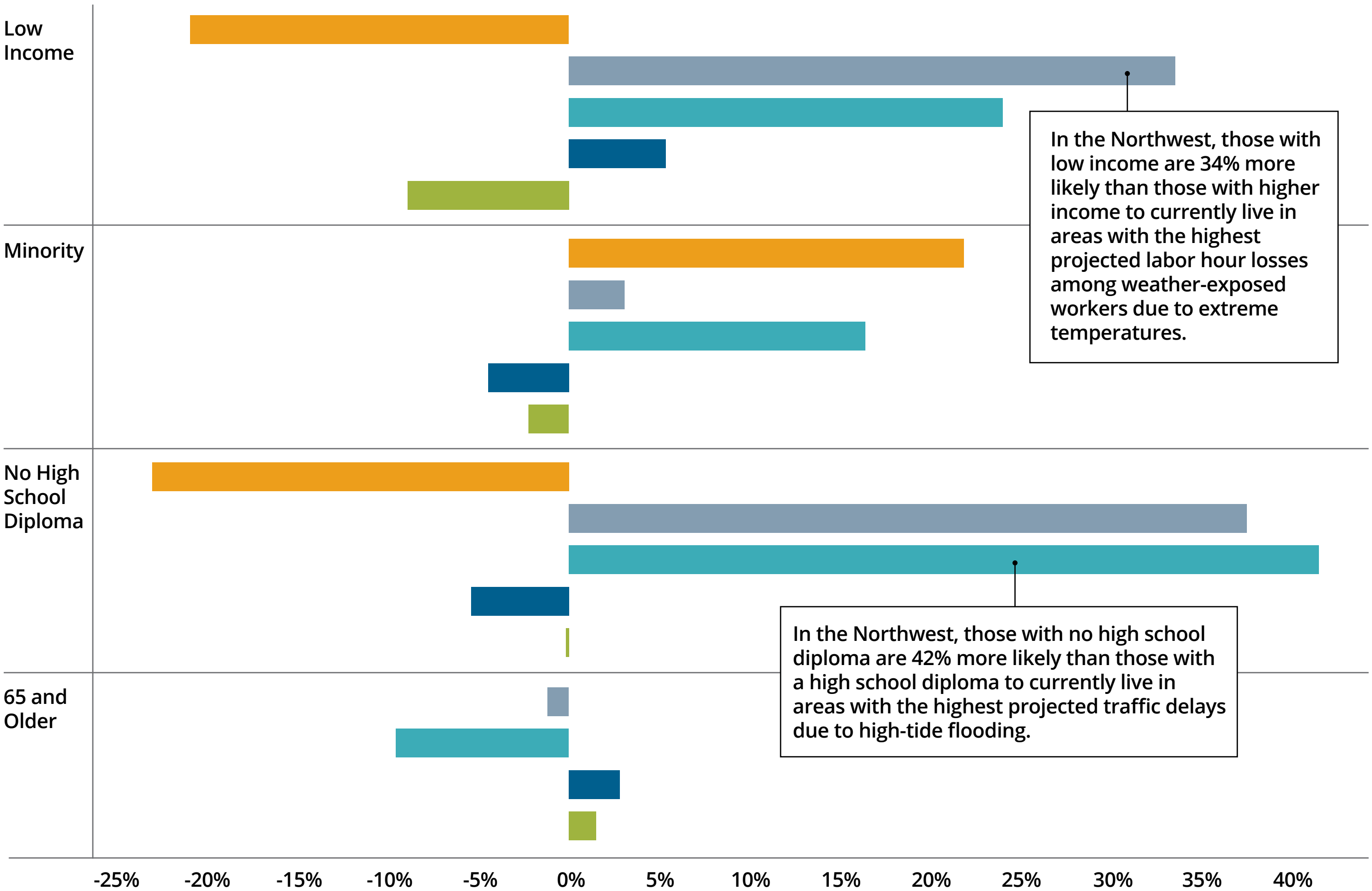
CHAPTER 10
SUMMARY OF REGIONAL RESULTS

This chapter presents a summary of the results for each region and each socially vulnerable group analyzed (Low Income, Minority, No High School Diploma, and 65 and Older). Results are presented for all key impact categories except for Extreme Temperature and Health because that analysis focuses on impacts in 49 urban areas.

SUMMARY OF REGIONAL RESULTS

Figure 10.1 – Differences in Risks to Socially Vulnerable Groups in the Northwest Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

COASTAL FLOODING AND TRAFFIC
Traffic delays from high-tide flooding.

COASTAL FLOODING AND PROPERTY
Property inundation due to sea level rise.

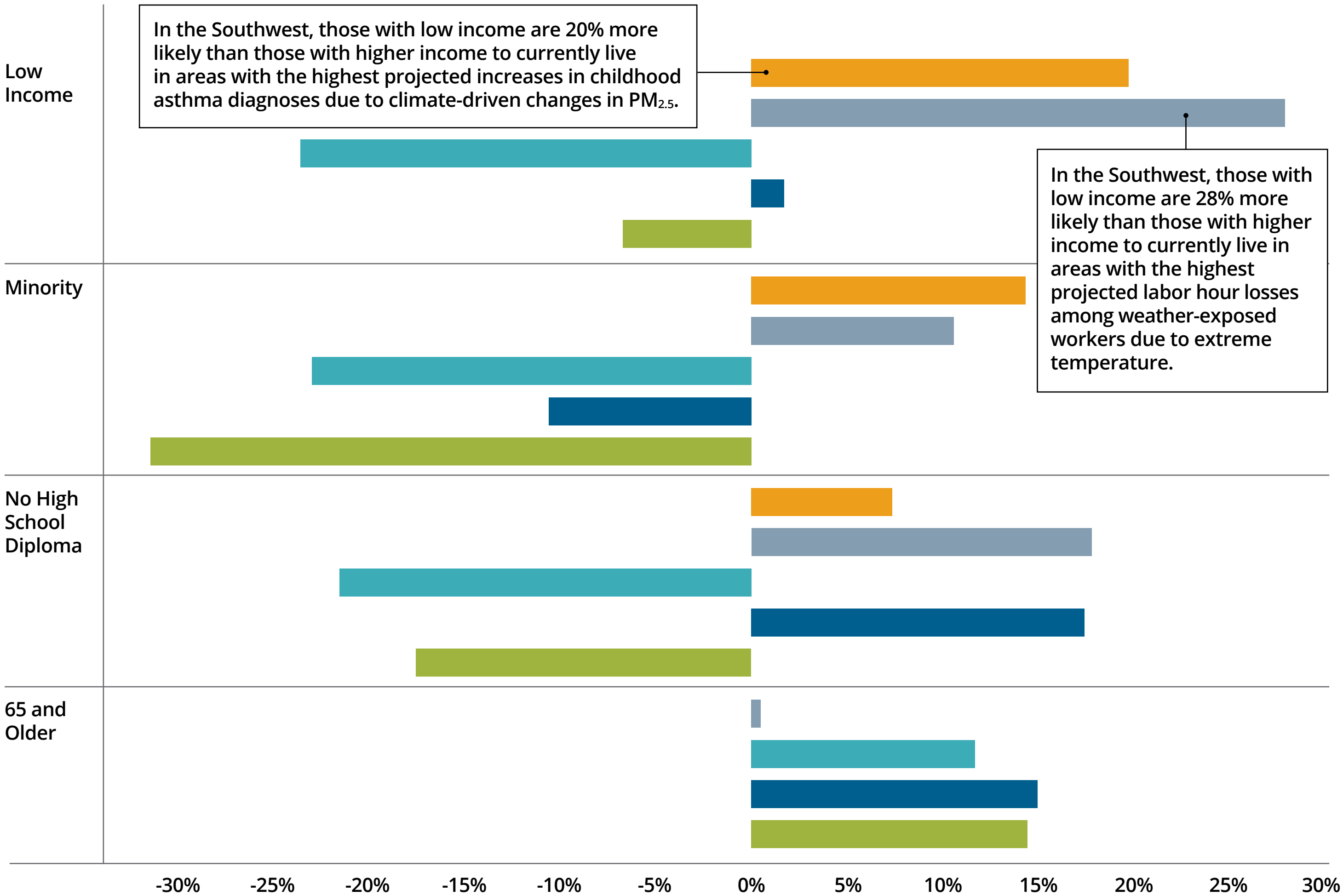
INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

*Impacts not estimated for 65 and Older.

SUMMARY OF REGIONAL RESULTS

Figure 10.2 – Differences in Risks to Socially Vulnerable Groups in the Southwest Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

COASTAL FLOODING AND TRAFFIC
Traffic delays from high-tide flooding.

COASTAL FLOODING AND PROPERTY
Property inundation due to sea level rise.

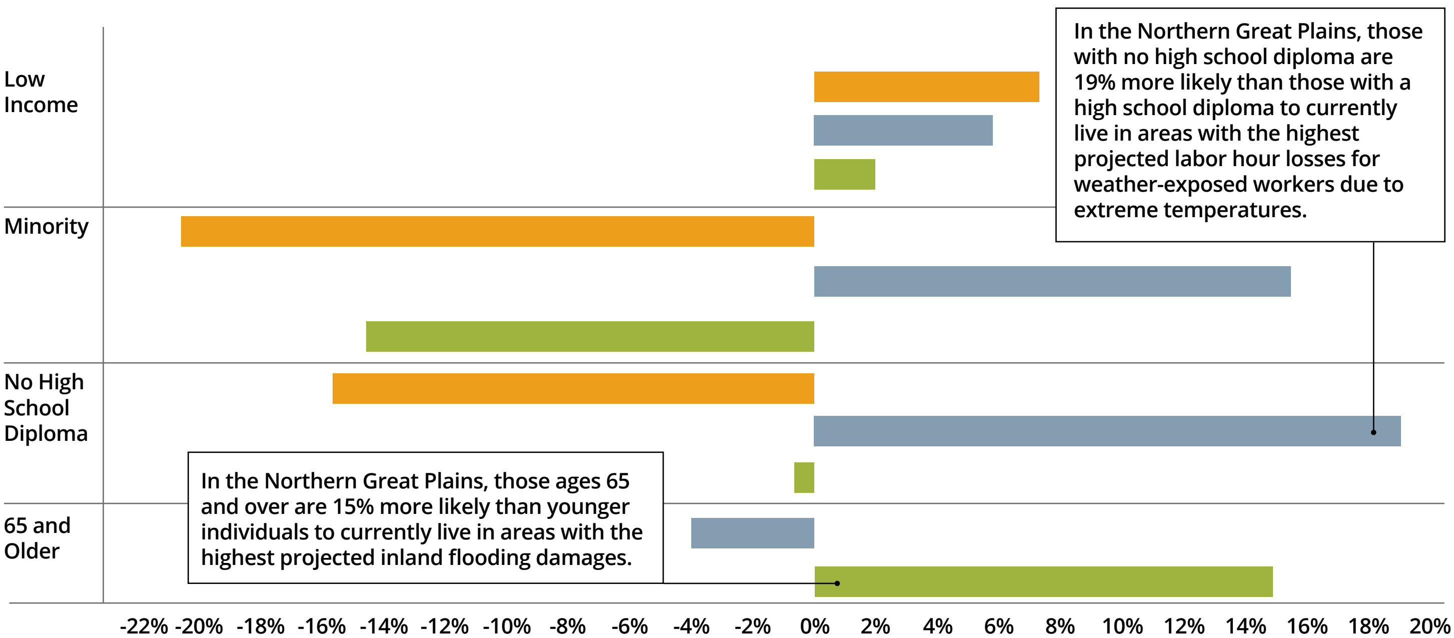
INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

*Impacts not estimated for 65 and Older.

SUMMARY OF REGIONAL RESULTS

Figure 10.3 – Differences in Risks to Socially Vulnerable Groups in the Northern Great Plains Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

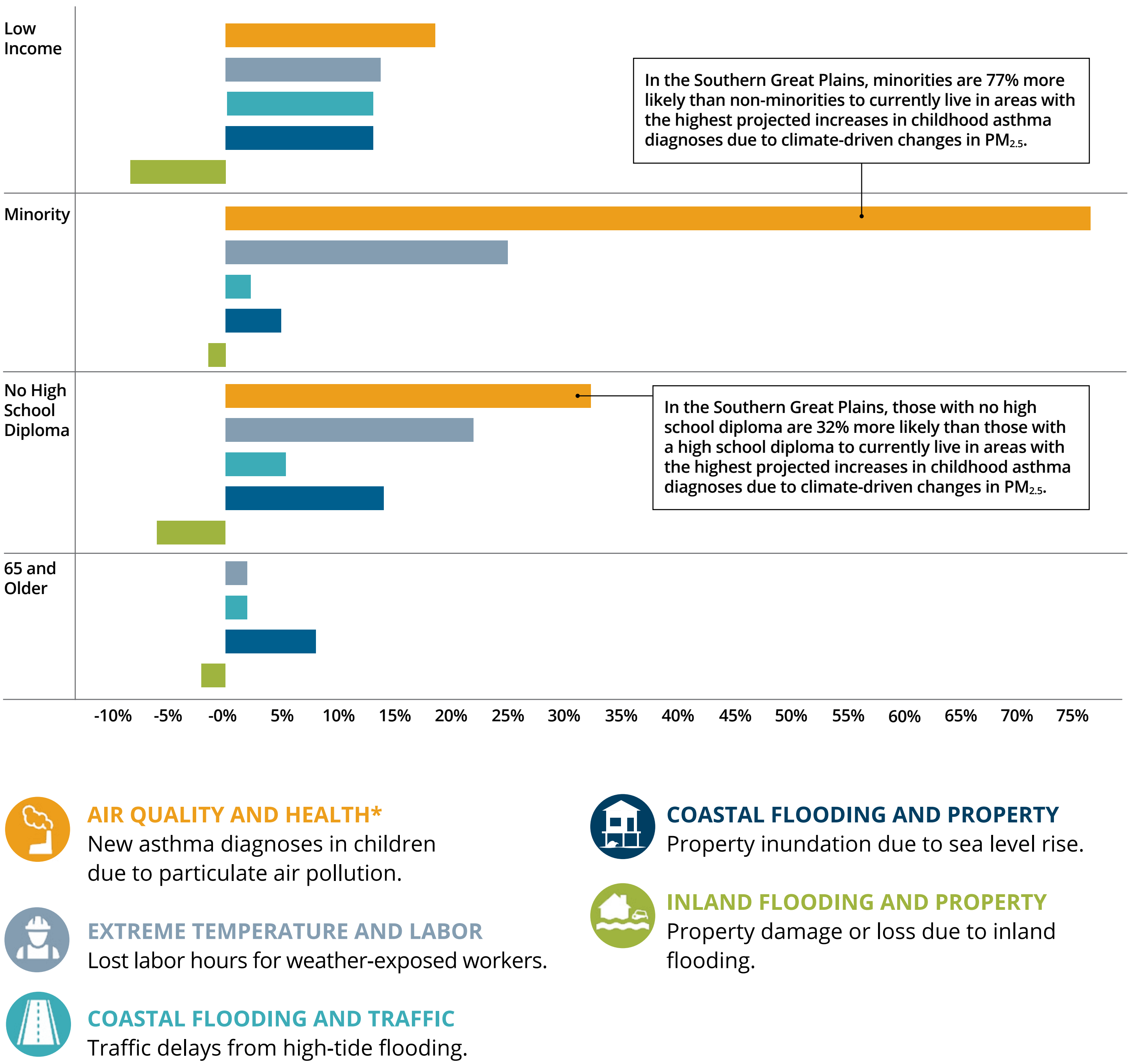
EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

*Impacts not estimated for 65 and Older.

SUMMARY OF REGIONAL RESULTS

Figure 10.4 – Differences in Risks to Socially Vulnerable Groups in the Southern Great Plains Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.

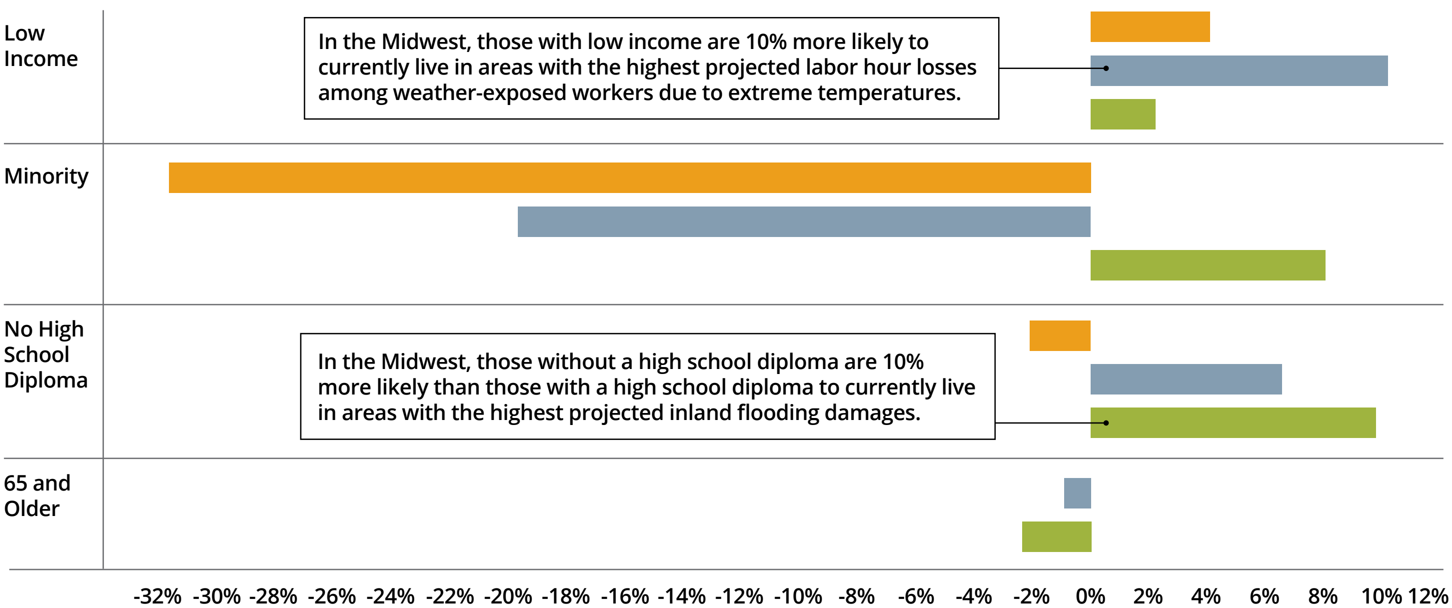


*Impacts not estimated for 65 and Older.

SUMMARY OF REGIONAL RESULTS

Figure 10.5 – Differences in Risks to Socially Vulnerable Groups in the Midwest Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

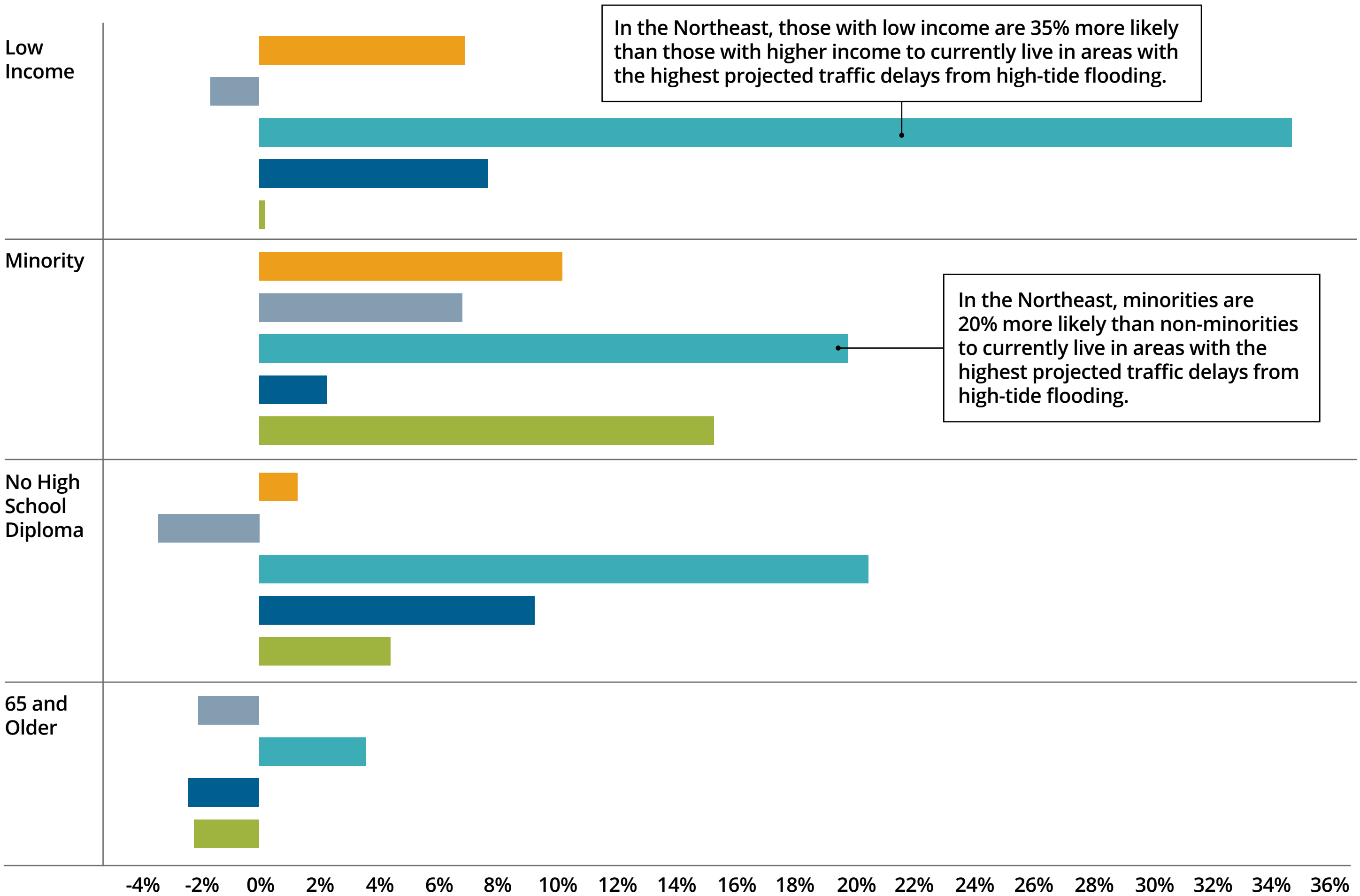
*Impacts not estimated for 65 and Older.

INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

SUMMARY OF REGIONAL RESULTS

Figure 10.6 – Differences in Risks to Socially Vulnerable Groups in the Northeast Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

COASTAL FLOODING AND TRAFFIC
Traffic delays from high-tide flooding.

COASTAL FLOODING AND PROPERTY
Property inundation due to sea level rise.

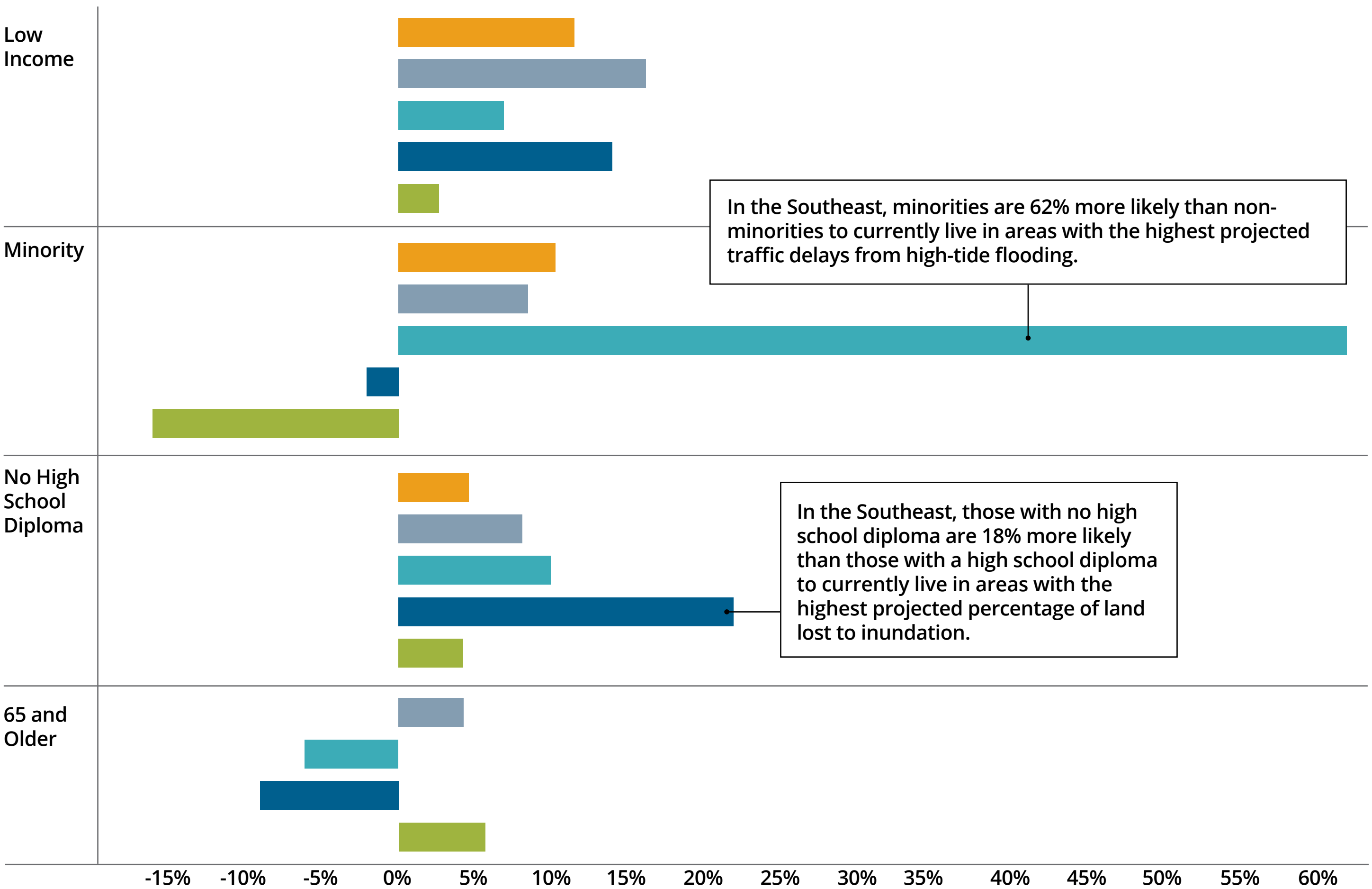
INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

*Impacts not estimated for 65 and Older.

SUMMARY OF REGIONAL RESULTS

Figure 10.7 – Differences in Risks to Socially Vulnerable Groups in the Southeast Relative to Reference Populations with 2°C of Global Warming or 50 cm of Global Sea Level Rise

The estimated risks for each socially vulnerable group are relative to each group's "reference" population, defined as all individuals other than those in the group being analyzed. The estimated risks presented in the chart are for scenarios with 2°C of global warming (relative to the 1986-2005 average) or 50 cm of global sea level rise (relative to 2000). For the inland flooding analysis, the baseline is 2001-2020. Results for additional scenarios are provided in the respective chapters and appendices.



AIR QUALITY AND HEALTH*
New asthma diagnoses in children due to particulate air pollution.

EXTREME TEMPERATURE AND LABOR
Lost labor hours for weather-exposed workers.

COASTAL FLOODING AND TRAFFIC
Traffic delays from high-tide flooding.

COASTAL FLOODING AND PROPERTY
Property inundation due to sea level rise.

INLAND FLOODING AND PROPERTY
Property damage or loss due to inland flooding.

*Impacts not estimated for 65 and Older.

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Executive Summary

1 USGCRP. 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

2 Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, and Sinh BT. 2012. Determinants of risk: exposure and vulnerability. In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, and Midgley PM (eds.)] A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

3 Thomas K, Hardy RD, Lazrus H, Mendez M, Orlove B, Rivera-Collazo I, Roberts JT, Rockman M, Warner BP, and Winthrop R. 2018. Explaining differential vulnerability to climate change: A social science review. WIREs Climate Change, 10(2). doi: 10.1002/wcc.565.

4 The analysis also examines the impacts of ozone on premature deaths (see Chapter 3 and Appendix D).

5 The analysis also examines exclusion of roads in some areas from protective adaptation measures (see Chapter 6 and Appendix G).

6 The estimated risks for each socially vulnerable group are calculated as the risks compared to each group's "reference" population, defined as all individuals other than those in the group being analyzed. For example, the reference population for Asian individuals includes all individuals who do not identify as Asian. For more information, please refer to the Approach chapter and Appendix C.

7 Results for other climate change scenarios are presented in the individual chapters of the report and the corresponding appendices.

8 This impact measure is calculated as the percentage of the total property value in each at-risk coastal Census block group that is projected to be lost to sea level rise inundation, in a scenario without any adaptation.

9 The estimated risks for each socially vulnerable group are calculated as the risks compared to each group's "reference" population, defined as all individuals other than those in the group being analyzed. For example, the reference population for Asian individuals includes all individuals who do not identify as Asian. For more information, please refer to the Approach chapter and Appendix C.

10 Results for other climate change scenarios are presented in the individual chapters of the report and the corresponding appendices.

11 This impact measure is calculated as the percentage of the total property value in each at-risk coastal Census block group that is projected to be lost to sea level rise inundation, in a scenario without any adaptation.

Chapter 1. Introduction

1 USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, DR, CW Avery, DR Easterling, KE Kunkel, KLM Lewis, TK Maycock, and BC Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

2 USGCRP. 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA. doi: 10.7930/NCA4.2018.

3 Thomas K, Hardy RD, Lazrus H, Mendez M, Orlove B, Rivera-Collazo I, Roberts JT, Rockman M, Warner BP, and Winthrop R. 2018. Explaining differential vulnerability to climate change: A social science review. WIREs Climate Change, 10(2). doi: 10.1002/wcc.565.

4 Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, and Sinh BT. 2012. Determinants of risk: exposure and vulnerability. In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, and Midgley PM (eds.)] A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

5 Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, and Sinh BT. 2012. Determinants of risk: exposure and vulnerability. In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, and Midgley PM (eds.)] A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

6 Thomas K, Hardy RD, Lazrus H, Mendez M, Orlove B, Rivera-Collazo I, Roberts JT, Rockman M, Warner BP, and Winthrop R. 2018. Explaining differential vulnerability to climate change: A social science review. WIREs Climate Change, 10(2). doi: 10.1002/wcc.565.

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Chapter 2. Approach

1 This “impacts by degree” framework has been employed in major scientific assessments, including those by the National Academies and the United Nations Intergovernmental Panel on Climate Change (IPCC). Sources: National Research Council. 2011. Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia. Washington, DC: The National Academies Press. doi: 10.17226/12877. IPCC. 2018. Summary for Policymakers. In *Global Warming of 1.5°C.* An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. [Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, and Waterfield T (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

2 The higher emissions scenario corresponds to representative concentration pathway (RCP) 8.5, the lower emissions scenario corresponds to RCP4.5, and the even lower scenario corresponds to RCP2.6. For more information regarding these forcing scenarios, see Hayhoe K, Edmonds J, Kopp RE, LeGrande AN, Sanderson BM, Wehner MF, and Wuebbles DJ. 2017. Climate models, scenarios, and projections. In *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles DJ, Fahey DW, Hibbard KA, Dokken DJ, Stewart BC, and Maycock TK (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 133-160, doi: 10.7930/J0WH2N54.

3 According to Hayhoe et al., 2017, the U.S. had already experienced over 0.5°C warming by 2016 (relative to the 1986-2005 baseline used in this report).

4 The six GCMs are: CanESM2, GFDL-CM3, CCSM4, GISS-E2-R, HadGEM2-ES, and MIROC5. Please see Appendix C for more information.

5 This 20-year baseline period is also used in the NCA4 and in the Climate Change Science Report that supports it.

6 IPCC. 2018. Framing and Context: Frequently Asked Questions (FAQ). In *Global Warming of 1.5°C*. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. [Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, and Waterfield T (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

7 IPCC. 2018. Summary for Policymakers. In *Global Warming of 1.5°C.* An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. [Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, and Waterfield T (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

8 Paris Agreement FCCC/CP/2015/10/Add.1 https://unfccc.int/documents/909.

9 Hayhoe K, Edmonds J, Kopp RE, LeGrande AN, Sanderson BM, Wehner MF, and Wuebbles DJ. 2017. Climate models, scenarios, and projections. In *Climate Science Special Report: Fourth National Climate Assessment, Volume I*

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[Wuebbles DJ, Fahey DW, Hibbard KA, Dokken DJ, Stewart BC, and Maycock TK (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 133-160, doi: 10.7930/J0WH2N54. These ranges do not, however, capture the full range of physically plausible global average sea level rise over the 21st century, with higher rates possible due to physical feedbacks in the Antarctic icesheets.

10 This report uses the regional delineations of the National Climate Assessment. Texas is the only coastal state in the Southern Great Plains region, therefore statements about coastal impacts in this region refer to the Texas coastline.

11 Estimated "relative" sea level rise means that the estimates incorporate both projected land and sea level changes. Relative sea level rise accounts for land uplift or subsidence, oceanographic effects, and responses of the geoid and the lithosphere to shrinking land ice.

12 Based on 2020 city population estimates from the U.S. Census. For more information, please see https://www.census.gov/programs-surveys/popest/technical-documentation/research/evaluation-estimates/2020-evaluation-estimates/2010s-cities-and-towns-total.html.

13 The analysis also examines the impacts of ozone on premature deaths (see Chapter 3 and Appendix D).

14 The analysis also examines exclusion of roads in some areas from protective adaptation measures (see Chapter 6 and Appendix G).

15 The focus on highest risks of experiencing climate change impacts is consistent with recommendations for federal climate science research from a recent report from the National Academies of Sciences, Engineering, and Medicine. National Academies of Sciences, Engineering, and Medicine. 2021. Global Change Research Needs and Opportunities for 2022-2031. Washington, DC: The National Academies Press. doi: 10.17226/26055.

16 In some cases, the areas that are projected to experience higher impacts are the same across two or more analyses. See the Regional Summary chapter for more information.

17 This report estimates climate change impacts to socially vulnerable populations based on current demographic distributions, as long-term and robust projections for national changes in demographics are currently unavailable. Recent U.S. Census data indicates the following demographic trends at a national level, many of which may continue into the future: a) less migration (i.e., lower mobility rates), b) increased urbanization, c) an increasingly aged population, d) small declines in the White, non-Hispanic/Latino population, and e) the most population growth occurring among African American/Black and Hispanic/Latino racial and ethnic groups. [see https://www.census.gov/topics/population.html for additional information]. Regarding income, the share of Americans in the lower national income tier increased from 25% to 29% between 1970-2019. During that same period, the sum of total income flowing to low income households decreased from 10 to 9% [see Pew Research Center, January 2020, "Most Americans Say There Is Too Much Economic Inequality in the U.S., but Fewer Than Half Call It a Top Priority" for more information]. As for high school graduation rates, The U.S. average adjusted cohort graduation rate for public high school students increased over the first eight years it was collected, from 79 percent in 2010–11 to 85 percent in 2017–18 [see U.S. Department of Education, National Center for Education Statistics. (2020). The Condition of Education 2020 (NCES 2020-144), Public High School Graduation Rates. for more information].

18 Previous literature has demonstrated the importance of climate sensitivity assumptions in understanding a wide range of potential changes to the climate system, as well as the effect of natural variability on timing and magnitude of impacts. Sources: Paltsev S, Monier E, Scott J, Sokolov A, and Reilly J. 2013. Integrated economic and climate projections for impact assessment. Climatic Change, 131, 21-33. doi:10.1007/s10584-013-0892-3. Monier E, Gao X, Scott JR, Sokolov AP, and Schlosser CA. 2014. A framework for modeling uncertainty in regional climate change. Climatic Change, 131, 51-66. doi:10.1007/s10584-014-1112-5. Monier E, and Gao X. 2014. Climate change impacts on extreme events in the United States: an uncertainty analysis. *Climatic Change,* 131, 67-81. doi:10.1007/s10584-013-1048-1. Mills D, Jones R, Carney K, St. Juliana A, Ready R, Crimmins A, Martinich J, Shouse K, DeAngelo B, and Monier E. 2014. Quantifying and Monetizing Potential Climate Change Policy Impacts on Terrestrial Ecosystem Carbon Storage and Wildfires in the United States. *Climatic Change,* 131, 163-178. doi:10.1007/s10584-014-1118-z.

19 The Sixth Assessment of the IPCC, which is scheduled for release in summer 2021, will provide updated scenarios and temperature projections based on the CMIP6 project. However, these newer projections were not available in time for use in this report.

19 Based on 2020 city population estimates from the U.S. Census. For more information, please see https://www.census.gov/programs-surveys/popest/technical-documentation/research/evaluation-estimates/2020-evaluation-estimates/2010s-cities-and-towns-total.html.

20 Table C17002 of the American Community Survey, 2014-2018, available at www.data.census.gov

21 Table B03002 of the American Community Survey, 2014-2018, available at www.data.census.gov

22 Table B15003 of the American Community Survey, 2014-2018, available at www.data.census.gov

23 Table B01001 of the American Community Survey, 2014-2018, available at www.data.census.gov

24 Ongoing studies, such as the Inter-sectoral Impact Model Intercomparison Project (ISI-MIP), are investigating the influence of structural uncertainties across sectoral impact models. Source: Huber V, Schellnhuber HJ, Arnell

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NW, Frieler K, Friend AD, Gerten D, Haddeland I, Kabat P, Lotze-Campen H, Lucht W, Parry M, Piontek F, Rosenzweig C, Schewe J, and Warszawski L. 2014. Climate impact research: beyond patchwork. *Earth System Dynamics,* 5, 399-408. doi: 10.5194/esd-5-399-2014.

25 For example, the Air Quality and Temperature Mortality analyses do not examine the compounding health risks that individuals could experience during heat waves with high ozone concentrations in the air. Although first order connectivity was achieved in limited cases (e.g., projected installation of coastal defenses in the Coastal Flooding analysis provides information on location and timing to inform where coastal roads may receive ancillary protection), improved connectivity between sectoral models would aid in gaining a more complete understanding of climate change impacts on socially vulnerable populations of the U.S.

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27 Sectors where adaptation is modeled adopt broad decision rules. However, adaptation actions are typically implemented at local scales. As such, the general adaptation scenarios considered in the analyses of this report will not capture the complex issues that drive adaptation decision-making at regional and local scales. For example, the Coastal Flooding analysis considers the cost effectiveness of adaptive responses to sea-level rise inundation and storm surge damages by comparing the costs of protection to the value of those properties at risk. While many factors at the property, community, region, and national levels will determine adaptive responses to coastal risks, this sectoral analysis uses the simplistic cost/benefit metric to enable consistent comparisons for the entire coastline. The adaptation scenarios and estimates presented in all sections of this report should not be construed as recommending any specific policy or adaptive action.

28 For example, the econometric methodology used in the labor analysis would capture any extreme temperature adaptations employed by outdoor industries in the base period.

29 This example demonstrates the process for calculating risks to the population age 65 and older in the Coastal Flooding and Traffic analysis at the *national* level. To calculate risks to this population in each region, the analysis follows the same steps, except in Step 4b it identifies areas in each region where impacts are highest (i.e., in the highest third of impacts). It then proceeds through the remaining steps to estimate the comparative risks to the socially vulnerable population of interest.

Chapter 3. Air Quality and Health

1 Human activities and natural processes release precursors for ground-level ozone (O_3) and particulate matter with a diameter less than 2.5 micrometers ($PM_{2.5}$), including methane (CH4), carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), sulfur dioxide (SO_2), ammonia (NH_3), organic carbon (OC), black carbon (BC), and dimethyl sulfide (DMS); and direct atmospheric pollutants, including mineral dust, sea salt, pollen, spores, and food particles. Source: C.G., P.D. Dolwick, N. Fann, L.W. Horowitz, V. Naik, R.W. Pinder, T.L. Spero, D.A. Winner, and L.H. Ziska, 2018: Air Quality. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 512–538. doi: 10.7930/NCA4.2018.CH13

2 $PM_{2.5}$ consists of fine inhalable particles with diameters that are generally 2.5 micrometers and smaller.

3 Ground-level ozone refers to ozone that is created by chemical reactions between oxides and nitrogen (NOx) and volatile organic compounds (VOC). This happens when pollutants emitted by cars, power plants, and other sources chemically react in the presence of sunlight.

4 Crimmins A, Balbus J, Gamble JL, Beard CB, Bell JE, Dodgen D, Eisen RJ, Fann N, Hawkins M, Herring SC, Jantarasami L, Mills DM, Saha M, Sarofim MC, Trtanj J, Ziska L. 2016. Executive Summary. The impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 24 pp. doi: 10.7930/JOOPOWXS.

5 Nolte CG, Dolwick PD, Fann N, Horowitz LW, Naik V, Pinder RW, Spero TL, Winner DA, and Ziska LH. 2018. Air Quality. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 512–538. doi: 10.7930/NCA4.2018.CH13.

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10 US EPA. 2019. Chapter 12: Populations and Lifestages Potentially at Increased Risk of a Particulate Matter-Related Health Effect. Integrated Science Assessment for Particulate Matter. Research Triangle Park, NC: United States Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment-RTP Division.

11 Tessum C, Paolella D, Chambliss S, Apte J, Hill J, and Marshall J. 2021. PM2.5 polluters disproportionately and systemically affect people of color in the United States. Science Advances, 7(18). doi: 10.1126/sciadv.abf4491

12 Colmer J, Hardman I, Shimshack J, and Voorheis J. 2020. Disparities in PM2.5 air pollution in the United States. Science, 369(6503):575-578. doi: 10.1126/science.aaz9353.

13 Kiomourtzoglou MA, Schwartz J, James P, Dominici F, and Zanobetti A. 2016. PM2.5 and mortality in 207 US cities: Modification by temperature and city characteristics. *Epidemiology*, 27(2):221-227.

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17 US EPA. 2019. Chapter 12: Populations and Lifestages Potentially at Increased Risk of a Particulate Matter-Related Health Effect. Integrated Science Assessment for Particulate Matter. Research Triangle Park, NC: United States Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment-RTP Division.

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25 Kiomourtzoglou MA, Schwartz J, James P, Dominici F, and Zanobetti A. 2016. PM2.5 and mortality in 207 US cities: Modification by temperature and city characteristics. *Epidemiology,* 27(2):221-227.

26 Kershaw S, Gower S, Rinner C, and Campbell M. 2013. Identifying inequitable exposure to toxic air pollution in racialized and low income neighborhoods to support pollution prevention. *Geospatial Health,* 7(2):265–278. doi: 10.4081/gh.2013.85.

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28 Fann NL, Nolte CG, Sarofim MC, Martinich J, and Nassikas NJ. 2021. Associations between simulated future changes in climate, air quality, and human health. *JAMA Network Open,* 4(1). doi: 10.1001/jamanetworkopen.2020.32064; Nolte CG, Spero TL, Bowden JH, Sarofim MC, Martinich J, and Mallard MS. 2021. Regional Temperature-Ozone Relationships Across the U.S. Under Multiple Climate and Emissions Scenarios. *Journal of the Air & Waste Management Association*, doi: 10.1080/10962247.2021.1970048.

29 For more information on these calculations, please see Table 3 of the Approach chapter. The calculations are weighted by the number of individuals in the relevant age groups for each impact category (0-17 for new asthma diagnoses, 0-18 for asthma ED visits, and 65 and older for premature mortality). Note that the numbers of individuals quantified in this step include all individuals and are

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not limited to the populations at risk of experiencing the impacts of premature mortality (adults 65 and older) or childhood asthma cases (individuals age 0 to 17).

30 EPA, 2021: National Air Quality –Status and Trends of Key Air Pollutants. United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Available online at www.epa.gov/air-trends.

31 See [Appendix D](), Section 4 for details on the geographic distribution of the high-impact Census tracts used in this analysis.

32 The underlying study for childhood asthma diagnoses did not evaluate effects from changes in ozone, therefore this analysis only covers changes due to $PM_{2.5}$.

33 See [Appendix D]() Section 4 for details on the geographic distribution of the high-impact Census tracts used in this analysis.

34 To stratify hazard ratios by race, authors of the underlying study analyzed asthma ED visits, a severe morbidity endpoint that is less frequent than asthma cases. As a result, there are fewer total asthma ED visits at 2°C and 4°C of warming, but greater disproportionality among socially vulnerable populations.

Chapter 4. Extreme Temperature and Health

1 Ebi KL, Balbus JM, Luber G, Bole A, Crimmins A, Glass G, Saha S, Shimamoto MM, Trtanj J, and White-Newsome JL. 2018. Human Health. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 539–571. doi: 10.7930/NCA4.2018.CH14.

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4 See, for example, Sanderson M, Arbuthnott K, Kovats S, Hajat S, and Falloon P. 2017. The use of climate information to estimate future mortality from high ambient temperature: A systematic literature review. *PLoS ONE,* 12(7). doi: 10.1371/journal.pone.0180369; Basu R, and Samet JM. 2002. Relation between Elevated Ambient Temperature and Mortality: A Review of the Epidemiologic Evidence. *Epidemiol Rev,* 24(2):190-202. doi: 10.1093/epirev/mxf007; Botzen WJW, Martinius ML, Brode P, Folkerts MA, Ignjacevic P, Estrada F, Harmsen CN, and Daanen HAM. 2020. Economic valuation of climate change-induced mortality: age dependent cold and heat mortality in the Netherlands. *Climate Change,* 162, 545-562; Bobb JF, Peng RD, Bell ML, Dominici F. Heat-related mortality and adaptation to heat in the United States. Environmental health perspectives. 2014 Aug;122(8):811-6; Hondula DM, Balling RC, Vanos JK, Georgescu M. Rising temperatures, human health, and the role of adaptation. Current climate change reports. 2015 Sep;1(3):144-54; Jenerette, G. Darrel, et al. Micro-scale urban surface temperatures are related to land-cover features and residential heat related health impacts in Phoenix, AZ USA. Landscape Ecology 31.4 (2016): 745-760.

5 See for example, Berko J, Ingram DD, Saha S, and Parker JD. 2014. Deaths Attributed to Heat, Cold, and Other Weather Events in the United States, 2006-2010. National Health Statistical Reports No. 76, 15 pp. National Center for Health Statistics, Hyattsville, MD; Ho HC, Knudby A, Chi G, Aminipouri M, and Lai YF. 2018. Spatiotemporal analysis of regional socio-economic vulnerability change associated with heat risks in Canada. Appl Geogr, 95(3):61-70; Manangan AP, Uejio CK, Saha S, Schramm PJ, Marinucci GD, Brown CL, Hess JJ, and Luber G. 2014. Assessing Health Vulnerability to Climate Change: A Guide for Health Departments. In *Climate and Health Technical Report Series.* Atlanta, GA: Centers for Disease Control and Prevention.

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7 Kenney WL, Craighead DH, and Alexander LM. 2014. Heat waves, aging, and human cardiovascular health. *Med Sci Sports Exerc,* 46(10):1891-1899; CDC. 2017. Natural Disasters and Severe Weather. Centers for Disease Control and Prevention, National Center for Environmental Health https://www.cdc.gov/disasters/extremeheat/heat_guide.html.

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9 Sarofim, M.C., S. Saha, M.D. Hawkins, D.M. Mills, J. Hess, R. Horton, P. Kinney, J. Schwartz, and A. St. Juliana, 2016: Ch. 2: Temperature-Related Death and Illness. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 43–68.

10 Eisenman DP, Wilhalme H, Tseng CH, Chester M, English P, Pincetl S, Fraser S, Vangala S, and Dhaliwal SK. 2016. Heat Death Associations with the built environment, social vulnerability and their interactions with rising temperature. *Health & Place,* 41, 89-99.

11 Also, adaptation is not constant over time, because lower societal adaptation (higher vulnerability) could also drive temperature mortality rates higher even in the absence of warming. See Putnam H, Hondula DM, Urban A, Berisha V, Iñiguez P, Roach M. It's not the heat, it's the vulnerability: attribution of the 2016 spike in heat-associated deaths in Maricopa County, Arizona. Environmental research letters. 2018 Sep 19;13(9):094022.

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13 Madrigano J, Jack D, Anderson GB, Bell ML, and Kinney PL. 2015. Temperature, ozone, and mortality in urban and non-urban counties in the northeastern United States. *Environ Health,* 14(3); Eisenman DP, Wilhalme H, Tseng CH, Chester M, English P, Pincetl S, Fraser S, Vangala S, and Dhaliwal SK. 2016. Heat Death Associations with the built environment, social vulnerability and their interactions with rising temperature. Health & Place, 41, 89-99; Berko J, Ingram DD, Saha S, and Parker JD. 2014. Deaths Attributed to Heat, Cold, and Other Weather Events in the United States, 2006-2010. National Health Statistical Reports No. 76, 15 pp. National Center for Health Statistics, Hyattsville, MD; Ho HC, Knudby A, Chi G, Aminipouri M, and Lai YF. 2018. Spatiotemporal analysis of regional socio-economic vulnerability change associated with heat risks in Canada. *Appl Geogr,* 95(3):61-70.

14 Eisenman DP, Wilhalme H, Tseng CH, Chester M, English P, Pincetl S, Fraser S, Vangala S, and Dhaliwal SK. 2016. Heat Death Associations with the built environment, social vulnerability and their interactions with rising temperature. *Health & Place,* 41, 89-99.

15 Berko J, Ingram DD, Saha S, and Parker JD. 2014. Deaths Attributed to Heat, Cold, and Other Weather Events in the United States, 2006-2010. National Health Statistical Reports No. 76, 15 pp. National Center for Health Statistics, Hyattsville, MD; Eisenman DP, Wilhalme H, Tseng CH, Chester M, English P, Pincetl S, Fraser S, Vangala S, and Dhaliwal SK. 2016. Heat Death Associations with the built environment, social vulnerability and their interactions with rising temperature. *Health & Place,* 41, 89-99.

16 Eisenman DP, Wilhalme H, Tseng CH, Chester M, English P, Pincetl S, Fraser S, Vangala S, and Dhaliwal SK. 2016. Heat Death Associations with the built environment, social vulnerability and their interactions with rising temperature. *Health & Place,* 41, 89-99.

17 Kenney WL, Craighead DH, and Alexander LM. 2014. Heat waves, aging, and human cardiovascular health. *Med Sci Sports Exerc,* 46(10):1891-1899; CDC. 2017. Natural Disasters and Severe Weather. Centers for Disease Control and Prevention, National Center for Environmental Health https://www.cdc.gov/disasters/extremeheat/heat_guide.html.

18 The analysis covers impacts in 49 large urban areas in the U.S. – in part because the best data are provided in urban areas, and in part because literature shows that the largest effects of extreme temperature mortality are likely to be in cities due to heat island effects. The underlying epidemiological relationships described in Mills et al. (2014) constraint the analysis to these 49 cities, therefore omitting large parts of the country and its population. Many factors affect how an urban population responds to extreme temperature effects, including building infrastructure, the prevalence of air conditioning, and the vulnerability of the local population to heat stress. As a result, each city in this analysis has its own city-specific response function for both heat and cold extremes.

19 Mills D, Schwartz J, Lee M, Sarofim M, Jones R, Lawson M, Duckworth M, and Deck L. 2014. Climate change impacts on extreme temperature mortality in select metropolitan areas in the United States. Climatic Change, 131, 83-95; U.S. EPA. 2017. Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. U.S. Environmental Protection Agency, Washington, D.C.

20 For more information on these calculations, please see Table 3 of the Approach chapter.

21 See Mills D, Schwartz J, Lee M, Sarofim M, Jones R, Lawson M, Duckworth M, and Deck L. 2014. Climate change impacts on extreme temperature mortality in select metropolitan areas in the United States. Climatic Change, 131, 83-95, and other detailed results, by city, in Table 2 in Appendix E. Midwestern cities may be more to likely to see a higher mortality incidence because residents are not used to or prepared for extreme heat and may not have taken steps to adapt infrastructure or had an opportunity to acclimate to more extreme heat. In New Orleans and Orlando, the reasons for high impacts may be related to the susceptibility of their populations.

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22 Prolonged power outages from storms and other climate-driven weather events can increase the risk of temperature-related mortality, as people are not able to access air-conditioned space. This effect is not captured in the analysis of this report, likely leading to underestimated risks.

23 Xu JQ, Murphy SL, Kochanek KD, Arias E. Mortality in the United States, 2018. NCHS Data Brief, no 355. Hyattsville, MD: National Center for Health Statistics. 2020.

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25 Reference populations are defined for each socially vulnerable group as the population that does not exhibit the social vulnerability determinant in question. For example, for the low income population, the reference population is the population that is not low income. That reference population does, however, include those with other social vulnerability determinants, such as minorities, those without high school diplomas, etc.

Chapter 5. Extreme Temperature and Labor

1 See Appendix F and Figure 5.2 of this chapter.

2 Ebi KL, Balbus JM, Luber G, Bole A, Crimmins A, Glass G, Saha S, Shimamoto MM, Trtanj J, and White-Newsome JL. 2018. Human Health. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 539–571. doi: 10.7930/NCA4.2018.CH14.

3 Graff Ziven J, and Neidell M. 2014. Temperature and the allocation of time: implications for climate change. *Journal of Labor Economics*, 32(1):1-26. doi: 10.1086/671766.

4 With regards to the length of the working season for various industries (e.g., agriculture, tourism, construction), the labor method is not ideally suited to answer questions about how longer warm seasons may lead to more or less time spent working among high risk workers. Building on findings from (Graff-Zivin and Neidell 2014), the investigation of this report focuses specifically on the impact of discrete very high temperature days, which are projected to occur more frequency in the future and can have detrimental health impacts for exposed workers.

5 Graff Ziven J, and Neidell M. 2014. Temperature and the allocation of time: implications for climate change. *Journal of Labor Economics,* 32(1):1-26. doi: 10.1086/671766.

6 Park J, Hallegatte S, Bangalore M, and Sandhoefner E. 2015. Households and Heat Stress: Estimating the Distributional Consequences of Climate Change. World Bank Group Policy Research Working Paper 7479. doi: 10.1596/1813-9450-7479.

7 Heal GM, and Park J. 2016. Temperature Stress and the Direct Impact of Climate Change: A Review of an Emerging Literature. *Review of Environmental Economics and Policy,* 10(2). doi: 0.1093/reep/rew007.

8 National Academies of Sciences, Engineering, and Medicine. 2018. Health-care utilization as a proxy in disability determination. Washington, DC: The National Academies Press. doi: 10.17226/24969.

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12 Sarofim, M.C., S. Saha, M.D. Hawkins, D.M. Mills, J. Hess, R. Horton, P. Kinney, J. Schwartz, and A. St. Juliana, 2016: Ch. 2: Temperature-Related Death and Illness. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 43–68.

13 Degree days are measures of how warm or cold a location is. A degree day compares the mean (the average of the high and low) outdoor temperature recorded for a location to a standard temperature, usually 65° F.

14 Neidell, M., J. Graff Zivin, M. Sheahan, J. Willwerth, C. Fant, M. Sarofim, J. Martinich. (In Press) Temperature and work: Time allocated to work under varying climate and labor market conditions. PLOSONE.

15 For more information on these calculations, please see Table 3 of the Approach chapter. The analysis first calculates the total number of individuals currently living in the study area. Next, it calculates the number of individuals currently living in the area where impacts are projected to be highest. Then, it calculates the likelihood that an individual in each socially vulnerable group

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currently lives in the high-impact areas, relative to the likelihood for an individual from each corresponding reference population. Note that although the analyses quantify the numbers of all individuals in the study area and high-impact areas, it weights the populations by the portion of individuals that work in weather-exposed industries when calculating the difference in risk.

16 See Appendix F for maps showing the projected change in days over 90°F at the Census tract level.

17 See Appendix F for details on the geographic distribution of the high-impact Census tracts used in this analysis.

18 Reference populations are defined for each socially vulnerable group as the population that does not possess the social vulnerability determinant in question. For example, for the low income population, the reference population is the population that is not low income. That reference population does, however, include those with other social vulnerability determinants, such as minorities, those without high school diplomas, etc.

19 Only one of the five socially vulnerable populations examined in the report—individuals over 65 years old—is projected to be less at risk of experiencing high-end reductions in labor hours. However, the difference in risk relative to those under 65 years old is very small, at an estimated -2% in the 2°F warming scenario and -1% in the 4°F warming scenario.

Chapter 6. Coastal Flooding and Traffic

1 U.S. Department of Transportation, Federal Highway Administration. 2017. National Household Travel Survey. http://nhts.ornl.gov.

2 Jacobs JM, Cattaneo LR, Sweet W, and Mansfield T. 2018. Recent and future outlooks for nuisance flooding impacts on roadways on the US East Coast. *Transportation Research Record: The Journal of the Transportation Research Board,* 2672(2); Lewchuk W, Laflèche M, Procyk S, Cook C, Dyson D, Goldring L, Lior K, Meisner A, Shields J, Tambureno A, and Viducis P. 2016. The Precarity Penalty: How Insecure Employment Disadvantages Workers and Their Families. *Alternative Routes: A Journal of Critical Social Research,* 27; MacLeod KE, Ragland DR, Prohaska TR, Smith ML, Irmiter C, and Satariano WA. 2015. Missed or Delayed Medical Care Appointments by Older Users of Nonemergency Medical Transportation. Gerontologist, 55(6):1026-1037; Syed ST, Gerber BS, and Sharp LK. 2013. Traveling towards disease: transportation barriers to health care access. *J Community Health*, 38(5):976-993.

3 Theiss, R. The future of work: Trends and challenges for low-wage workers. Economic Policy Institute Briefing Paper #341. https://files.epi.org/2012/bp341-future-of-work.pdf

4 Kneebone E, and Holmes N. 2015. The growing distance between people and jobs in metropolitan America. Brookings Institute Metropolitan Policy Program working paper. Washington, DC. Available at: https://www.brookings.edu/wp-content/uploads/2016/07/srvy_jobsproximity.pdf.

5 Lewchuk W, Laflèche M, Procyk S, Cook C, Dyson D, Goldring L, Lior K, Meisner A, Shields J, Tambureno A, and Viducis P. 2016. The Precarity Penalty: How Insecure Employment Disadvantages Workers and Their Families. *Alternative Routes: A Journal of Critical Social Research,* 27.

6 MacLeod KE, Ragland DR, Prohaska TR, Smith ML, Irmiter C, and Satariano WA. 2015. Missed or Delayed Medical Care Appointments by Older Users of Nonemergency Medical Transportation. *Gerontologist,* 55(6):1026-1037. doi: 10.1093/geront/gnu002.

7 Syed ST, Gerber BS, and Sharp LK. 2013. Traveling towards disease: transportation barriers to health care access. *J Community Health,* 38(5):976-993. doi: 10.1007/s10900-013-9681-1.

8 Sweet W, Dusek G, Obeysekera J, and Marra JJ. 2018. Patterns and Projections of High Tide Flooding Along the U.S. Coastline Using a Common Impact Threshold. NOAA Technical Report NOSCO-OPS 086.

9 Fant C, Jacobs JM, Chinowsky P, Sweet W, Weiss N, Sias JE, Martinich J, and Neumann JE. (2021) Mere nuisance or growing threat? The physical and economic impact of high tide flooding on US road networks. *Journal of Infrastructure Systems*. doi: 10.1061/(ASCE)IS.1943-555X.0000652

10 In this analysis, the baseline levels of traffic delay include two reasonably anticipated adaptations to reduce traffic delay risk, (1) driver-initiated or official detour rerouting that directs drivers around the inundated road and (2) ancillary protection, where high tide flooding is prevented using protective strategies, such as sea walls and beach nourishment that are built to protect nearby land and structures, but also prevent flooding on roadways. These adaptations are included in all estimates of this chapter. The analysis also considers roads that could be excluded from receiving protective adaptation to mitigate high-tide flooding. The direct adaptation scenario considers the alleviation of high-tide flooding induced traffic delays through the implementation of two well established adaptation options: (1) build a sea wall to hold back the flood water, and (2) raise the road profile above the effective threshold.

11 Fant C, Jacobs JM, Chinowsky P, Sweet W, Weiss N, Sias JE, Martinich J, and Neumann JE. (In Press) Mere nuisance or growing threat? The physical and economic impact of high tide flooding on US road networks. In Review in the *Journal of Infrastructure Systems*.

12 For more information on these calculations, please see Table 3 of the Approach chapter.

13 Note that in Figure 6.2 and all results presented here for high-tide flooding, the Southeast NCA region is divided into a Gulf and Atlantic component, because of the substantial differences in local relative sea level rise and

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tidal ranges for the Gulf and Atlantic coasts (with land subsidence being higher in the Gulf area).

14 Reference populations are defined for each socially vulnerable group as the population that does not possess the social vulnerability determinant in question. For example, for the low income population, the reference population is the population that is not low income. That reference population does, however, include those with other social vulnerability determinants, such as minorities, those without high school diplomas, etc.

Chapter 7. Coastal Flooding and Property

1 NOAA. 2016. Economics and Demographics. Office for Coastal Management, National Oceanic and Atmospheric Administration. https://coast.noaa.gov/states/fast-facts/economics-and-demographics.html.

2 Coastal counties are defined according to the Federal Emergency Management Agency's definition, which states that a coastal county must have a coastline bordering the open ocean or the Great Lakes or contain coastal high hazard areas.

3 NOAA. 2016. Economics and Demographics. Office for Coastal Management, National Oceanic and Atmospheric Administration. https://coast.noaa.gov/states/fast-facts/economics-and-demographics.html.

4 Fleming E, Payne J, Sweet W, Craghan M, Haines J, Hart JF, Stiller H, and Sutton-Grier A. 2018. Coastal Effects. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 322–352. doi: 10.7930/NCA4.2018.CH8.

5 Fleming E, Payne J, Sweet W, Craghan M, Haines J, Hart JF, Stiller H, and Sutton-Grier A. 2018. Coastal Effects. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 322–352. doi: 10.7930/NCA4.2018.CH8.

6 Lieberman-Cribbon W, Gillezeau C, Schwartz RM, and Taioli E. 2020. Unequal social vulnerability to Hurricane Sandy flood exposure. *J Expo Sci Environ Epidemiol*. doi: 10.1038/s41370-020-0230-6.

7 Center for Climate Integrity. 2019. High tide tax: the price to protect coastal communities from rising seas.

8 Fleming, E., J. Payne, W. Sweet, M. Craghan, J. Haines, J.F. Hart, H. Stiller, and A. Sutton-Grier, 2018: Coastal Effects. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 322–352. doi: 10.7930/NCA4.2018.CH8

9 Moss RH, Avery S, Baja K, Burkett M, Chischilly AM, Dell J, Fleming PA, Geil K, Jacobs K, Jones A, Knowlton K, Koh J, Lemos MC, Melillo J, Pandya R, Richmond TC, Scarlett L, Snyder J, Stults M, Waple AM, Whitehead J, Zarrilli D, Ayyub BM, Fox J, Ganguly A, Joppa L, Julius S, Kirshen P, Kreutter R, McGovern A, Meyer R, Neumann J, Solecki W, Smith J, Tissot P, Yohe G, and Zimmerman R. 2019. Evaluating knowledge to support climate action: A framework for sustained assessment. Weather, Climate, and Society, 11(3):465-487. doi:10.1175/WCAS-D-18-0134.1.

10 Buchanan M, Kulp S, Cushing L, Morello-Frosch R, Nedwick T, and Strauss B. 2020. Sea level rise and coastal flooding threaten affordable housing. *Environmental Research Letters,* 15(12). doi: 10.1088/1748-9326/abb266.

11 Bhattachan A, Jurjonas MD, Moody AC, Morris PR, Sanchez GM, Smart LS, Taillie PJ, Emanuel RE, and Seekamp EL. 2018. Sea level rise impacts on rural coastal social-ecological systems and the implications for decision making. *Environmental Science and Policy,* 90, 122-134. doi: 10.1016/j.envsci.2018.10.006.

12 Martinich J, Neumann J, Ludwig L, and Jantarasami L. 2013. Risks of sea level rise to disadvantaged communities in the United States. *Mitigation and Adaptation Strategies for Global Change,* 18, 169- 185. doi: 10.1007/s11027-011-9356-0.

13 Gamble, J.L., J. Balbus, M. Berger, K. Bouye, V. Campbell, K. Chief, K. Conlon, A. Crimmins, B. Flanagan, C. Gonzalez-Maddux, E. Hallisey, S. Hutchins, L. Jantarasami, S. Khoury, M. Kiefer, J. Kolling, K. Lynn, A. Manangan, M. McDonald, R. Morello-Frosch, M.H. Redsteer, P. Sheffield, K. Thigpen Tart, J. Watson, K.P. Whyte, and A.F. Wolkin, 2016: Ch. 9: Populations of Concern. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 247–286.

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15 Please see the Approach chapter and Appendix C for more information on the SLR projections used in the analysis.

16 Please see Appendix H for more details on this approach.

17 Impacts are calculated as the ratio of total damages to total property value within each block group.

18 For more information on these calculations, please see Table 3 of the Approach chapter.

19 As described in the Approach section of this report, the global levels of sea level change are adjusted for location-specific factors (e.g., vertical land movement,

ENDNOTES

currents), to provide locally-relevant rates for determining vulnerability.

20 As this analysis is conducted at Census block group scale, it is important to note that the approach is not able to capture all of the micro-scale hydraulic and infrastructure dynamics important for precisely estimating flood risk. As such, there are likely to exist biases due to the correlations between hydrology, socioeconomics, and existing flood protection.

21 Reference populations are defined for each socially vulnerable group as the population that does not possess the social vulnerability determinant in question. For example, for the low income population, the reference population is the population that is not low income. That reference population does, however, include those with other social vulnerability determinants, such as minorities, those without high school diplomas, etc.

22 Based on groupings in the American Community Survey, this analysis groups together American Indian and Alaska Native individuals. Since there are relatively fewer Alaska Native individuals living in the Southeast, these findings are more representative of effects for American Indian individuals. In addition, it is important to reiterate that this analysis is confined to the contiguous U.S. and does not include Alaska.

23 Reference populations are defined for each socially vulnerable group as the population that does not possess the social vulnerability determinant in question. For example, for the low income population, the reference population is the population that is not low income. That reference population does, however, include those with other social vulnerability determinants, such as minorities, those without high school diplomas, etc.

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25 Other factors may include local zoning bylaws, future land use plans, the presence of development-supporting infrastructure, or proximity to sites with high cultural value. As this analysis projects potential protection and abandonment of coastal properties, it is acknowledged that there are important considerations that drive the decisions that homeowners will make in response to risks from SLR. In some cases, residents may have strong emotional and/or ancestral attachment to their land, or be resistant to leaving vulnerable properties because they do not have the social structure elsewhere or financial liquidity that would enable them to do so.

26 The areas projected to be excluded from adaptation in these regions are generally characterized by low population and structure density, which raise technical challenges for cost-effective adaptation (as modeled in the NCPM response framework), and/or lower property values.

Chapter 8. Inland Flooding and Property

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2 Wobus C, Zheng P, Stein J, Lay C, Mahoney H, Lorie M, Mills D, Spies R, Szafranski B, and Martinich J. 2019. Projecting changes in expected annual damages from riverine flooding in the United States. *Earth's Future,* 7(5):516–527. doi: 10.1029/2018EF001119. Riverine flooding can also be caused by heavy snow melt (which is considered in this analysis) and ice jams (which are not considered).

3 A second type of freshwater flooding, known as pluvial flooding, is caused by the excessive rainfall itself, and is often associated with urban drainage systems reaching a state of over-capacity, rather than rain causing a river system to exceed its capacity. Pluvial flooding is also expected to grow worse as a result of climate change (see Price J, Wright L, Fant C, and Strzepek K. 2014. Calibrated Methodology for Assessing Climate Change Adaptation Costs for Urban Drainage Systems. *Urban Water Journal,* 13(4). doi: 10.1080/1573062X.2014.991740), but is not considered in this analysis.

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22 For more information on these calculations, please see Table 3 of the Approach chapter.

23 As this analysis is conducted at Census block group scale, it is important to note that the approach is not able to capture all of the micro-scale hydraulic and infrastructure dynamics important for precisely estimating flood risk. As such, there are likely to exist biases due to the correlations between hydrology, socioeconomics, and existing flood protection.

24 This analysis uses a different baseline period (2001-2020) compared to other impact analyses of this report. See Appendix I for additional details and rationale.

25 Gamble JL, Balbus J, Berger M, Bouye K, Campbell V, Chief K, Conlon K, Crimmins A, Flanagan B, Gonzalez-Maddux C, Hallisey E, Hutchins S, Jantarasami L, Khoury S, Kiefer M, Kolling J, Lynn K, Manangan A, McDonald M, Morello-Frosch R, Redsteer MH, Sheffield P, Thigpen Tart K, Watson J, Whyte KP, and Wolkin AF. 2016. Ch. 9: Populations of Concern. In *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.* U.S. Global Change Research Program, Washington, DC, 247–286.

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September 2021
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Sierra Club and Prairie Rivers Network
NEPA Scoping Comments on TVA's Proposed Sugar Camp Coal Mine Expansion
October 2, 2023

Exhibit List

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From:	adkproffitt@everyactioncustom.com on behalf of Diane Proffitt
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
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Dear NEPA Specialist Elizabeth Smith,

Coal mined is coal burned. Allowing the expansion of the Sugar Camp Mine will directly result in unacceptable climate changing emissions and pollution from extraction to combustion of coal. TVA should not give Sugar Camp Mine approval to mine this coal and divestiture of TVA coal reserves should be done in a way to keep coal in the ground and meet national climate goals. TVA should consider the following comments in the scope of their upcoming environmental review:

1.) Sugar Camp Energy has proved that it is not able to responsibly manage its operations. This is evidenced by: The Sugar Camp Mine has consistently failed to remove coal in an environmentally sound manner as evidenced by its repeated quarters in non-compliance with basic permit levels, including 125 state and federal violations from 2015 to 2018.

a.) Sugar Camp had a fire that shut down much of the mine. They were penalized for failing to timely inform miners of the fire. Also, they dumped PFAS in the mine in an effort to put out the fire. For that, they are being sued by the State of Illinois, Prairie Rivers Network and Sierra Club.

b.) In July 2022, a pipeline associated with the Sugar Camp Mine ruptured and spilled 20,000 gallons of mine wastewater near Macedonia, Illinois.

c.) In June 2022, the U.S. Department of Labor's Mine Safety and Health Administration (MSHA) proposed nearly $1.2 million in civil penalties to M-Class Mining LLC, one of the operators of the Sugar Camp Coal Mine. The mine faces 14 citations, including 10 related to the operator's neglect of the miners' safety and health, after operators failed to evacuate miners or notify the MSHA when a fire broke out underground.

2.) The Big Muddy River is an aquatic resource with high societal, cultural, and ecological value to southern Illinois. Sugar Camp intends to discharge high levels of chloride into the Big Muddy River. This will have the effect of harming aquatic life, reducing dissolved oxygen (DO) levels and promoting harmful algal blooms particularly when considered together with the Pond Creek Mine, also owned by Foresight. The Big Muddy River is already on the impaired waters list for low dissolved oxygen and phosphorus.

3.) The TVA calls itself a "leader in the nation's drive to a clean energy future" and as a federal entity TVA should be working toward the nation's climate goals.

a.) If TVA's proceeds with divestiture of coal and land rights in Southern Illinois they should not sell the reserves to be mined by someone else.

b.) The impacts of extracting TVA-owned coal include pollution and climate impacts from processing, transportation, combustion, and disposal of combustion waste. The full life cycle of coal and the impacts of co-pollutants and coal ash should be considered in an analysis, with a particular focus on environmental justice communities.

TVA has a unique opportunity to help the United States' meet its climate goals by ensuring this coal is left in the

ground forever. TVA must reject Sugar Camp Mine's request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
Diane Proffitt
909 Laurel Ave Wilmington, IL 60481-1463

From:	joseph_appell@everyactioncustom.com on behalf of Joseph Appell
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Sunday, October 1, 2023 11:48:07 PM

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Sincerely,
Joseph Appell
2125 Bedford Rd Freeport, IL 61032-3505

From:	jk2renewables@everyactioncustom.com on behalf of Jean Korte
To:	nepa
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We should not be expanding coal use. Allowing the expansion of the Sugar Camp Mine will directly result in unacceptable climate changing emissions and pollution from extraction to combustion of coal. TVA should not give Sugar Camp Mine approval to mine this coal and divestiture of TVA coal reserves should be done in a way to keep coal in the ground and meet national climate goals. TVA should consider the following comments in the scope of their upcoming environmental review:

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Sincerely,
Jean Korte
250 Kingsbury Ct Highland, IL 62249-2921

From:	nancu46@everyactioncustom.com on behalf of Nancy Voss
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
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Sincerely,
Nancy Voss
306 S Prospect Ave Champaign, IL 61820-4715

From:	Blair@everyactioncustom.com on behalf of John Blair
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Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Sunday, October 1, 2023 10:11:37 PM

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This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the "Report Phishing" button located on the Outlook Toolbar at the top of your screen.

Dear NEPA Specialist Elizabeth Smith,

Coal mined is coal burned. Allowing the expansion of the Sugar Camp Mine will directly result in unacceptable climate changing emissions and pollution from extraction to combustion of coal. TVA should not give Sugar Camp Mine approval to mine this coal and divestiture of TVA coal reserves should be done in a way to keep coal in the ground and meet national climate goals. TVA should consider the following comments in the scope of their upcoming environmental review:

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a.) Sugar Camp had a fire that shut down much of the mine. They were penalized for failing to timely inform miners of the fire. Also, they dumped PFAS in the mine in an effort to put out the fire. For that, they are being sued by the State of Illinois, Prairie Rivers Network and Sierra Club.

b.) In July 2022, a pipeline associated with the Sugar Camp Mine ruptured and spilled 20,000 gallons of mine wastewater near Macedonia, Illinois.

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2.) The Big Muddy River is an aquatic resource with high societal, cultural, and ecological value to southern Illinois. Sugar Camp intends to discharge high levels of chloride into the Big Muddy River. This will have the effect of harming aquatic life, reducing dissolved oxygen (DO) levels and promoting harmful algal blooms particularly when considered together with the Pond Creek Mine, also owned by Foresight. The Big Muddy River is already on the impaired waters list for low dissolved oxygen and phosphorus.

3.) The TVA calls itself a "leader in the nation's drive to a clean energy future" and as a federal entity TVA should be working toward the nation's climate goals.

a.) If TVA's proceeds with divestiture of coal and land rights in Southern Illinois they should not sell the reserves to be mined by someone else.

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TVA has a unique opportunity to help the United States' meet its climate goals by ensuring this coal is left in the

ground forever. TVA must reject Sugar Camp Mine's request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
John Blair
800 Adams Ave Evansville, IN 47713-2213

From:	timmary747@everyactioncustom.com on behalf of Mary Mathews
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Sunday, October 1, 2023 7:58:45 PM

[You don't often get email from timmary747@everyactioncustom.com. Learn why this is important at https://aka.ms/LearnAboutSenderIdentification]

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Dear NEPA Specialist Elizabeth Smith,

For the sake of everyone, we must stop: mining coals, burning coal, and storing coal ash dangerously. Mining and burning coal is bad for the heath of people, the environment, and the world.

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Sincerely,
Mary Mathews
1111 S Waukegan Rd Lake Forest, IL 60045-7300

From: marysampson4@everyactioncustom.com on behalf of Mary Sampson
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Sunday, October 1, 2023 7:29:52 PM

Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
Mary Sampson
207 S Austin Ave Decatur, IL 62522-1839

From: jwdmed@everyactioncustom.com on behalf of Mary Ellen DeClue
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Sunday, October 1, 2023 5:36:46 PM

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Dear NEPA Specialist Elizabeth Smith,

Foresight Energy is the operator for Deer Run Mine in Hillsboro, IL. Please do not subject more communities to its reckless, profit at any cost manner of doing business. Coal mining, especially longwall mining, permanently damages farmland, water resources, contributes to the climate crisis, and harms the health of communities.

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Sincerely,
Mary Ellen DeClue
366 Westlake Trl Litchfield, IL 62056-4220

From: ntgoodall@everyactioncustom.com on behalf of Nancy Goodall
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Sunday, October 1, 2023 5:27:38 PM

[You don't often get email from ntgoodall@everyactioncustom.com. Learn why this is important at https://aka.ms/LearnAboutSenderIdentification]

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Sincerely,
Nancy Goodall
3503 N470 East Rd Sidell, IL 61876

From: rob.kanter@everyactioncustom.com on behalf of Robert Kanter
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Sunday, October 1, 2023 4:22:35 PM

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Sincerely,
Robert Kanter
1009 W Park Ave Champaign, IL 61821-3333

From: jwfallaw@everyactioncustom.com on behalf of James Fallaw
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Sunday, October 1, 2023 4:20:09 PM

Dear NEPA Specialist Elizabeth Smith,

I am a father of two teenagers. I urge you to act in order to give our children and their children a safe future.

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Sincerely,
James Fallaw
2006 Broadmoor Dr Champaign, IL 61821-5850

From: jess.beyler@everyactioncustom.com on behalf of Rebecca Beyler
To: nepa

Subject: NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Sunday, October 1, 2023 1:22:40 PM

Dear NEPA Specialist Elizabeth Smith,

This is completely crazy. We are talking about carbon sequestration and we are talking about expanding coal mining. Ummm.....do I need to point out that carbon sitting in the ground as coal is carbon that is sequestered and it's been sequestered for FREE! at ZERO taxpayer dollars! at ZERO energy expense! Come on guys. What are you thinking? Either we are taking the need to stop putting carbon into the air seriously or we are not. Simply not expanding a coal mine is one of the simplest steps to take. If we do not, collectively, have the will to say "No" to another dollar for a coal mine exec and his cronies, than we are too weak to be worth saving as a species. The time to do something different is right now. You have a chance to matter. Take it. Do not allow Sugar Camp Mine to expand. Just don't.

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Sincerely,
Rebecca Beyler
408 W Elm St Apt 4 Urbana, IL 61801-7206

From:	kristincorncamp@everyactioncustom.com on behalf of Kristin Camp
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Sunday, October 1, 2023 1:02:37 PM

[You don't often get email from kristincorncamp@everyactioncustom.com. Learn why this is important at https://aka.ms/LearnAboutSenderIdentification]

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Sincerely,
Kristin Camp
8695 E 2330 North Rd Collison, IL 61831-9707

From:	swalsh185@everyactioncustom.com on behalf of Sarah Walsh
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Sunday, October 1, 2023 12:42:11 PM

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ground forever. TVA must reject Sugar Camp Mine's request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
Sarah Walsh
1732 W Leland Ave Chicago, IL 60640-4561

From:	brockauerbachlynn@everyactioncustom.com on behalf of Brock Auerbach-Lynn
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Sunday, October 1, 2023 1:48:05 AM

[You don't often get email from brockauerbachlynn@everyactioncustom.com. Learn why this is important at https://aka.ms/LearnAboutSenderIdentification]

This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the "Report Phishing" button located on the Outlook Toolbar at the top of your screen.

Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
Brock Auerbach-Lynn
2127 W Pierce Ave Apt 3A Chicago, IL 60622-1824

From: culp.lisa@everyactioncustom.com on behalf of Lisa Musgrave
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Saturday, September 30, 2023 10:15:06 PM

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Sincerely,
Lisa Musgrave
1032 N Ridgewood Ln Palatine, IL 60067-3449

From:	larrycreekmur@everyactioncustom.com on behalf of Larry Creekmur
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Saturday, September 30, 2023 6:31:00 PM

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Sincerely,
Larry Creekmur
5231 S Beck Rd Rochelle, IL 61068-9620

From:	aishasobh@everyactioncustom.com on behalf of Aisha Sobh
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Saturday, September 30, 2023 3:46:57 PM

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This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the "Report Phishing" button located on the Outlook Toolbar at the top of your screen.

Dear NEPA Specialist Elizabeth Smith,

Seriously, I cannot believe we are going through this again. Sugar Camp Mine should not exist. This flies in the face of everything we know about our climate and future. Do NOT allow this farce to continue!

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Sincerely,
Aisha Sobh
2024 Cureton Dr Urbana, IL 61801-6226

From: jacobhoots@everyactioncustom.com on behalf of Jacob Hoots
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Saturday, September 30, 2023 2:35:23 PM

Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
Jacob Hoots
1169 Highland Ave Oak Park, IL 60304-2244

From:	aliciahenry228@everyactioncustom.com on behalf of Alicia Henry
To:	nepa
Subject:	NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Saturday, September 30, 2023 10:03:52 AM

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Sincerely,
Alicia Henry
36 Boardwalk Cir Bloomington, IL 61701-1459

From:	Kayahaus@everyactioncustom.com on behalf of Kay Ahaus
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Saturday, September 30, 2023 9:35:34 AM

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Sincerely,
Kay Ahaus
200 Rinderer Rd Trenton, IL 62293-4544

From:	suzieberkes@everyactioncustom.com on behalf of Suzanne Berkes
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Saturday, September 30, 2023 8:29:21 AM

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Sincerely,
Suzanne Berkes
15615 Laurel Dr Danville, IL 61834-5761

From:	joetteconger@everyactioncustom.com on behalf of Joette Conger
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Saturday, September 30, 2023 8:20:17 AM

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Dear NEPA Specialist Elizabeth Smith,

Coal mining is unnecessary and it hurts communities. The USA does not need more coal mines, and expansion of this mine will only hurt southern Illinois.

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Sincerely,
Joette Conger
2218 Rockefeller Dr Geneva, IL 60134-4708

From:	dragonfly0788@everyactioncustom.com on behalf of Dick Todd
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Saturday, September 30, 2023 6:03:19 AM

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This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the "Report Phishing" button located on the Outlook Toolbar at the top of your screen.

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Sincerely,
Dick Todd
26434 US Highway 34 Princeton, IL 61356-9593

From:	yellowstart5@everyactioncustom.com on behalf of Jeffrey Sanders
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Saturday, September 30, 2023 4:00:30 AM

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Sincerely,
Jeffrey Sanders
9201 Drake Ave Evanston, IL 60203-1650

From:	jillkb@everyactioncustom.com on behalf of Jill B
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Saturday, September 30, 2023 1:36:18 AM

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Sincerely,
Jill B
44 Lake Shore Dr Putnam, IL 61560-9762

From:	donlychorn1@everyactioncustom.com on behalf of Donly Chorn
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Saturday, September 30, 2023 12:37:51 AM

Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
Donly Chorn
310 N Milwaukee Ave Apt 412 Lake Villa, IL 60046-8528

From:	eeguinness@everyactioncustom.com on behalf of Eric Edwards
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:47:27 PM

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Sincerely,
Eric Edwards
1373 Prairie Ct West Chicago, IL 60185-5147

From: dsrusso@everyactioncustom.com on behalf of Susan Russo
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Friday, September 29, 2023 11:27:30 PM

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Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
Susan Russo
3 N Jackson St Batavia, IL 60510-1813

From:	walterchcharlotte52@everyactioncustom.com on behalf of Charlotte Arnstein
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:26:04 PM

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All coal in the ground should be left there! Coal-burning power plants should be shut down. Climate Change is HERE!

Charlotte C. Arnstein

Sincerely,
Charlotte Arnstein
101 W Windsor Rd # 6103 Urbana, IL 61802-6663

From:	mperkowitz@everyactioncustom.com on behalf of Marc Perkowitz
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 9:30:41 PM

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Sincerely,
Marc Perkowitz
1205 W Palatine Rd Arlington Heights, IL 60004-3669

From:	51940@everyactioncustom.com on behalf of Bonita Staas
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 9:12:51 PM

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Dear NEPA Specialist Elizabeth Smith,

SHAME ON YOU FOR KEEPING COAL GOING!

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Sincerely,
Bonita Staas
11294 N Henderson Rd Orangeville, IL 61060-9676

From: pweyhrich711@everyactioncustom.com on behalf of Patty Weyhrich
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Friday, September 29, 2023 8:36:43 PM

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Dear NEPA Specialist Elizabeth Smith,

I am a homeowner in southern Illinois and have lived here since 1974. I appreciate your attention to my concerns. I am opposed to the expansion of Sugar Camp mine:
1. Sugar Camp mine has had cited safety violations over the years
2. America needs to move to renewable energy to achieve carbon reduction goals
3. Climate goals require a transition away from fossil fuels.
4. Coal extraction destroys the natural botanical landscape, disrupts human and animal habitat, and generates air, water, and sound pollution. It creates an overall wasteland and does not employ technological advances that are more efficient in generating energy.

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Sincerely,
Patty Weyhrich
38 Southmoor St Carbondale, IL 62903-7696

From: d-kimme@everyactioncustom.com on behalf of Duane Kimme
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Friday, September 29, 2023 7:27:00 PM

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Sincerely,
Duane Kimme
703 La Sell Dr Champaign, IL 61820-6817

From:	amccabe4@everyactioncustom.com on behalf of Ann McCabe
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 7:20:38 PM

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Sincerely,

Ann McCabe
5145 N Lincoln Ave Chicago, IL 60625-2549

From: babettejo53@everyactioncustom.com on behalf of Babette Neuberger
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Friday, September 29, 2023 7:15:37 PM

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Dear NEPA Specialist Elizabeth Smith,

We are in the midst of the climate crisis; and the fate of humanity as we know it is on the line! As the U.N. Secretary General has said, all existing fossil fuel reserves MUST remain in the ground lest we pass the tipping point ! It is quite absurd to even consider the expansion of coal mining.

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Sincerely,
Babette J Neuberger, J.D., M.P.H.

Sincerely,
Babette Neuberger
4303 N Hermitage Ave Chicago, IL 60613-1105

From:	drew.bergstrom@everyactioncustom.com on behalf of Mr.BERGSTROM
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 7:10:49 PM

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Sincerely,
Mr. BERGSTROM
6725 N Mount Hawley Rd Peoria, IL 61614-2913

From:	rosi.mcleese@everyactioncustom.com on behalf of Rosi McLeese
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 7:03:13 PM

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Sincerely,
Rosi McLeese
1076 Bucks Pond Rd Monticello, IL 61856-8058

From:	pjejmw@everyactioncustom.com on behalf of Paula Enstrom
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 7:01:33 PM

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Sincerely,
Paula Enstrom
764 11th St Charleston, IL 61920-2112

From:	marysedrop@everyactioncustom.com on behalf of Mary Shesgreen
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 6:46:59 PM

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Tennessee Valley Authority must not make the climate crisis worse by expanding any coal mine. What a bad idea. For over a decade now, wise people have been saying No New Fossil Fuel Infrastructure. That clearly means that coal mines must shut down, not expand.

Thank you,

Mary Shesgreen
Elgin, IL

Sincerely,
Mary Shesgreen
402 Orange St Elgin, IL 60123-7545

From:	Sieberstom@everyactioncustom.com on behalf of Debbie Siebers
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 6:46:58 PM

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Sincerely,
Debbie Siebers
2578 Alta Ct Lisle, IL 60532-3401

From: jwray1939@everyactioncustom.com on behalf of Jerald Wray
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Friday, September 29, 2023 6:27:48 PM

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Sincerely,
Jerald Wray
1609 Sandpiper Ct Champaign, IL 61821-6464

From:	jbeverly@everyactioncustom.com on behalf of J.Beverly
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 6:05:35 PM

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Sincerely,
J. Beverly
803 Shurts St Urbana, IL 61801-6858

From:	chrismain1219@everyactioncustom.com on behalf of Christine Main
To:	nepa
Subject:	NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 6:05:19 PM

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Sincerely,
Christine Main
1219 W Charles St Champaign, IL 61821-4521

From:	r.mcleese@everyactioncustom.com on behalf of Robert McLeese
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 6:01:05 PM

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Sincerely,
Robert McLeese
1076 Bucks Pond Rd Monticello, IL 61856-8058

From:	calandon@everyactioncustom.com on behalf of Craig Landon
To:	nepa
Subject:	NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 5:48:46 PM

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Sincerely,
Craig Landon
24797 Homeridge Dr Jerseyville, IL 62052-6386

From:	dhatch46@everyactioncustom.com on behalf of DiAnne Hatch
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 5:29:24 PM

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Sincerely,
DiAnne Hatch
1405 Woodfield Dr Mahomet, IL 61853-3627

From:	cclarkin@everyactioncustom.com on behalf of Cathy Clarkin
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 5:29:15 PM

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Dear NEPA Specialist Elizabeth Smith,

Ending coal and embracing clean energy will combat global heating, reduce air pollution and related illness, and ensure that our state is livable for our kids and grandkids.

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Cathy Clarkin
116 S West St Naperville, IL 60540-4353

From:	jennymcm@everyactioncustom.com on behalf of Jennifer Ellis
To:	nepa
Subject:	NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 4:01:56 PM

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Jennifer Ellis
711 S Elm Blvd Champaign, IL 61820-5805

From:	gpkolb@everyactioncustom.com on behalf of Gary Kolb
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 3:22:21 PM

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Climate change is a serious issue deserving all of our attention. Burning more coal is only going to add to the problem. It is time instead for solutions.

Sincerely,
Gary Kolb
1 Southmoor St Carbondale, IL 62903-7696

From:	opltocc@everyactioncustom.com on behalf of don Oplt
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 2:45:09 PM

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Sincerely,
don Oplt
832 Grand Ave Edwardsville, IL 62025-1435

From:	opltocc@everyactioncustom.com on behalf of Toni Oplt
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 2:44:44 PM

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Sincerely,
Toni Oplt
832 Grand Ave Edwardsville, IL 62025-1435

From:	nisd1985@everyactioncustom.com on behalf of MICHAEL CORCORAN
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 2:36:50 PM

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Sincerely,
MICHAEL CORCORAN
219 W Cherry St Carmi, IL 62821-1480

From:	mr.todd.kinney@everyactioncustom.com on behalf of Todd Kinney
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 2:15:40 PM

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Sincerely,
Todd Kinney
609 W Indiana Ave Urbana, IL 61801-4833

From:	gad8459@everyactioncustom.com on behalf of Grace Denton
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 1:48:59 PM

Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
Grace Denton
25330 Maxwell St Manhattan, IL 60442-6218

From:	ejason1227@everyactioncustom.com on behalf of Eric Jason
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 1:26:08 PM

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Sincerely,
Eric Jason
3411 Brittany Dr Joliet, IL 60435-8750

From:	schakoian@everyactioncustom.com on behalf of Sharon Chakoian
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 1:24:11 PM

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Sincerely,
Sharon Chakoian
154 Ridge Ave Crystal Lake, IL 60014-3417

From:	lerves@everyactioncustom.com on behalf of L Reeves
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 1:16:08 PM

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Sincerely,
L Reeves
19934 Hickory Stick Ln Mokena, IL 60448-1368

From:	rgm@everyactioncustom.com on behalf of Rudolf Mortimer
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 1:04:20 PM

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Sincerely,
Rudolf Mortimer
3413 S Persimmon Cir Urbana, IL 61802-7128

From:	avengethecathars@everyactioncustom.com on behalf of Peter Gunther
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 12:59:13 PM

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Sincerely,
Peter Gunther
5628 N Spaulding Ave Chicago, IL 60659-3638

From:	wszalek1@everyactioncustom.com on behalf of Andy Wszalek
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 12:53:13 PM

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Sincerely,
Andy Wszalek
510 E Washington St Urbana, IL 61801-4321

From: dhansen75820@everyactioncustom.com on behalf of David Hansen
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Friday, September 29, 2023 12:46:31 PM

Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
David Hansen
3528 Clinton Ave Berwyn, IL 60402-3323

From:	d.entwhistle@everyactioncustom.com on behalf of Dianne Entwhistle
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 12:40:23 PM

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Sincerely,
Dianne Entwhistle
370 N West Ave Elmhurst, IL 60126-2126

From: georgem@everyactioncustom.com on behalf of George Murray
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Friday, September 29, 2023 12:27:47 PM

Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
George Murray
3746 N Hermitage Ave Fl 3 Chicago, IL 60613-3509

From:	jgahris@everyactioncustom.com on behalf of Jeff Gahris
To:	nepa
Subject:	NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 12:26:53 PM

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Sincerely,
Jeff Gahris
1826 E Willow Ave Wheaton, IL 60187-5954

From:	kkoch95@everyactioncustom.com on behalf of Kelsey Koch
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 12:22:20 PM

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Sincerely,
Kelsey Koch
1109 N Busey Ave Urbana, IL 61801-1609

From:	jokling611@everyactioncustom.com on behalf of Joanna Kling
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 12:15:52 PM

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Sincerely,
Joanna Kling
112 W Whitehall Ct Urbana, IL 61801-6600

From:	jcgreen.1@everyactioncustom.com on behalf of Jeff Green
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 12:15:27 PM

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Sincerely,
Jeff Green
1708 Wildberry Dr Unit E Glenview, IL 60025-1750

From:	erictinley@everyactioncustom.com on behalf of Eric Tinley
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 12:10:35 PM

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Sincerely,
Eric Tinley
516 E Lincoln St Princeton, IL 61356-2245

From:	jp55biod@everyactioncustom.com on behalf of Jim Sweeney
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 12:07:48 PM

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Sincerely,
Jim Sweeney
1773 Selo Dr Schererville, IN 46375-2250

From:	cberti@everyactioncustom.com on behalf of Chris Berti
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 12:06:40 PM

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This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the "Report Phishing" button located on the Outlook Toolbar at the top of your screen.

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Sincerely,
Chris Berti
411 W Nevada St Urbana, IL 61801-4110

From:	galle333@everyactioncustom.com on behalf of Scott Allen
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:57:45 AM

Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
Scott Allen
327 Riley Dr Bloomington, IL 61701-2186

From:	taradonald777@everyactioncustom.com on behalf of Katherine Barnash
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:56:21 AM

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Sincerely,
Katherine Barnash
3170 N Sheridan Rd Chicago, IL 60657-4830

From:	colorgrain@everyactioncustom.com on behalf of Gary Peters
To:	nepa
Subject:	NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:49:59 AM

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Sincerely,

Gary Peters
1502 W Springfield Ave Champaign, IL 61821-3106

From:	pcrvkr@everyactioncustom.com on behalf of Verlyn Rosenberger
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:49:54 AM

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Sincerely,
Verlyn Rosenberger
356 E Holiday Dr Decatur, IL 62526-2338

From:	marc.r.alexander@everyactioncustom.com on behalf of Marc Alexander
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:42:46 AM

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Sincerely,
Marc Alexander
1705 Gentry Square Ln Apt 107 Champaign, IL 61821-5973

From:	dawnie_angel@everyactioncustom.com on behalf of Dawn Albanese
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:42:28 AM

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Sincerely,
Dawn Albanese
156 Basswood Dr Elk Grove Village, IL 60007-1718

From:	sull_99@everyactioncustom.com on behalf of Brian Sullivan
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:35:30 AM

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Sincerely,
Brian Sullivan
831 S Dunton Ave Arlington Heights, IL 60005-2547

From:	washburn@everyactioncustom.com on behalf of Mark Washburn
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:33:52 AM

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TVA has a unique opportunity to help the United States' meet its climate goals by ensuring this coal is left in the

ground forever. TVA must reject Sugar Camp Mine's request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
Mark Washburn
2068 County Road 125 E Mahomet, IL 61853-8907

From:	hidla@everyactioncustom.com on behalf of Heidi Kiesler
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:30:51 AM

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This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the "Report Phishing" button located on the Outlook Toolbar at the top of your screen.

Dear NEPA Specialist Elizabeth Smith,

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b.) In July 2022, a pipeline associated with the Sugar Camp Mine ruptured and spilled 20,000 gallons of mine wastewater near Macedonia, Illinois.

c.) In June 2022, the U.S. Department of Labor's Mine Safety and Health Administration (MSHA) proposed nearly $1.2 million in civil penalties to M-Class Mining LLC, one of the operators of the Sugar Camp Coal Mine. The mine faces 14 citations, including 10 related to the operator's neglect of the miners' safety and health, after operators failed to evacuate miners or notify the MSHA when a fire broke out underground.

2.) The Big Muddy River is an aquatic resource with high societal, cultural, and ecological value to southern Illinois. Sugar Camp intends to discharge high levels of chloride into the Big Muddy River. This will have the effect of harming aquatic life, reducing dissolved oxygen (DO) levels and promoting harmful algal blooms particularly when considered together with the Pond Creek Mine, also owned by Foresight. The Big Muddy River is already on the impaired waters list for low dissolved oxygen and phosphorus.

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Sincerely,
Heidi Kiesler
243 Dennis Ln Glencoe, IL 60022-1319

From: carolyntrimble1@everyactioncustom.com on behalf of Carolyn Trimble
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Friday, September 29, 2023 11:20:05 AM

Dear NEPA Specialist Elizabeth Smith,

Burning coal leads to pollution of air and water. Coal Ash accumulates and must be disposed of. The cost of this, and the cost to the health of the citizens of all
the surrounding states is huge.

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Sincerely,
Carolyn Trimble
404 W Iowa St Urbana, IL 61801-4032

From: lotorwin4me@everyactioncustom.com on behalf of Rhetta Jack
To: nepa
Subject: NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Friday, September 29, 2023 11:17:40 AM

Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
Rhetta Jack
840 Independence Rdg Springfield, IL 62702-3416

From:	jchase45@everyactioncustom.com on behalf of Judith Chase
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:16:46 AM

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Sincerely,
Judith Chase
613 Silver Glen Rd Mchenry, IL 60050-6513

From:	missikiti@everyactioncustom.com on behalf of Carol Gloor
To:	nepa
Subject:	NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:15:32 AM

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This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the “Report Phishing” button located on the Outlook Toolbar at the top of your screen.

Dear NEPA Specialist Elizabeth Smith,

I live in Savanna, IL, a town on the upper Mississippi River. The watershed of the river,, in its totality, is important to our economy by providing recreation and also barge loading. Something happening far down river still impacts the entire river.

Coal mined is coal burned. Allowing the expansion of the Sugar Camp Mine will directly result in unacceptable climate changing emissions and pollution from extraction to combustion of coal. TVA should not give Sugar Camp Mine approval to mine this coal and divestiture of TVA coal reserves should be done in a way to keep coal in the ground and meet national climate goals. TVA should consider the following comments in the scope of their upcoming environmental review:

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Sincerely,
Carol Gloor
946 N 4th St Savanna, IL 61074-1363

From:	bettyj1953@everyactioncustom.com on behalf of Betty Johnson
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:13:30 AM

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Sincerely,
Betty Johnson
1404 Maywood Dr Champaign, IL 61821-5017

From:	megan.huckaba@everyactioncustom.com on behalf of megan barber
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:13:22 AM

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Dear NEPA Specialist Elizabeth Smith,

As a concerned citizen of the fine state of Illinois, I sincerely hope that you read everything in this petition. Read it again, then share it with your friends, enemies, neighbors, relatives, even the grocery check-out personnel! It is critical that this information is shared and responded to in a responsible manner. We are putting our trust in you.

Coal mined is coal burned. Allowing the expansion of the Sugar Camp Mine will directly result in unacceptable climate changing emissions and pollution from extraction to combustion of coal. TVA should not give Sugar Camp Mine approval to mine this coal and divestiture of TVA coal reserves should be done in a way to keep coal in the ground and meet national climate goals. TVA should consider the following comments in the scope of their upcoming environmental review:

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b.) In July 2022, a pipeline associated with the Sugar Camp Mine ruptured and spilled 20,000 gallons of mine wastewater near Macedonia, Illinois. HOW WERE THE CITIZENS OF MACEDONIA COMPESATED FOR CONTAMINATION OF THEIR WATER SUPPLY?

c.) In June 2022, the U.S. Department of Labor's Mine Safety and Health Administration (MSHA) proposed nearly $1.2 million in civil penalties to M-Class Mining LLC, one of the operators of the Sugar Camp Coal Mine. The mine faces 14 citations, including 10 related to the operator's neglect of the miners' safety and health, after operators failed to evacuate miners or notify the MSHA when a fire broke out underground. THEY CONTINUE TO PUT THEIR EMPLOYEE'S LIVES AT RISK!

2.) The Big Muddy River is an aquatic resource with high societal, cultural, and ecological value to southern Illinois. Sugar Camp intends to discharge high levels of chloride into the Big Muddy River. This will have the effect of harming aquatic life, reducing dissolved oxygen (DO) levels and promoting harmful algal blooms particularly when considered together with the Pond Creek Mine, also owned by Foresight. The Big Muddy River is already on the impaired waters list for low dissolved oxygen and phosphorus.   WE NEED CLEAN VIABLE WATERWAYS! WATER IS CRITICAL FOR THE SUPPORT OF ALL LIFE ON EARTH!

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Sincerely,
megan barber
2905 E Main St Urbana, IL 61802-2229

From:	mark@everyactioncustom.com on behalf of Mark Hirsbrunner
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:13:19 AM

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Sincerely,
Mark Hirsbrunner
206 W Charles St Apt 202 Champaign, IL 61820-8306

From:	wildflower52000@everyactioncustom.com on behalf of Rebecca LaGesse
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:11:09 AM

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Sincerely,
Rebecca LaGesse
26 Woodland Ave Elgin, IL 60123-5314

From:	jrkreid@everyactioncustom.com on behalf of Jake Kreider
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:10:57 AM

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This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the "Report Phishing" button located on the Outlook Toolbar at the top of your screen.

Dear NEPA Specialist Elizabeth Smith,

Coal mined is coal burned. Allowing the expansion of the Sugar Camp Mine will directly result in unacceptable climate changing emissions and pollution from extraction to combustion of coal. TVA should not give Sugar Camp Mine approval to mine this coal and divestiture of TVA coal reserves should be done in a way to keep coal in the ground and meet national climate goals. TVA should consider the following comments in the scope of their upcoming environmental review:

1.) Sugar Camp Energy has proved that it is not able to responsibly manage its operations. This is evidenced by: The Sugar Camp Mine has consistently failed to remove coal in an environmentally sound manner as evidenced by its repeated quarters in non-compliance with basic permit levels, including 125 state and federal violations from 2015 to 2018.

a.) Sugar Camp had a fire that shut down much of the mine. They were penalized for failing to timely inform miners of the fire. Also, they dumped PFAS in the mine in an effort to put out the fire. For that, they are being sued by the State of Illinois, Prairie Rivers Network and Sierra Club.

b.) In July 2022, a pipeline associated with the Sugar Camp Mine ruptured and spilled 20,000 gallons of mine wastewater near Macedonia, Illinois.

c.) In June 2022, the U.S. Department of Labor's Mine Safety and Health Administration (MSHA) proposed nearly $1.2 million in civil penalties to M-Class Mining LLC, one of the operators of the Sugar Camp Coal Mine. The mine faces 14 citations, including 10 related to the operator's neglect of the miners' safety and health, after operators failed to evacuate miners or notify the MSHA when a fire broke out underground.

2.) The Big Muddy River is an aquatic resource with high societal, cultural, and ecological value to southern Illinois. Sugar Camp intends to discharge high levels of chloride into the Big Muddy River. This will have the effect of harming aquatic life, reducing dissolved oxygen (DO) levels and promoting harmful algal blooms particularly when considered together with the Pond Creek Mine, also owned by Foresight. The Big Muddy River is already on the impaired waters list for low dissolved oxygen and phosphorus.

3.) The TVA calls itself a "leader in the nation's drive to a clean energy future" and as a federal entity TVA should be working toward the nation's climate goals.

a.) If TVA's proceeds with divestiture of coal and land rights in Southern Illinois they should not sell the reserves to be mined by someone else.

b.) The impacts of extracting TVA-owned coal include pollution and climate impacts from processing, transportation, combustion, and disposal of combustion waste. The full life cycle of coal and the impacts of co-pollutants and coal ash should be considered in an analysis, with a particular focus on environmental justice communities.

TVA has a unique opportunity to help the United States' meet its climate goals by ensuring this coal is left in the

ground forever. TVA must reject Sugar Camp Mine's request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
Jake Kreider
513 Wheatley Dr Mahomet, IL 61853-4237

From:	ValRichardBeasley@everyactioncustom.com on behalf of Val Beasley
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:08:03 AM

[You don't often get email from valrichardbeasley@everyactioncustom.com. Learn why this is important at https://aka.ms/LearnAboutSenderIdentification]

This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the "Report Phishing" button located on the Outlook Toolbar at the top of your screen.

Dear NEPA Specialist Elizabeth Smith,

Coal mined is coal burned. Allowing the expansion of the Sugar Camp Mine will directly result in unacceptable climate changing emissions and pollution from extraction to combustion of coal. Much of the carbon dioxide released from burning that coal would persist in the atmosphere for centuries. It would also be a source of mercury that circles the planet and commonly reached aquatic sediments where it is converted into methyl mercury that harms aquatic animal and human health alike.

TVA should not approve the Sugar Camp Mine, and the divestiture should leave the coal in the ground to help meet national climate goals. TVA should consider the following comments in the scope of their upcoming environmental review:

1.) Sugar Camp Energy repeatedly failed to remove coal in an environmentally sound manner as evidenced by its non-compliance with basic permit levels, as reflected in 125 state and federal violations from 2015 to 2018.

a.) Sugar Camp had a fire that shut down much of the mine. They were penalized for failing to timely inform miners of the fire. Also, they dumped PFAS in the mine in an effort to put out the fire. For that, they are being sued by the State of Illinois, Prairie Rivers Network and Sierra Club.

b.) In July 2022, a pipeline associated with the Sugar Camp Mine ruptured and spilled 20,000 gallons of mine wastewater near Macedonia, Illinois.

c.) In June 2022, the U.S. Department of Labor's Mine Safety and Health Administration (MSHA) proposed nearly $1.2 million in civil penalties to M-Class Mining LLC, one of the operators of the Sugar Camp Coal Mine. The mine faces 14 citations, including 10 related to the operator's neglect of the miners' safety and health, after operators failed to evacuate miners or notify the MSHA when a fire broke out underground.

2.) The Big Muddy River is an aquatic resource with high societal, cultural, and ecological value to southern Illinois. Sugar Camp intends to discharge high levels of chloride into the Big Muddy River. This will have the effect of harming aquatic life, reducing dissolved oxygen (DO) levels and promoting harmful algal blooms particularly when considered together with the Pond Creek Mine, also owned by Foresight. The Big Muddy River is already on the impaired waters list for low dissolved oxygen and excessive phosphorus.

3.) The TVA calls itself a "leader in the nation's drive to a clean energy future" and, as a federal entity, TVA should be operating in ways that help meet the nation's climate goals.

a.) If TVA's divests its coal and land rights in Southern Illinois, they should not sell the reserves to be mined by someone else.

b.) The impacts of extracting TVA-owned coal include pollution and climate impacts from processing, transportation, combustion, and disposal of combustion waste. The full life cycle of coal and the impacts of co-pollutants and coal ash should be considered in an analysis, with a particular focus on environmental justice communities.

TVA has a unique opportunity to help the United States' meet its climate goals by ensuring this coal is left in the ground forever. Given current knowledge and the needs for the near- and long-term future, TVA must reject Sugar Camp Mine's request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
Val Beasley
198 Blackberry Hl Port Matilda, PA 16870-7016

From:	Ettinger.Albert@everyactioncustom.com on behalf of Albert Ettinger
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:07:42 AM

Dear NEPA Specialist Elizabeth Smith,

Coal mined is coal burned. Allowing the expansion of the Sugar Camp Mine will directly result in unacceptable climate changing emissions and pollution from extraction to combustion of coal. TVA should not give Sugar Camp Mine approval to mine this coal and divestiture of TVA coal reserves should be done in a way to keep coal in the ground and meet national climate goals. TVA should consider the following comments in the scope of their upcoming environmental review:

1.) Sugar Camp Energy has proved that it is not able to responsibly manage its operations. This is evidenced by: The Sugar Camp Mine has consistently failed to remove coal in an environmentally sound manner as evidenced by its repeated quarters in non-compliance with basic permit levels, including 125 state and federal violations from 2015 to 2018.

a.) Sugar Camp had a fire that shut down much of the mine. They were penalized for failing to timely inform miners of the fire. Also, they dumped PFAS in the mine in an effort to put out the fire. For that, they are being sued by the State of Illinois, Prairie Rivers Network and Sierra Club.

b.) In July 2022, a pipeline associated with the Sugar Camp Mine ruptured and spilled 20,000 gallons of mine wastewater near Macedonia, Illinois.

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3.) The TVA calls itself a "leader in the nation's drive to a clean energy future" and as a federal entity TVA should be working toward the nation's climate goals.

a.) If TVA's proceeds with divestiture of coal and land rights in Southern Illinois they should not sell the reserves to be mined by someone else.

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ground forever. TVA must reject Sugar Camp Mine's request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
Albert Ettinger
7100 N Greenview Ave Chicago, IL 60626-2629

From:	cindy@everyactioncustom.com on behalf of Cindy Shepherd
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:02:42 AM

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This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the "Report Phishing" button located on the Outlook Toolbar at the top of your screen.

Dear NEPA Specialist Elizabeth Smith,

I love Southern Illinois and have many friends and colleagues there. Spending time with them is precious and somewhat bittersweet: Southern IL is a special place and has borne a heavy environmental burden for Illinois' and the nation's reliance on coal. Please do not compound this injustice by approving expanded mining at a time when the region is beginning to move toward a more just economy and beginning to realize the benefits of renewable energy and tourism. Coal mines pollute local waters and land, and Sugar Creek's owners have shown themselves to be unconcerned about those consequences of their scramble for profit. And burning coal exacerbates extreme weather, flooding and other hazards that are particularly dangerous to under resourced communities in the southern part of our state. Please prevent these hazard from making lives in Southern Illinois more difficult.
Coal mined is coal burned. Allowing the expansion of the Sugar Camp Mine will directly result in unacceptable climate changing emissions and pollution from extraction to combustion of coal. TVA should not give Sugar Camp Mine approval to mine this coal and divestiture of TVA coal reserves should be done in a way to keep coal in the ground and meet national climate goals. TVA should consider the following comments in the scope of their upcoming environmental review:

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b.) In July 2022, a pipeline associated with the Sugar Camp Mine ruptured and spilled 20,000 gallons of mine wastewater near Macedonia, Illinois.

c.) In June 2022, the U.S. Department of Labor's Mine Safety and Health Administration (MSHA) proposed nearly $1.2 million in civil penalties to M-Class Mining LLC, one of the operators of the Sugar Camp Coal Mine. The mine faces 14 citations, including 10 related to the operator's neglect of the miners' safety and health, after operators failed to evacuate miners or notify the MSHA when a fire broke out underground.

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3.) The TVA calls itself a "leader in the nation's drive to a clean energy future" and as a federal entity TVA should be working toward the nation's climate goals.

a.) If TVA's proceeds with divestiture of coal and land rights in Southern Illinois they should not sell the reserves to be mined by someone else.

b.) The impacts of extracting TVA-owned coal include pollution and climate impacts from processing, transportation, combustion, and disposal of combustion waste. The full life cycle of coal and the impacts of co-pollutants and coal ash should be considered in an analysis, with a particular focus on environmental justice communities.

TVA has a unique opportunity to help the United States' meet its climate goals by ensuring this coal is left in the ground forever. TVA must reject Sugar Camp Mine's request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
Cindy Shepherd
2010 Burlison Dr Urbana, IL 61801-5805

From:	Michael.J.Tamm@everyactioncustom.com on behalf of Michael Tamm
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 11:01:30 AM

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Dear NEPA Specialist Elizabeth Smith,

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c.) In June 2022, the U.S. Department of Labor's Mine Safety and Health Administration (MSHA) proposed nearly $1.2 million in civil penalties to M-Class Mining LLC, one of the operators of the Sugar Camp Coal Mine. The mine faces 14 citations, including 10 related to the operator's neglect of the miners' safety and health, after operators failed to evacuate miners or notify the MSHA when a fire broke out underground.

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ground forever. TVA must reject Sugar Camp Mine’s request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
Michael Tamm
921 N Brainard Ave La Grange Park, IL 60526-1409

From:	cparrone@everyactioncustom.com on behalf of Cindy Parrone
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:59:17 AM

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ground forever. TVA must reject Sugar Camp Mine's request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
Cindy Parrone
PO Box 103 Murphysboro, IL 62966-0103

From:	jennifer.cassel@everyactioncustom.com on behalf of Jenny Cassel
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:55:06 AM

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Dear NEPA Specialist Elizabeth Smith,

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ground forever. TVA must reject Sugar Camp Mine's request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
Jenny Cassel
5641 W Berenice Ave Chicago, IL 60634-2706

From:	woodthrusheola@everyactioncustom.com on behalf of Rhonda Rothrock
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:53:20 AM

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Dear NEPA Specialist Elizabeth Smith,

TVA should not give approval to Sugar Camp Energy. This company has an egregious and dismal history of bad management and misbehavior.
TVA should consider the following comments in the scope of their upcoming environmental review:

1.) Sugar Camp Energy has proved that it is not able to responsibly manage its operations. This is evidenced by: The Sugar Camp Mine has consistently failed to remove coal in an environmentally sound manner as evidenced by its repeated quarters in non-compliance with basic permit levels, including 125 state and federal violations from 2015 to 2018.

a.) Sugar Camp had a fire that shut down much of the mine. They were penalized for failing to timely inform miners of the fire. Also, they dumped PFAS in the mine in an effort to put out the fire. For that, they are being sued by the State of Illinois, Prairie Rivers Network and Sierra Club.

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Sincerely,
Rhonda Rothrock
7398 Hickory Ridge Rd Pomona, IL 62975-2018

From:	aliceenglebretsen@everyactioncustom.com on behalf of Alice Englebretsen
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:49:55 AM

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Sincerely,
Alice Englebretsen
501 E California Ave Urbana, IL 61801-4335

From:	dediec@everyactioncustom.com on behalf of Don Dieckmann
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:48:15 AM

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Sincerely,
Don Dieckmann
4614 Wisteria Dr Alton, IL 62002-7158

From:	mmarek@everyactioncustom.com on behalf of Margaret Marek
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:45:49 AM

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Sincerely,
Margaret Marek
867 W State St Jacksonville, IL 62650-1909

From:	nelmslou@everyactioncustom.com on behalf of Louis Nelms
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:42:37 AM

Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
Louis Nelms
9331 N CR 3800E Mason City, IL 62664-7208

From:	rcnauert@everyactioncustom.com on behalf of Robert Nauert
To:	nepa
Subject:	NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:42:08 AM

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Sincerely,
Robert Nauert
243 Dennis Ln Glencoe, IL 60022-1319

From:	marileawhite@everyactioncustom.com on behalf of Marilea White
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:41:03 AM

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Sincerely,
Marilea White
711 S Cottage Ave Normal, IL 61761-4337

From:	arlenenyc@everyactioncustom.com on behalf of Arlene Zuckerman
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:40:09 AM

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Sincerely,
Arlene Zuckerman
11035 72nd Rd Apt 606 Forest Hills, NY 11375-5476

From:	annhburger@everyactioncustom.com on behalf of Ann Burger
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:35:38 AM

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Sincerely,
Ann Burger
506 W Washington St Urbana, IL 61801-4052

From:	gentnerdarcy@everyactioncustom.com on behalf of Darcy Gentner
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:35:04 AM

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Sincerely,
Darcy Gentner
1811 Larch Pl Urbana, IL 61801-5932

From:	cwbullard3@everyactioncustom.com on behalf of Clark Bullard
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:34:49 AM

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Sincerely,
Clark Bullard
2206 Boudreau Cir Urbana, IL 61801-6601

From:	dewalt@everyactioncustom.com on behalf of R Edward DeWalt
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:34:09 AM

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Sincerely,
R Edward DeWalt
606 W Clark St Champaign, IL 61820-4612

From:	npienta@everyactioncustom.com on behalf of Nina Struss
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:26:50 AM

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This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the "Report Phishing" button located on the Outlook Toolbar at the top of your screen.

Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
Nina Struss
1703 21st St Rock Island, IL 61201-3630

From:	caryjcook@everyactioncustom.com on behalf of Cary Cook
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 10:22:07 AM

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It is time for goal to be over.

Sincerely,
Cary Cook
11310 N Coon Rd Orangeville, IL 61060-9626

From:	jkohmstedt@everyactioncustom.com on behalf of Jeff Kohmstedt
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Friday, September 29, 2023 9:44:19 AM

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Sincerely,
Jeff Kohmstedt
1103 Lincolnshire Dr Champaign, IL 61821-5605

From:	dasdmb@everyactioncustom.com on behalf of Dusty Swedberg
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Thursday, September 28, 2023 5:39:29 PM

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Sincerely,
Dusty Swedberg
602 W Washington St Champaign, IL 61820-3333

From: amanda.pankau@everyactioncustom.com on behalf of Amanda Pankau
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Thursday, September 28, 2023 5:26:43 PM

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Sincerely,
Amanda Pankau
1071 Bucks Pond Rd Monticello, IL 61856-8058

From:	adriennebnaumann10@everyactioncustom.com on behalf of Adrienne Naumann
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Thursday, September 28, 2023 5:23:05 PM

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Sincerely,
Adrienne Naumann
8210 Tripp Ave Skokie, IL 60076-2756

From:	ben@everyactioncustom.com on behalf of Ben Galewsky
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 8:23:38 AM

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Sincerely,
Ben Galewsky
608 W Nevada St Urbana, IL 61801-4018

From: Pamela Tate
To: nepa
Subject: Comments on Sugar Camp Mine"s expension
Date: Monday, October 2, 2023 3:58:35 PM

Dear TVA,

I believe that allowing the expansion of the Sugar Camp Mine will directly result in unacceptable climate changing emissions and pollution from extraction to combustion of coal. I urgently ask TVA to not give Sugar Camp Mine approval to mine this coal. Divesting TVA's coal reserves should be carried out in a way that keeps coal in the ground and meets national and Paris climate goals. Please consider the following:

- The TVA calls itself a "leader in the nation's drive to a clean energy future" and as a federal agency, the TVA should be working toward reaching the nation's climate goals.
- The impacts of extracting TVA-owned coal include pollution and climate impacts from processing, transportation, combustion, and disposal of combustion waste. The full life cycle of coal and the impacts of co-pollutants and coal ash should be considered in your analysis, with a particular focus on environmental justice communities.
- The Big Muddy River is an aquatic resource with great societal, cultural, and ecological value to southern Illinois. Sugar Camp intends to discharge high levels of **chloride** into this river. This will harm aquatic life, reduce dissolved oxygen (DO) levels and promote harmful algal blooms, particularly when considered together with the Pond Creek Mine, also owned by Foresight. The Big Muddy River is already on the impaired waters list for low dissolved oxygen and phosphorus. Why would you consider making the situation for aquatic life even worse?
- Why is TVA even considering selling its reserves of coal to someone else? Divestiture of coal and land rights should always include keeping fossil fuels in the ground where they belong.
- And to top it off, Sugar Camp Energy has proved that it is not able to responsibly and lawfully manage its operations. It is public record that the Sugar Camp Mine has consistently failed to remove coal in an environmentally sound manner. It has been in non-compliance with basic permit levels, including 125 state and federal violations between 2015 and 2018.

  a.) Sugar Camp Mine had a fire that shut down much of the mine. The mine was penalized for failing to timely inform miners of the fire. Also, Sugar Camp dumped PFAS in the mine in an effort to put out the fire. For that outrageous action, they are being sued by the State of Illinois, Prairie Rivers Network and Sierra Club.

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You have a unique opportunity to help the country meet its climate goals by ensuring that this coal is left in the ground forever. It is imperative that you reject Sugar Camp Mine's request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,

Pamela Tate
Oak Park, IL resident
Campaigns Chair,
Climate Reality Project Metro Chicago Chapter

From:	arlis.bates@everyactioncustom.com on behalf of Mary Arlis Bates
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 9:15:31 PM

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ground forever. TVA must reject Sugar Camp Mine's request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
Mary Arlis Bates
104 Elizabeth Dr Litchfield, IL 62056-1783

From:	arlis.bates@everyactioncustom.com on behalf of Mary Arlis Bates
To:	nepa
Subject:	NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 9:04:32 PM

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This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the “Report Phishing” button located on the Outlook Toolbar at the top of your screen.

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104 Elizabeth Dr Litchfield, IL 62056-1783

From:	jdaviscu69@everyactioncustom.com on behalf of Jennifer Henshaw
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 5:39:13 PM

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Sincerely,
Jennifer Henshaw
905 E Oregon St Urbana, IL 61801-4406

From:	crusso1957@everyactioncustom.com on behalf of Carla Womack
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 5:29:19 PM

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Sincerely,
Carla Womack
2010 Hickory Ridge Rd Pomona, IL 62975-2325

From:	pam@everyactioncustom.com on behalf of Pamela Tate
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 3:13:56 PM

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Sincerely,
Pamela Tate
1133 Linden Ave Oak Park, IL 60302-1242

From:	Jaderyckman93@everyactioncustom.com on behalf of Jade Ryckman
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 3:12:26 PM

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Sincerely,
Jade Ryckman
406 W Vine St Champaign, IL 61820-2923

From: karylsd@everyactioncustom.com on behalf of Karyl Dressen
To: nepa
Subject: NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Monday, October 2, 2023 12:50:32 PM

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Dear NEPA Specialist Elizabeth Smith,

I am a resident of Montgomery County, Illinois, where Foresight Energy's Deer Run Mine is located. My community is suffering the effects of their longwall mining. Homes and buildings are gone or uninhabitable. The state highway I travel has been undermined and subsided by 4 longwall panels thus far, and has been completely closed to traffic at times. The "planned subsidence" of longwall mining is just industry whitewashing for a mining method more profitable for them without regard for the permanent damage it incurs. My family's once flat farm ground now has areas which have subsided 6 to 7 feet with erosion and permanently altered drainage. The mine currently has 2 high hazard coal impoundments, and more will be needed, continuing the contamination of streams and groundwater. Mined coal is coal burned. Allowing the expansion of the Sugar Camp Mine will directly result in unacceptable climate changing emissions and pollution from extraction to combustion of coal. TVA should not give Sugar Camp Mine approval to mine this coal and divestiture of TVA coal reserves should be done in a way to keep coal in the ground and meet national climate goals. TVA should consider the following comments in the scope of their upcoming environmental review:

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Sincerely,
Karyl Dressen
20057 School House Ave Coffeen, IL 62017-2228

From:	executivedirector@everyactioncustom.com on behalf of Cynthia Kanner
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 12:47:21 PM

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Sincerely,
Cynthia Kanner
920 Susan Ct Algonquin, IL 60102-3071

From: szoke3@everyactioncustom.com on behalf of Ava Szoke
To: nepa
Subject: NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Monday, October 2, 2023 11:31:01 AM

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Sincerely,
Ava Szoke
1688 Pond Ridge Rd Murphysboro, IL 62966-5344

From:	dany@everyactioncustom.com on behalf of Daniel Robles
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 11:26:32 AM

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Sincerely,
Daniel Robles
3912 W Argyle St Chicago, IL 60625-9361

From:	mcijoann@everyactioncustom.com on behalf of JoAnn McIntosh
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 11:06:34 AM

Dear NEPA Specialist Elizabeth Smith,

Coal mined is coal burned. Allowing the expansion of the Sugar Camp Mine will directly result in unacceptable climate changing emissions and pollution from extraction to combustion of coal. TVA should not give Sugar Camp Mine approval to mine this coal and divestiture of TVA coal reserves should be done in a way to keep coal in the ground and meet national climate goals. TVA should consider the following comments in the scope of their upcoming environmental review:

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b.) In July 2022, a pipeline associated with the Sugar Camp Mine ruptured and spilled 20,000 gallons of mine wastewater near Macedonia, Illinois.

c.) In June 2022, the U.S. Department of Labor's Mine Safety and Health Administration (MSHA) proposed nearly $1.2 million in civil penalties to M-Class Mining LLC, one of the operators of the Sugar Camp Coal Mine. The mine faces 14 citations, including 10 related to the operator's neglect of the miners' safety and health, after operators failed to evacuate miners or notify the MSHA when a fire broke out underground.

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3.) The TVA calls itself a "leader in the nation's drive to a clean energy future" and as a federal entity TVA should be working toward the nation's climate goals.

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b.) The impacts of extracting TVA-owned coal include pollution and climate impacts from processing, transportation, combustion, and disposal of combustion waste. The full life cycle of coal and the impacts of co-pollutants and coal ash should be considered in an analysis, with a particular focus on environmental justice communities.

TVA has a unique opportunity to help the United States' meet its climate goals by ensuring this coal is left in the

ground forever. TVA must reject Sugar Camp Mine’s request to expand their mine and ensure that TVA-owned coal is kept in the ground!

Sincerely,
JoAnn McIntosh
181 Bagwell Rd Clarksville, TN 37043-6810

From: meglovenora@everyactioncustom.com on behalf of Margaret Miller
To: nepa
Subject: NEPA Scoping Comments on TVA’s Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date: Monday, October 2, 2023 11:06:28 AM

Dear NEPA Specialist Elizabeth Smith,

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Sincerely,
Margaret Miller
501 E High St Urbana, IL 61801-3460

From:	virginia.woulfe-beile@everyactioncustom.com on behalf of Virginia Woulfe-Beile
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 10:17:33 AM

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Sincerely,
Virginia Woulfe-Beile
3214 Whitford Pl Godfrey, IL 62035-1232

From:	ben@everyactioncustom.com on behalf of Ben Galewsky
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 8:23:38 AM

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Sincerely,
Ben Galewsky
608 W Nevada St Urbana, IL 61801-4018

From:	adkproffitt@everyactioncustom.com on behalf of Diane Proffitt
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 5:46:54 AM

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Sincerely,
Diane Proffitt
909 Laurel Ave Wilmington, IL 60481-1463

From:	amy@everyactioncustom.com on behalf of Amy Johnson
To:	nepa
Subject:	NEPA Scoping Comments on TVA's Sugar Camp Coal Mine No. 1 Proposed Expansion Significant Boundary Revision 8
Date:	Monday, October 2, 2023 9:52:19 PM

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Sincerely,

Amy Johnson
2115 N Whipple St Chicago, IL 60647-3810

From: Lisa Salinas
To: Smith, Elizabeth
Cc: McKenzie, Jeffrey T.

Subject: Sugar Camp Mine Defective Notice
Date: Tuesday, October 3, 2023 6:46:29 AM

I just saw this notice posted and see that the comment time has closed.

I would like to point out that the title of your notices (and published in the Federal Register) is misleading. The notice makes it appear that the point of the notice is about an expansion at the mine, and about an expansion permit, when in fact there is a line tucked into the notice about unloading this whole TVA asset.

It is a very defective notice and you should in good faith post a separate notice for comment about the potential of divesting g the asset. That is a HUGE issue with significant consequences—far greater than an expansion.

TVA currently has extensive potential environmental liabilities related to this mine. The current mine operator is known for its alleged scorched earth legal dodge of any and all environmental liabilities, and has allegedly lied about toxic PFAS used on your controlled property. There are extensive issues with landowners' rights being trampled, extensive slurry injection issues and more.

It in most probable that the only party willing to buy the asset, if it is divested is the dodging polluter. And one can envision the terms would include for the polluter to "assume" all liability for TVA.

TVA has an obligation to the public to act in the best interest of the public—and under no circumstances should engage in any dodgy actions to surreptitiously unload an asset and dump liabilities.

And why isn't TVA taking action against the mine operator to recoup damages rather than continuing to support the parent company's, Foresight Energy's, exit from Chapter 11?

Lisa Salinas

"TVA Seeks Public Input on Environmental Review of Mining Expansion"

"TVA will also evaluate the divestiture of TVA's mineral rights and associated land rights in the area."

https://www.tva.com/newsroom/press-releases/tva-seeks-public-input-on-environmental-review-of-mining-expansion

Sent from my iPhone

Elizabeth Smith, NEPA Specialist
Tennessee Valley Authority
400 West Summit Hill Drive, #WT 11B
Knoxville, TN 37902

Being Sent via email to: NEPA@tva.gov

Comment RE: TVA Sugar Camp Mine No. 1 NEPA Scoping Comments Proposed Expansion Significant Boundary Revision 8

Comment to the Tennessee Valley Authority

Dear Ms. Smith,

If TVA is truly what it claims as, "committed to sustainability and continuous improvement, proactive stewardship in managing our natural resources and environmental footprint,"[1] then it seems to me it must decide to end any further coal rights sales and determine to take the most responsible divestment action possible which is to determine action for no further mining of this TVA coal. I urge TVA to divest itself of the proposed Sugar Camp Mine No 1 acres of coal rights by putting all the rights into a secure, permanent conservation easement type status that ensures none of the coal will be mined.

The TVA stated policy regarding climate issues refers to its climate change mitigation work, that includes reducing its carbon emissions through cleaner production options and energy efficiency initiatives.[2] I ask TVA how can you claim to have a valid climate change policy if you are enabling continued mining of and use of coal at the Sugar Camp Mine for decades ahead as the world is a Code Red for Climate? Sale of any of the proposed 21,868 acres of TVA coal rights to this mine will only increase the U.S. failure to act on climate in a timely manner.

The TVA clearly knows that some of its coal rights being considered for the Sugar Camp Mine contain surface land rights. From an earlier news article in 2018, it was made clear that the TVA mineral rights for some locations contain surface rights that could enable the coal mine to purchase surface land at a minimal cost, in addition to having rights to the coal underground. These coal rights were sold when the highly mechanized underground longwall mining was not known. People who sold the rights thought they were assisting the nation in helping provide energy when climate change impacts and concerns for carbon based fuels were not critical as they are now. It is clear that the economic, social and environmental impacts of this expansion will include surface land impacts from TVA sale of the coal rights. This situation is completely unethical now, considering increases in property values, known global impacts of climate change.

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[1] https://www.tva.com/environment/environmental-stewardship/environmental-policy#:~:text=TVA%20actively%20reduces%20its%20carbon,hydropower%2C%20nuclear%20and%20natural%20gas

[2] Ibid.

The surface rights will greatly increase the economic burdens to the public and to society if any decision is made by TVA to sell the coal rights for use by Sugar Camp Mine, or for use by any coal mine.

I urge the TVA to select an alternative that removes the proposed coal rights from any current or future sale for any extractive minerals use, and ask that the TVA choose to deny the sale of these coal rights to Sugar Camp Mine No. 1.

Sincerely,

Joyce Blumenshine

2419 East Reservoir

Peoria, IL 61614

tva.com