**ENVIRONMENTAL LAW & POLICY CENTER**
Protecting the Midwest's Environment and Natural Heritage

September 14, 2021

Ms. Lisa Felice
Michigan Public Service Commission
7109 W. Saginaw Hwy.
P. O. Box 30221
Lansing, MI 48909

RE: MPSC Case No. U-20763

Dear Ms. Felice:

The following is attached for paperless electronic filing:

**Direct Testimony and Exhibits ELP-1 through ELP-7 of Peter Erickson**

**Direct Testimony and Exhibits ELP-8 through ELP-10 of Peter Howard**

**Direct Testimony and Exhibits ELP-11 through ELP-16 of Jonathan Overpeck**

**Direct Testimony and Exhibits of ELP-17 through ELP-25 of Elizabeth Stanton**

**Proof of Service**

Sincerely,

Margrethe K. Kearney

Margrethe Kearney
Environmental Law & Policy Center
mkearney@elpc.org

cc: Service List, Case No. U-20763

**STATE OF MICHIGAN**
**MICHIGAN PUBLIC SERVICE COMMISSION**

| | | |
|---|---|---|
| In the matter of **ENBRIDGE ENERGY, LIMITED PARTNERSHIP** application for the Authority to Replace and Relocate the Segment of Line 5 Crossing the Straits of Mackinac into a Tunnel Beneath the Straits of Mackinac, if Approval is Required Pursuant to 1929 PA 16; MCL 483.1 et seq. and Rule 447 of the Michigan Public Service Commission's Rules of Practice and Procedure, R 792.10447, or the Grant of other Appropriate Relief | ) ) ) ) ) ) ) ) ) ) ) | Case No. U-20763 |

# DIRECT TESTIMONY OF PETER A. ERICKSON

**ON BEHALF OF**

**THE ENVIRONMENTAL LAW & POLICY CENTER AND THE MICHIGAN CLIMATE ACTION NETWORK**

**September 14, 2021**

## I. BACKGROUND AND QUALIFICATIONS

**Q: Please state your name, business name and address.**

A: My name is Peter A. Erickson. I am a Senior Scientist and the Climate Policy Program Director at Stockholm Environment Institute—U.S., a 501(c)(3) organization affiliated with Tufts University and based at 11 Curtis Avenue, Somerville, Massachusetts 02144. I work out of the Seattle office at 1402 Third Avenue, Suite 925, Seattle, Washington 98101.

**Q: What is your educational background?**

A: I received a Bachelor of Arts from Carleton College in 1998. My major field of study was Geology; I also studied mathematics extensively. In 2007, I took courses in intermediate microeconomics and macroeconomics at the University of Washington.

**Q: Can you briefly describe your professional background and expertise?**

A: I have worked in environmental research and consulting for over 20 years. During the last thirteen years, my professional focus has been on greenhouse gas (GHG) emissions accounting and the role of policy mechanisms in reducing GHG emissions. Specifically, I have conducted and led research projects on these topics on behalf of numerous partners and clients, including international institutions (e.g., the United Nations Framework Convention on Climate Change, the World Bank), the U.S. government (U.S. Environmental Protection Agency), state governments (e.g., State of Washington, State of Oregon), and local governments (e.g., City of Seattle). I have authored numerous peer-reviewed studies on how policies, actions, or infrastructure projects increase or decrease greenhouse gas emissions. These include studies about the GHG emissions implications of the proposed Keystone XL pipeline,[1] of the United States government's fossil fuel leasing

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[1] Erickson, P., & Lazarus, M. (2014). Impact of the Keystone XL pipeline on global oil markets and greenhouse gas emissions. *Nature Climate Change*, 4(9), 778–781. https://doi.org/10.1038/nclimate2335

practices,[2] and of federal and state-level subsidies to US oil and gas production.[3] These and other projects are documented in my Curriculum Vitae, attached as Exhibit ELP-1 (PAE-1). In addition, I am an invited reviewer to the GHG emission reduction chapters in Working Group III of the Intergovernmental Panel on Climate Change's (IPCC) upcoming *Sixth Assessment Report.*

**Q: Have you ever testified in front of the Michigan Public Service Commission?**

A: No. Case No. U-20763 is my first time testifying in front of the Michigan Public Service Commission.

**Q: Have you testified in other jurisdictions?**

A: Yes. I have testified in front of the United States House Committee on Oversight and Reform, Subcommittee on Environment, on the topic of greenhouse gas emissions. I have also testified in front of the Pollution Control Hearings Board for The State of Washington on that topic.[4] I have submitted expert testimony to the United States District Court, District of Oregon,[5] and to the Shoreline Hearings Board for the State of Washington[6] regarding estimates of greenhouse gas emissions. I submitted an expert letter to the District Court of the Hague, Netherlands, regarding methods of estimating greenhouse gas emissions.[7] My

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[2] Erickson, P., & Lazarus, M. (2018). Would constraining US fossil fuel production affect global CO2 emissions? A case study of US leasing policy. *Climatic Change*, 150, 29–42. https://doi.org/10.1007/s10584-018-2152-z

[3] Achakulwisut, P., Erickson, P., & Koplow, D. (2021). Effect of subsidies and regulatory exemptions on 2020-2030 oil and gas production and profits in the United States. *Environmental Research Letters*.

[4] Advocates for a Cleaner Tacoma *et al. v.* Puget Sound Clean Air Agency, Puget Sound Energy. Pollution Control Hearings Board for the State of Washington. PCHB No. P19-087c.

[5] *Juliana et al. v. United States*, United States District Court, District of Oregon. Case No. 6:15-cv-01517-TC.

[6] Columbia Riverkeeper *et al. v.* Cowlitz County *et al.* Shoreline Hearings Board for the State of Washington. SHB No. 17-010c.

[7] At the request of the plaintiffs, I submitted a letter to the District Court of the Hague in *Vereniging Milieudefensie et al. v. Royal Dutch Shell* (Case Number C/09/571932 / HA ZA 19-379) regarding methods of estimating greenhouse gas emissions associated with oil production. The letter is available at: https://www.sei.org/publications/climate-case-shell-sei-letter-court/

work on estimating greenhouse gas emissions has been directly cited by the United States Court of Appeals for the Ninth Circuit[8] and by the United States District Court of Alaska.[9]

**Q: On whose behalf are you submitting this testimony?**

A: I am submitting this testimony on behalf of the Environmental Law & Policy Center and the Michigan Climate Action Network.

**Q: Are you sponsoring any exhibits?**

A: Yes. I am sponsoring the following exhibits:

- ELP-1 (PAE-1) – Curriculum Vitae of Peter A. Erickson
- ELP-2 (PAE-2) – IPCC (2021), Summary for Policymakers. *In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*
- ELP-3 (PAE-3) – Angel, J. R., et al (2018). *Chapter 21: Midwest. Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment, Volume II*. U.S. Global Change Research Program
- ELP-4 (PAE-4) – Burger and Wentz (2019), "*Evaluating the Effects of Fossil Fuel Supply Projects on Greenhouse Gas Emissions and Climate Change under NEPA*"
- ELP-5 (PAE-5) –Heyes et al (2018), "*The Economics of Canadian Oil Sands*"
- ELP-6 (PAE-6) – Erickson et al (2014), "*Impact of the Keystone XL pipeline on global oil markets and greenhouse gas emissions*"

[8] *Ctr. for Biological Diversity v. Bernhardt*, 982 F.3d 723, 738 (9th Cir. 2020).
[9] Sovereign Inupiat for a Living Arctic v. Bureau of Land Mgmt., No. 3:20-CV-00290-SLG, 2021 WL 3667986, at *20 n. 201 (D. Alaska Aug. 18, 2021)).

- ELP-7 (PAE-7) –Achakulwisut, Erickson, and Koplow (2021), "Effect of subsidies and regulatory exemptions on 2020–2030 oil and gas production and profits in the United States"

**Q: What materials did you review in preparing this testimony?**

A: I reviewed relevant portions of Enbridge's application and testimony, Enbridge and Commission reports and websites, discovery responses from Enbridge, and other party responses to requests for discovery from Enbridge. I also reviewed and relied upon a variety of scientific and economic journal articles, reports, and other literature, and publicly available data and analysis in forming my opinions. Where I explicitly rely upon a source in forming my opinion, I cite to it in my testimony.

## II. OVERVIEW OF TESTIMONY

**Q: What is the purpose of your testimony?**

A: The purpose of my testimony is to estimate, quantify, and explain the level of greenhouse gas emissions associated with Enbridge's Proposed Project. This will include both the greenhouse gas emissions resulting from the construction and operation of the Proposed Project, as well as the greenhouse gases contained in or associated with the oil and natural gas liquids ("NGL") fuel carried by the pipeline. I will also estimate the change in global greenhouse gas emissions that would arise as a consequence of the Proposed Project, as measured relative to a no-action scenario, where Enbridge discontinues use of the existing pipeline in the Straits of Mackinac, but does not construct the Proposed Project. This latter approach evaluates likely differences in global oil supply and consumption when comparing the no-action scenario to the Proposed Project being built.

**Q: Please describe the project for which Enbridge seeks approval.**

A: Enbridge Energy, Limited Partnership ("Enbridge") currently operates an oil pipeline called Line 5, which transports oil and Natural Gas Liquids ("NGL") from western Canada to eastern Canada. A portion of Line 5 currently consists of two 20-inch diameter pipelines that run through the Straits of Mackinac in Michigan. In this case, Enbridge is seeking approval to build an underground tunnel, and to replace and relocate into that tunnel the portion of the Line 5 petroleum pipeline that currently sits on the bottom of the Straits (the "Proposed Project").

**Q: What methods did you use to estimate the greenhouse gas emissions associated with the Proposed Project?**

A: I use standard greenhouse gas emissions accounting practices, consistent with those laid out in guidance by the Greenhouse Gas Protocol initiative,[10] and report my results in standard units of millions of metric tons of carbon-dioxide equivalent ($CO_2e$). In brief, with respect to the construction of the Proposed Project, these methods involve estimating what activities occur in association with the Proposed Project (for example, the use of a machine to bore the tunnel under the Straits of Mackinac), how much energy is used by each activity (for example, how much electricity is used by the tunnel-boring machine), and how much greenhouse gas emissions are associated with each unit of energy (for example, how much carbon dioxide is released by the power plants that make the electricity for the tunnel-boring machine). I use similar methods to estimate the greenhouse gas emissions associated with the operation of the Proposed Project, and also when estimating the greenhouse gas

[10] For example, the GHG Protocol's *Corporate Accounting and Reporting Standard*, their *Project Accounting* standard, and their *Policy and Action Standard* lay out methods for estimating GHG emissions associated with specific projects, including procedures for assessing emissions relative to a counterfactual, no-action baseline.

emissions associated with the oil and NGL that will be transported through the Proposed Project after completion.

**Q: Are these methods commonly used by experts when estimating greenhouse gas emissions from oil pipelines?**

A: Yes. My methods are consistent with those used in other greenhouse gas assessments of oil pipelines, such as the Keystone XL pipeline, and indeed I check my work against those other estimates, as well as against the peer-reviewed, scientific literature and against standards for life-cycle assessment (LCA) and oil market analysis. All data sources I rely upon directly are cited here in this document.

**Q: Can you summarize your conclusions?**

A: I reach three main conclusions that I describe in my testimony.

- First, I estimate that the Proposed Project is associated with about 87 million metric tons carbon-dioxide equivalent ($CO_2e$) annually.
- Second, I conclude that, when compared to a scenario in which the existing Line 5 pipeline no longer operates, construction and operation of the Proposed Project would lead to an *increase* of about 27 million metric tons $CO_2e$ annually in global greenhouse gas emissions from the production and combustion of oil.
- Third, by enabling the continued, long-term production and combustion of oil, construction of the project would work against, and therefore be inconsistent with, the goals of the global Paris Agreement and Michigan's Healthy Climate Plan.

**Q: Does your analysis include an estimate of the greenhouse gas emissions from the existing dual pipelines Enbridge operates in the Straits of Mackinac?**

A: No. I am aware that the Governor of Michigan and the Director of the Michigan Department of Natural Resources notified Enbridge on November 13, 2020, that the state revoked and terminated the 1953 Easement which allows Line 5 to operate in the Straits. My understanding is that this revocation and termination would require Line 5 to discontinue operation. However, I also discuss below why it is appropriate to consider a "no-action" scenario even in the absence of the Governor's actions. As a result, my analysis includes a scenario where I assume that if the Proposed Project is not completed, Line 5 will no longer operate.

## III. OVERVIEW OF CLIMATE CHANGE AND THE NEED FOR GREENHOUSE GAS EMISSIONS CUTS

**Q: How does the current understanding about the effects of climate change inform your discussion of GHG emissions and Enbridge's Proposed Project?**

A: To provide some context, here I first provide some basic information about the state of climate science and the need for rapid and steep cuts in GHG emissions over the coming decades. Around the world, with just 1.1 degree Celsius (C) of warming experienced to date, we are already seeing serious harms that include increasing flooding, wildfires, droughts, heat waves, expanded impacts of pests and pathogens, and other effects. As addressed in more detail by other testifying experts in this case, these types of events are all plausibly linked to climate change.[11] For example, three "five-hundred year" floods occurred in Houston, Texas in just three years, with one storm – Hurricane Harvey –

[11] For an additional summary of these effects, see: Holdren, J. P. (2018, September). The Science & Policy of Climate Change: An Update on the Challenge and the Opportunity. Presented at the Low-emissions Solutions Conference, San Francisco, CA. (https://lowemissions.solutions/static/uploads/180911_GCAS_Holdren.pdf)

producing rainfall that "likely exceeded that of any known historical storm in the continental United States."[12] In many areas of the world and the country, increasing summer temperatures are already making working outdoors dangerous. A scientific review of the effects of climate change on health has concluded, "[t]he life of every child born today will be profoundly affected by climate change. Without accelerated intervention, this new era will come to define the health of people at every stage of their lives."[13] In the new, most recent assessment of the science behind climate change, the Intergovernmental Panel on Climate Change described the observed rate of climate change as both "unprecedented" and "unequivocally" caused by human activities.[14]

**Q: Are there similar impacts as a result of climate change in the Midwest region or Michigan in particular?**

A: In the Midwest of the United States, climate change will lead to increased temperatures and precipitation that will reduce agricultural productivity, erode soils, and lead to pest outbreaks, while also leading to poor air quality, substantial loss of life, and worsening economic conditions for people.[15]

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[12] Hayhoe, K., Wuebbles, D. J., Easterling, D. R., Fahey, D. W., Doherty, S., Kossin, J. P., … Wehner, M. F. (2018). Chapter 2: Our Changing Climate. *Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment, Volume II*.

[13] Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Boykoff, M., … Montgomery, H. (2019). The 2019 report of The Lancet Countdown on health and climate change: Ensuring that the health of a child born today is not defined by a changing climate. *The Lancet*. https://doi.org/10.1016/S0140-6736(19)32596-6

[14] IPCC. (2021). Summary for Policymakers, attached as Exhibit ELP-2 (PAE-2). *In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

[15] Angel, J. R., Swanson, C., Boustead, B. M., Conlon, K., Hall, K. R., Jorns, J. L., Kunkel, K. E., Lemos, M. C., Lofgren, B. M., Ontl, T., Posey, J., Stone, K., Takle, E., & Todey, D. (2018). Chapter 21: Midwest. Impacts, Risks, and Adaptation in the United States: *The Fourth National Climate Assessment, Volume II.* U.S. Global Change Research Program, attached as Exhibit ELP-3 (PAE-3). https://doi.org/10.7930/NCA4.2018.CH21

**Q: Do GHG emissions need to be reduced to limit the impacts of climate change?**

A: Yes. GHG emissions need to be substantially reduced to limit the impacts of climate change. For example, the U.S. Government's *Fourth National Climate Assessment* describes, consistent with the findings of the international scientific community, that climate risks can only be adequately addressed with "substantial and sustained reductions in global greenhouse gas emissions."[16] As the report notes, "[f]uture risks from climate change depend primarily on decisions made today."[17]

More broadly, guidance on how quickly GHG emissions need to be reduced can be found in international agreements such as the United Nations Framework Convention on Climate Change (UNFCCC), through which nations have been working collectively to address the risks of climate change throughout the world. The most recent landmark agreement of countries that are party to the UNFCCC, including the United States, is the Paris Agreement of 2015. The Paris Agreement commits countries to "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." In adopting the Paris Agreement, countries also asked the Intergovernmental Panel on Climate Change (IPCC) to produce a report on what emissions levels would be needed to achieve the 1.5 °C limit.[18]

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[16] Reidmiller, D. R., Avery, C. W., Easterling, D. R., Kunkel, K. E., Lewis, K. L. M., Maycock, T. K., & Stewart, B. C. (2018). *Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment, Volume II.* U.S. Global Change Research Program. https://doi.org/10.7930/NCA4.2018. Page 25.
[17] *Ibid*, page 26.
[18] UNFCCC. (2015). Decision 1/CP.21: Adoption of the Paris Agreement. Retrieved from United Nations Framework Convention on Climate Change website: http://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf

**Q: What level of reductions did the IPCC conclude would be necessary to achieve the 1.5 °C limit?**

A: The IPCC, in its special report, *Global Warming of 1.5 °C,* describes that net global carbon dioxide ($CO_2$) emissions must reach zero to halt warming, and specifically that emissions levels must reach zero by about the year 2050 in order to meet the 1.5 °C with no or "limited" overshoot (exceedance) of the temperature limit. Even *if* other means of removing $CO_2$ are developed and applied at large scale, the IPCC found that, between 2020 and 2050, gross global $CO_2$ emissions from fossil fuel combustion and industry would need to decline by about 70%.[19] These findings were broadly re-affirmed by the IPCC in its recent report *Climate Change 2021: The Physical Science Basis*, even as their new report on GHG emission reduction scenarios is not due until early 2022.[20]

**Q: How must fossil-fuel based energy systems change to meet the 1.5 °C limit?**

A: Use and production of all three major fossil fuels – coal, gas, and oil – must decline dramatically to meet the 1.5 °C limit. Over the next three decades (through 2050), the IPCC finds that, to attain the 1.5 °C limit with no or limited temperature overshoot, coal use must decline by an average of 6% annually (for a total of 82% between 2020 and 2050), gas use by an average of 2% annually (for a total of 43%), and oil use by an average of 3% annually (for a total of 65%).[21] Further, one of the longstanding principles of the international negotiations, termed "common but differentiated responsibilities," is that reductions in the U.S. and other highly developed countries must proceed faster than these global averages,

[19] Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., … Vilariño, M. V. (2018). *Mitigation pathways compatible with 1.5°C in the context of sustainable development. In Special Report on the impacts of global warming of 1.5 °C.* Retrieved from http://www.ipcc.ch/report/sr15/ Figure 2.6, page 117 and Table 2.4, page 119.

[20] IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press.

[21] Rogelj et al 2018, Table 2.6, page 132.

on account of our historic responsibility for climate change and our relatively high capacity to financially support solutions.

## IV. GREENHOUSE GAS EMISSIONS ASSOCIATED WITH THE PROPOSED PROJECT

**Q: Are there GHG emissions associated with the Proposed Project?**

A: Yes. For the Proposed Project, Enbridge would build a tunnel and replace and relocate into that tunnel the portion of the Line 5 petroleum pipeline that currently sits on the bottom of the Straits of Mackinac. There are two main ways in which the Proposed Project will result in GHG emissions. First, GHG emissions will be released by the equipment used to build and operate the tunnel. Second, the Proposed Project will handle and transport petroleum that, once combusted, releases even greater quantities of GHG emissions than from Project construction or operation.

**Q: Let's take those two sources of GHG emissions in turn. First, what is your estimate of the GHG emissions associated with the construction and operation of the pipeline for this Proposed Project?**

A: I estimate the GHG emissions associated with construction of the pipeline to be about 87,000 metric tons carbon dioxide equivalent ($CO_2e$). I estimate that operation of the pipeline will result in about 520 metric tons $CO_2e$ annually.

**Q: What is $CO_2e$?**

A: Emissions from different greenhouse gases, each of which causes different amounts of warming, are often combined into a single metric of $CO_2$ *equivalent* by using the concept of global warming potential (GWP). For example, a ton of methane causes many times more warming than a ton of carbon dioxide, and this ratio is called the GWP of methane. In the IPCC's latest *Sixth Assessment Report*, the GWP of fossil methane is reported as

29.8 over a 100-year timeframe. One metric ton of methane is therefore 29.8 metric tons $CO_2e$ over 100 years according to the IPCC. Throughout my testimony, I focus my own calculations mainly on $CO_2$; in making these calculations, I include other, non-$CO_2$ GHGs like methane ($CH_4$) indirectly and only to the extent that they were calculated by primary sources, such as by the US EPA's eGrid tool (on a $CO_2$e basis, and inheriting any GWP assumptions made by each primary source). Further, any time I refer to a ton, I mean a metric ton unless stated otherwise, and which I may occasionally abbreviate as just the letter *t*.

**Q: How did you arrive at 87,000 metric tons $CO_2$e as an estimate of the GHG emissions from construction of the Proposed Project?**

A: I used standard GHG accounting practices to arrive at this estimate, using information provided by Enbridge and basic facts about the Proposed Project, and by relying on other published information about how much energy is used to carry out the proposed activities.

First, descriptions of the main activities and materials needed to construct the pipeline are readily available in project documents, e.g. the *Tunnel Design and Construction Report* dated December 23, 2020 (Exhibit A-13) and other documents provided by Enbridge. These activities include the use of a tunnel-boring machine, operation of other construction equipment, and the making and installation of key construction materials, including steel and concrete.

Second, I used published estimates about similar equipment, machinery, and materials to estimate how much energy is used for each activity.

Third, to complete the picture, I gathered basic data about how much GHG emissions are released from each unit of activity or energy.

**Q: Is this typical of the methodology employed by experts in your field?**

A: Yes. Together, these three steps – and their underlying data and assumptions – are, in my opinion, reasonable and consistent with assumptions in major government GHG inventories and assessments, such as the U.S. EPA's national GHG inventory and the US State Department's assessment of the Keystone XL pipeline.

**Q: Can you summarize your estimates?**

A: Yes. My estimates of the GHG emissions from the activities and materials needed to construct the Proposed Project are shown in Table 1 below. As shown, I estimate the total GHG emissions associated with construction to be about 87,000 metric tons carbon dioxide equivalent ($CO_2e$).

**TABLE 1. EMISSIONS ASSOCIATED WITH CONSTRUCTION OF THE PROJECT**

| **Source of construction-related emissions** | **Emissions (metric tons $CO_2e$)[22]** | **Method notes and assumptions** |
|---|---|---|
| Equipment: tunnel boring machine (TBM) and related tunneling equipment (using electricity) | 56,000 | Based on electricity consumption during construction estimated by Enbridge for south side of the Straits |
| Equipment: other (electricity) | 2,300 | Based on electricity consumption during construction estimated by Enbridge for north side of the Straits |
| Equipment: other vehicles (diesel) | 5,100 | Includes excavators, grading equipment, loaders, dump trucks, and other vehicles |
| Materials: concrete for tunnel liner and roadway | 19,000 | Based on estimated cement content of Enbridge's estimated concrete usage |
| Materials: steel for pipeline | 3,300 | Based on 0.625-inch thick steel, 30-inch outer diameter pipeline, and average $CO_2$-intensity of US steel |
| Land-clearing | 570 | Estimated by Enbridge[23] |
| **Estimated total construction emissions** | **87,000** | (Individual figures may not add to total due to rounding)[22] |

The estimate in Table 1 includes what I see as the major sources of emissions associated with project construction, but does not include several much-smaller sources of emissions associated with constructing the tunnel, such as for making the steel for electrical conduit

[22] All estimates here are rounded to two significant digits. As a result, the individual figures may not add to the total due to rounding.
[23] Enbridge Response to Michigan Public Service Commission Staff Discovery Request 6(8).

or rebar, or for making the grout that will occupy the annular space surrounding the concrete tunnel liner. Accordingly, I believe my estimate is conservative.

**Q: Table 1 lists detailed assumptions about each major source of construction-related emissions. Can you describe these assumptions for the equipment used to construct the tunnel?**

A: Yes. First, I assume that the tunnel excavator will, like other tunnel-boring machines, be operated using electricity. Enbridge has estimated the electricity usage during construction at the south terminus of the tunnel, where the tunnel boring machine (TBM) will be based, to be 66,184 megawatt-hours (MWh), and so I use this figure for the electricity used by the TBM and other, minor uses based at the south terminus. I then estimate the GHG emissions associated with each unit of electricity, using data specific to the Straits of Mackinac region from the US EPA, to be 0.851 metric tons of $CO_2e$ per MWh of non-baseload electricity consumed; that figure is for electricity from the RFC Michigan eGrid regions, as derived from the US EPA's eGrid tool.[24]

**Q: What assumptions did you use for the other equipment?**

A: For equipment other than the tunnel-boring machine, such as other electric equipment at the north side of the Straits, and for loaders and dump trucks, my approach is similar. For electricity usage, I use estimates provided by Enbridge. For vehicles, I use published estimates about how much energy (here, diesel) was used for this kind of equipment from another, similar project, and then use data from the U.S. EPA about how much GHG emissions are released by combusting each unit of diesel.

[24] https://www.epa.gov/egrid/summary-data. A metric ton is 1,000 kilograms.

**Q: What specific assumptions and calculations did you make about this other equipment?**

A: I use an electricity estimate from Enbridge[25] for the north side to characterize other electrical equipment. For off- and on-road vehicles, such as loaders and grading equipment, used to excavate and grade material, I use an estimate of energy consumption of 0.25 million btu per cubic meter (mmbtu / $m^3$) for such equipment, based on another recent tunnel boring project (Parsons Brinckerhoff, 2011)[26] and apply that estimate to the 272,000 cubic meters of material I anticipate will be excavated for the Proposed Project (a 24.5-foot diameter bore for 20,350 feet, based on Enbridge's tunnel design documents[27]). I assume that energy for these vehicles is mostly diesel, with resulting $CO_2$ emissions of 74 kg $CO_2$ / mmbtu per Annex 2 of US EPA's national inventory (U.S. EPA, 2021).[28]

**Q: Table 1 also lists detailed assumptions about the materials used to construct the tunnel. Can you describe these?**

A: Yes. The two major materials used to construct the Proposed Project are concrete (for the tunnel lining and interior roadway) and steel (for the pipeline itself). Each of these materials is GHG-emissions-intensive to manufacture.

**Q: How does the production and use of concrete result in GHG emissions?**

A: For concrete, the main source of GHG emissions is $CO_2$ from making cement, which is the binding agent in concrete. Making cement relies on a substantial amount of heat, usually

[25] Enbridge Response to Michigan Public Service Commission Staff Discovery Request 6(9).
[26] Parsons Brinckerhoff. (2011). *Alaskan Way Viaduct Replacement Project: Final Environmental Impact Statement*. https://data.wsdot.wa.gov/publications/Viaduct/
[27] The 24.5 foot diameter bore assumes an inside tunnel diameter of 21 feet, a tunnel wall thickness of 15 inches, and an extra 6 inches of bore space around the outside, all of which were published in Enbridge's *Tunnel Design and Construction Report for the Straits Line 5 Replacement Segment*. December 23, 2020, Exhibit A-13.
[28] US EPA (2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019. U.S. Environmental Protection Agency. https://www.epa.gov/ghgemissions/).

from burning coal or natural gas, and also relies on a chemical reaction, involving lime, which releases $CO_2$ directly. I use information provided by Enbridge to estimate how much cement is needed, and then information from an industry group – the Global Cement and Concrete Association – to estimate that making each ton of US-made cement releases 0.75 tons $CO_2$.

**Q: What specific assumptions and calculations did you make about concrete used in the Proposed Project?**

A: Enbridge's report "Tunnel Design and Construction Report for the Straits Line 5 Replacement Segment," dated December 23, 2020 (Exhibit A-13), reports the tunnel length at 20,350 feet, the tunnel inside diameter of 21 feet, and the tunnel wall thickness of 15 inches. This information implies a volume of concrete of about 66,000 cubic yards. This is very similar to the value reported by Enbridge[29] that 65,330 tons of reinforced concrete will be needed. Because the numbers are so close, I rely here on the 65,330 tons reported by Enbridge. Further, additional project specifications report an average cement content of about 800 pounds of cementitious materials per cubic yard of concrete.[30] Together, this implies the need for about 24,000 tons of cement for the tunnel walls. Additional cement would be needed for the roadway inside the tunnel; I calculate that separately.

**Q: How does the production and use of steel result in GHG emissions?**

A: For steel, similarly, emissions are released both from making heat (e.g., from burning coal or other fossil fuels) and from chemical reactions inherent in the steel-making process.

[29] Enbridge Response to Environmental Law & Policy Center and Michigan Climate Action Network Discovery Request 1.

[30] "Cementitious" materials are primarily cement, but may include amounts of cement alternatives, such as fly ash. I calculated the 800 figure as the average of minimum 611 and maximum 1000 pounds of cementitious material per cubic yard, per page 317416 – 17 of the precast concrete tunnel specs in the following document: https://www.michigan.gov/documents/mdot/Enbridge_Submittal_-_Jointly_Developed_Project_Specs_715739_7.pdf).

Similar to my methodology for cement, I estimate the quantity and type of steel needed to make the pipeline that is part of the Project based on information provided by Enbridge and the GHG emissions associated with each unit of US-made steel provided by a research study.

**Q: What specific assumptions and calculations did you make about steel used in the Proposed Project?**

A: Information provided by Enbridge (Exhibit A-14), provides specifications for the steel pipeline, including the outside diameter of 30 inches and the wall thickness of 0.625. From this and the 20,350 ft length, I estimated the need for about 14 million cubic inches of steel. API 5L steel has a density of about 0.28 pounds per cubic inch (calculated from Table 4 of the American Petroleum Institute's *Specification for Line Pipe*),[31] implying the need for about 2,000 short tons of steel, or 1,800 metric tons. The average $CO_2$-intensity of blast-furnace steel in the U.S. is 1.83 t $CO_2$ / t of crude steel.[32] I use the GHG-emissions intensity of blast-furnace steel, not electric-arc steel, because the quantity of steel made by electric arc furnaces is constrained by how much scrap steel is available, so it is more plausible that the marginal source of steel is instead from blast furnaces.

**Q: Are there also GHG emissions associated with the operation of the Proposed Project?**

A: Yes. After the Proposed Project is constructed, there are GHG emissions associated with operating the tunnel, such as electricity to operate lighting and ventilation systems, and the electric service vehicles that would travel inside the tunnel. I estimate that GHG emissions associated with operating the tunnel itself would be approximately 520 metric tons $CO_2e$

[31] Available at https://law.resource.org/pub/us/cfr/ibr/002/api.5l.2004.pdf.

[32] See Figure 16 of Hasanbeigi, A., & Springer, C. (2019). How Clean is the US Steel Industry? An International Benchmarking of Energy and $CO_2$ intensities. Global Efficiency Intelligence.

annually. This does not include any emissions associated with operating the existing Line 5 Mackinaw City Pump Station.

**Q: Can you explain how you arrived at the 520 metric tons CO2e annually associated with the operation of the Proposed Project?**

A: Ongoing operation of the Proposed Project will involve energy and associated greenhouse gas emissions for the tunnel's ventilation fans, for the sump pump inside the tunnel, for the tunnel service vehicle that operates inside the tunnel, and for lighting, all for many years into the future. Based on electricity usage for these items at other similar tunnels, I estimate that GHG emissions associated with operating the tunnel would be approximately 520 metric tons $CO_2e$ annually. More specifically, I estimate the tunnel itself would use about 600 megawatt-hours (MWh) of electricity per year, [33] which is a conservative estimate compared to confidential information provided by Enbridge in discovery and not cited here. At the US EPA's reported GHG-intensity of electricity in the Straits of Mackinac region of 0.87 tons $CO_2e$/MWh,[34] 600 MWh of electricity consumption translates into about 520 t $CO_2e$.

**Q: Now that you have discussed estimated GHG emissions from construction and operation of the project, let's turn to the second source of GHG emissions you referenced above. Are there GHG emissions associated with the oil and NGL products that will be shipped through the Proposed Project?**

[33] Based on average annual electricity consumption of 193 kWh/m for TBM tunnel types (Peeling, J., Wayman, M., Mocanu, I., Nitsche, P., Rands, J., & Potter, J. (2016). Energy Efficient Tunnel Solutions. Transportation Research Procedia, 14, 1472–1481. https://doi.org/10.1016/j.trpro.2016.05.221), discounted by 50% for lighting electricity since the Proposed Project would not normally be lit.
[34] This is the average GHG intensity for electricity consumed from the RFC Michigan and RFC West regions, which each border the Straits, in EPA's eGrid tool.

A: Yes, there are GHG emissions associated with the oil and NGL that will be transported using the pipeline contained in Enbridge's Proposed Project. I estimate that the GHG emissions associated with the crude oil and NGLs handled by the Proposed Project will be 87,000,000 metric tons $CO_2$e annually.

**Q: Please explain how you arrived at 87,000,000 metric tons $CO_2$e annually.**

A: The Proposed Project will also be associated with greenhouse gas emissions from the petroleum (oil and NGL) handled by the project. The Proposed Project is expected to handle 540,000 barrels per day (b/d) of liquid, comprising about 450,000 b/d of crude oil, and 90,000 b/d of natural gas liquids,[35] chiefly propane and butane,[36] again all for many years into the future. GHG emissions are released at each stage of producing, processing, and combusting petroleum, and so I estimate the total emissions by splitting the "life cycle" of a barrel of crude oil or NGL into stages, which are typically referred to in this type of analysis as the "upstream" and "downstream" stages.

**Q: What are the upstream stages?**

A: Here, I use the term *upstream* to refer to all stages that happen before, or upstream, of final combustion. So, *upstream* refers to the initial extraction and processing of petroleum, such as the operation of oil wells and any other equipment needed to process or handle the oil, as well as for oil refining (oil refining is sometimes considered *midstream*, but for my purposes here I will include it under upstream).

[35] Liquid volumes carried by the pipeline are taken from page 2-2 of Dynamic Risk Assessment Systems. (2017). *Alternatives Analysis for the Straits Pipelines*.

[36] I estimate the propane and butane fractions based on Muse Stancil. (2019). Review of the Report "Assessment of Alternative Methods of Supplying Propane to Michigan in the Absence of Line 5" for Enbridge, provided by Enbridge in response to Michigan Environmental Council, Grand Traverse Band of Ottawa and Chippewa Indians, Tip of the Mitt Watershed Council, and National Wildlife Federation Discovery Request 21.

**Q: How do you estimate GHG emissions from the upstream stages?**

A: For the upstream stages, I rely on research that estimated how much emissions are released for production and processing of petroleum from Western Canada and the Bakken formation in North Dakota and Montana in the United States, since these regions would be the source of the petroleum carried by the pipeline.

**Q: What do you conclude about GHG emissions from upstream stages based on your review of available literature?**

A: According to research by Stanford University and colleagues for the Oil-Climate Index, producing light oil from these formations in Western Canada and North Dakota releases about 55 kg $CO_2e$ per barrel. Refining them releases an additional 18 kg $CO_2e$ per barrel. I calculate these numbers as the average of the flare and no-flare case for the US Bakken formation in the Oil-Climate Index (Oil Climate Index, 2016).[37]

Q: **What is the downstream stage?**

A: By downstream, I mean combustion at point of end use.

**Q: How do you estimate emissions from the downstream stage?**

A: For the downstream stage I estimate emissions based on how much carbon is contained in a barrel of crude oil. According to the United States Environmental Protection Agency, a barrel of crude oil (or its derivatives) releases an average of 432 kg $CO_2$ once combusted.[38] A barrel of propane and butane releases 236 and 282 kg $CO_2$, respectively. These figures are derived from combining energy content (mmbtu/barrel) from Tables A-39 and A-41

[37] Oil Climate Index Webtool—Phase II. Carnegie Endowment for International Peace. http://oci.carnegieendowment.org/#total-emissions).

[38] This value of 432 kg $CO_2$ per barrel from the US EPA is nearly identical to the value of 429 kg $CO_2e$ produced by the Oil-Climate index for Bakken oil. I use the EPA value since the EPA also provides values for propane and butane, and so I can use a consistent source for the largest (combustion) source of emissions across all three liquids.

and carbon contents (t C / mmbtu) from Table A-29 of Annex 2 of the US EPA's national GHG inventory (U.S. EPA, 2021).[39]

**Q: What do you do next?**

A: The last step in quantifying the emissions associated with petroleum handled by the Project is to estimate what, if any, of the petroleum handled would not ultimately be combusted or otherwise oxidized to $CO_2$, and for which the emission factors above would therefore not apply. I estimate that 8% of the petroleum handled would ultimately not be combusted or otherwise be oxidized, since it would end up underground as long-term storage, e.g. as plastics buried in landfills that no longer release $CO_2$. Accordingly, I reduce the per-barrel emissions estimates listed above for the "downstream" stage by 8%.

**Q: What do you base that assumed reduction on?**

A: I base it on a peer-reviewed study that is the most detailed assessment I am aware of that investigates what fraction of North American oil production is not ultimately combusted.[40] That article evaluates what fraction of oil is used for non-energy uses such as petrochemicals, lubricants, and other industrial uses, as well as what fraction of these otherwise "non-energy uses" are indeed ultimately combusted, such as when plastics are burned at waste-to-energy plants or tires are burned at cement kilns, and concludes that 8.02% of petroleum liquids end up as net carbon storage.

**Q: What is the end result of this process?**

[39] U.S. EPA. (2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019. U.S. Environmental Protection Agency. https://www.epa.gov/ghgemissions/).

[40] Heede, R. Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers, 1854–2010. *Climatic Change* **122,** 229–241 (2014). https://doi.org/10.1007/s10584-013-0986-y

A: In total, using the individual assumptions above, I estimate that the GHG emissions associated with the crude oil and NGLs handled by the Proposed Project will be 87,000,000 metric tons of $CO_2e$ annually.

**Q: Based on your analysis in this testimony, do you have any observations about the GHG emissions associated with the construction and operation of the Proposed Project as compared to the GHG emissions linked to the crude oil and NGL?**

A: Yes. These emissions associated with the crude oil and NGLs handled by the Proposed Project are much larger than emissions associated with constructing and operating the Proposed Project itself. The following table compares all emissions using a common unit of time: one year. To do this, I amortize the emissions associated with construction over the planned 99-year life of the pipeline. I chose a 99-year amortization period because Enbridge refers to a design life of "no less than 99 years" for the tunnel (*Tunnel Design and Construction Report,* page 5).

**TABLE 2. SUMMARY OF GREENHOUSE GAS EMISSIONS ASSOCIATED WITH THE PROPOSED PROJECT**

| **GHG emissions category** | **Average annual emissions (metric tons $CO_2e$)** | **Notes** |
|---|---:|---:|
| Tunnel construction | 870 | Amortized over 99 year lifetime |
| Tunnel operation | 520 | |
| Liquids (crude oil and NGL) handled | 87,000,000 | |

**V. <u>INCREMENTAL GREENHOUSE GAS (GHG) EMISSIONS CAUSED BY THE PROPOSED PROJECT</u>**

**Q: Have you estimated the GHG emissions associated with the Proposed Project in any other way?**

A: Yes. I also estimated the incremental GHG emissions associated with the Project relative to a no-action scenario.

**Q: What is a "no-action" scenario?**

A: A no-action scenario is a scenario in which the Proposed Project does not go forward. In light of the Governor's actions, described above, if the Proposed Project does not go forward, Line 5 will no longer operate.

**Q: Does your analysis depend on the Governor's actions being upheld in the courts?**

A: No. Even if the Governor had not revoked the 1953 Easement, it still would make sense to consider a "no-action" scenario. Enbridge's stated purpose for the Proposed Project is to remove an environmental threat to the Straits of Mackinac caused by the location of the existing pipeline. Irrespective of the Governor's actions, it would be appropriate to consider whether Enbridge could achieve its stated purpose by shutting down the existing pipeline without constructing the Proposed Project.

**Q: What are "incremental" GHG emissions, and how are they different from your analysis above?**

A: My estimates of GHG emissions above included the major, "gross" sources of GHG emissions reasonably *attributable* to the Proposed Project. A different way of looking at the GHG emissions is instead to estimate what emissions are caused by, or a consequence of, the Project – what could be termed the "net" or "incremental" emissions. This type of estimate relies on assessing how GHG emissions would change with the Proposed Project, compared to a no-action scenario where the Project does not go forward. This *consequential* view can therefore be useful for decision-makers interested in how any given project, such as the Proposed Project, will incrementally increase GHG emissions.

**Q: Why are consequential emissions different from those attributable to the Proposed Project?**

A: Because if the Proposed Project were not built, some of the GHG emissions I estimated above would still occur. Some of the oil and NGL products that would have been transported through the Proposed Project would still be transported by other methods, and still consumed. However, for the reasons I explain below, fewer oil and NGL products would be transported and consumed if the Proposed Project were not built, resulting in lower overall GHG emissions.

**Q: Is this a common approach in the field of estimating greenhouse gas emissions?**

A: Yes. Estimating incremental GHG emissions is a common feature of many GHG emissions estimation methods, including those discussed in the GHG Protocol's *Policy and Action Standard* and those reviewed in Burger and Wentz (2020), "Evaluating the Effects of Fossil Fuel Supply Projects on Greenhouse Gas Emissions and Climate Change under NEPA". The approach here is sometimes termed a *consequential* life-cycle assessment, whereas the approach in the prior section is sometimes termed an *attributional* life-cycle assessment. These terms and approaches are a common methodology used in the field of life cycle assessment, and are discussed in peer-reviewed papers often relied upon in my field, such as Brander, M., & Ascui, F. (2015).[41]

[41] The Attributional-Consequential Distinction and Its Applicability to Corporate Carbon Accounting. In *Corporate Carbon and Climate Accounting* (pp. 99–120). Springer, Cham. https://doi.org/10.1007/978-3-319-27718-9_5

**Q: What do you estimate incremental GHG emissions to be?**

A: Below I estimate the incremental GHG emissions associated with the Project to be about 27,000,000 metric tons $CO_2e$ annually. This is lower than my estimate of all emissions associated with the Project of 87,000,000 metric tons $CO_2e$ annually because, in my estimation, some of those emissions would occur even if the Proposed Project does not proceed.

**Q: How did you estimate incremental GHG emissions associated with the Proposed Project?**

A: To quantify the incremental GHG emissions of an energy project or action, one must first describe how that project or action will change the energy market. In the case of the Proposed Project, the availability of oil pipelines, including Line 5, affects global GHG emissions because pipelines help increase the supply of oil. Evaluation of these dynamics is a typical methodology for analyzing incremental GHG emissions of an energy infrastructure project. An overview of such approaches can be found in Section IV of the peer-reviewed paper by Burger and Wentz (2020), "Evaluating the Effects of Fossil Fuel Supply Projects on Greenhouse Gas Emissions and Climate Change under NEPA," attached as Exhibit ELP-4 (PAE-4).[42] The oil market is well-connected globally, and there is a straight-forward connection between oil supply and oil consumption. The more oil is available (and at lower cost), the lower the global price of oil, and the more oil is consumed. And, the more oil is consumed, the higher are GHG emissions from producing and burning oil.

[42] Burger, M., & Wentz, J. (2020). Evaluating the Effects of Fossil Fuel Supply Projects on Greenhouse Gas Emissions and Climate Change under NEPA. *William & Mary Environmental Law and Policy Review*, 44(2), 423–530.

**Q: How do pipelines impact global markets for oil?**

A: Pipelines increase the supply of oil by providing transport of oil to market when other options do not exist or are higher cost. This is widely understood, and is nicely summarized for Canadian oil in the peer-reviewed article, Heyes et al (2018), "The Economics of Canadian Oil Sands" – attached as Exhibit ELP-5 (PAE-5).[43] That article focuses on oil sands, but with principles that also apply to light oil. Further, when oil supply is greater, prices are lower, an effect which is summarized in my own peer-reviewed work: Erickson, P., & Lazarus, M. (2014), attached here as Exhibit ELP-6 (PAE-6). Impact of the Keystone XL pipeline on global oil markets and greenhouse gas emissions. *Nature Climate Change,* 4(9), 778–781.[44] As these peer-reviewed articles demonstrate, the effects of shifts in oil supply can be quantified using economic principles and models, which is what I do here.

**Q: Why do you compare the Proposed Project to a "no-action" scenario?**

A: Estimating the effect of the Proposed Project on oil supply requires clearly articulating what would happen in a "no-action" scenario, so that the effect of the Proposed Project can be compared to that, and the incremental effect of the Proposed Project can be quantified. Given that the State of Michigan is revoking and terminating the 1953 Easement that allows Line 5 to operate under the Straits, it is reasonable to consider the no-action scenario to be one in which the Line 5 pipeline is not operational. Even if the 1953 Easement remained valid, it would be appropriate to consider a no-action scenario in which Enbridge shuts down the existing Line 5 and does not replace it with a new segment of pipeline. Enbridge's stated purpose for the project is to "alleviate an environmental concern to the Great Lakes

[43] Heyes, A., Leach, A., & Mason, C. F. (2018). The economics of Canadian oil sands. *Review of Environmental Economics and Policy*, 12(2), 242–263. https://doi.org/10.1093/reep/rey006
[44] Also available at https://doi.org/10.1038/nclimate2335

raised by the State of Michigan relating to the approximate four miles of Enbridge's Line 5 that currently crosses the Straits of Mackinac."[45] One way to achieve that purpose would be to remove Line 5 from the Straits and decommission the pipeline.

**Q: What would happen if the existing dual pipelines in the Straits of Mackinac were shut down, and the Proposed Project was not built?**

A: In such a case, where the Line 5 pipeline through the Straits of Mackinac is not replaced, more of the oil from Montana, North Dakota, and Western Canada would likely be transported by rail, which is generally more expensive than pipelines for transporting petroleum. The key difference of the scenario *with* the Proposed Project and the scenario *without* the Project is therefore the cost of transporting oil out of these regions of North America. I will refer to these regions as the greater Williston Basin, which includes both the Bakken and Duvernay formations. This is what I analyze in more detail below.

**Q: What are the main differences between moving oil by rail as compared to pipeline that affect the incremental GHG emissions associated with the Proposed Project?**

A: Studies have found that the added cost for moving light crude oil by rail, as compared to by pipeline, is about USD $6 per barrel more expensive than pipelines. Different studies have found values somewhat above or below this value, but in my opinion, $6 per barrel is a reasonable, midrange estimate. However, I will discuss how my results could be lower or higher if the actual cost premium were different.

[45] Application at ¶2.

**Q: Did you do an independent analysis of what the various alternatives to transporting oil and NGL via Line 5 would be?**

A: No. I understand that a number of alternative analyses have been undertaken by various experts and groups. However, such a detailed analysis is not necessary for purposes of my analysis of GHG emissions. Rather, I rely on a regional average estimate of how constraints on pipeline capacity can increase the costs for moving oil, based on review of a number of sources.

**Q: What sources did you consult to estimate the range of increase in costs for transporting oil from the greater Williston Basin by rail instead of by pipeline?**

A: I consulted several sources. One was a statistical analysis of actual pipeline and rail crude oil tariffs, conducted by researchers at the University of Waterloo in Canada.[46] An analysis by university economists, Heyes *et al*. (2018), cited previously, report a range between $3 per barrel (which they attribute to the US State Department) and $9 per barrel (which they attribute to the TransCanada corporation).[47] A banking and financial services company, Scotiabank, also estimated that insufficient pipeline capacity would lead to an increase in costs of oil from Alberta about $6 per barrel.[48] Lastly, Alternative 3 of the Dynamic Risk report *Alternatives Analysis for the Straits Pipeline*, though it was addressing a specific rail path from Superior, Wisconsin to Sarnia, Michigan (and not the system-wide average cost

[46] Morrison, A., Bachmann, C., & Saccomanno, F. (2018). Developing an Empirical Pipeline and Rail Crude Oil Mode Split and Route Assignment Model. *Transportation Research Record,* 2672(9), 261–272. Available at https://doi.org/10.1177/0361198118801350.

[47] Heyes, A., Leach, A., & Mason, C. F. (2018). The economics of Canadian oil sands. *Review of Environmental Economics and Policy*, 12(2), 242–263. https://doi.org/10.1093/reep/rey006

[48] Based on the difference between the MSW (light crude) discounts in the "healthy pipeline" ($3/bbl discount) versus "base case" case ($9/bbl discount) in Chart 1 of Scotiabank (2018). Shut in? Assessing the merits of government supply intervention in the Alberta oil industry. Available at https://www.scotiabank.com/content/dam/scotiabank/sub-brands/scotiabank-economics/english/documents/commodity-note/shut-in-government-intervention-assessment_2018-11-21.pdf.

premium of moving oil by rail from the Greater Williston Basin, which is my focus here), also found a rail cost premium of about $6 per barrel. The key point for my analysis is that the added cost of alternative transport can make it more costly to supply oil and therefore decrease oil consumption, as I describe in more detail below.

**Q: Are there greenhouse gas emissions from alternative methods of transporting oil?**

A: Yes. The other factor that relates to GHG emissions is that the GHG emissions associated with moving oil by rail are, like cost, also slightly higher. The increase is small, about 6 kg $CO_2e$ per barrel transported by rail instead of by pipeline, which is just 1% of the total GHG emissions associated with a barrel of oil.[49] However, this difference must also be accounted for, as I do below.

**Q: Have you quantified how oil supply from the greater Williston Basin would be affected in the no-action scenario, where the existing line stops operating and the Proposed Project is not built?**

A: Yes. In the absence of the Line 5 pipeline, some oil fields in the greater Williston Basin may not be able to afford an added cost of $6 per barrel for transporting their oil by rail, since that extra charge would erase any profit that would be expected by oil-field developers. In such a case, prospective new oil fields may not be developed, and so less oil would be supplied to the global oil market compared to the scenario where the Proposed Project is constructed.

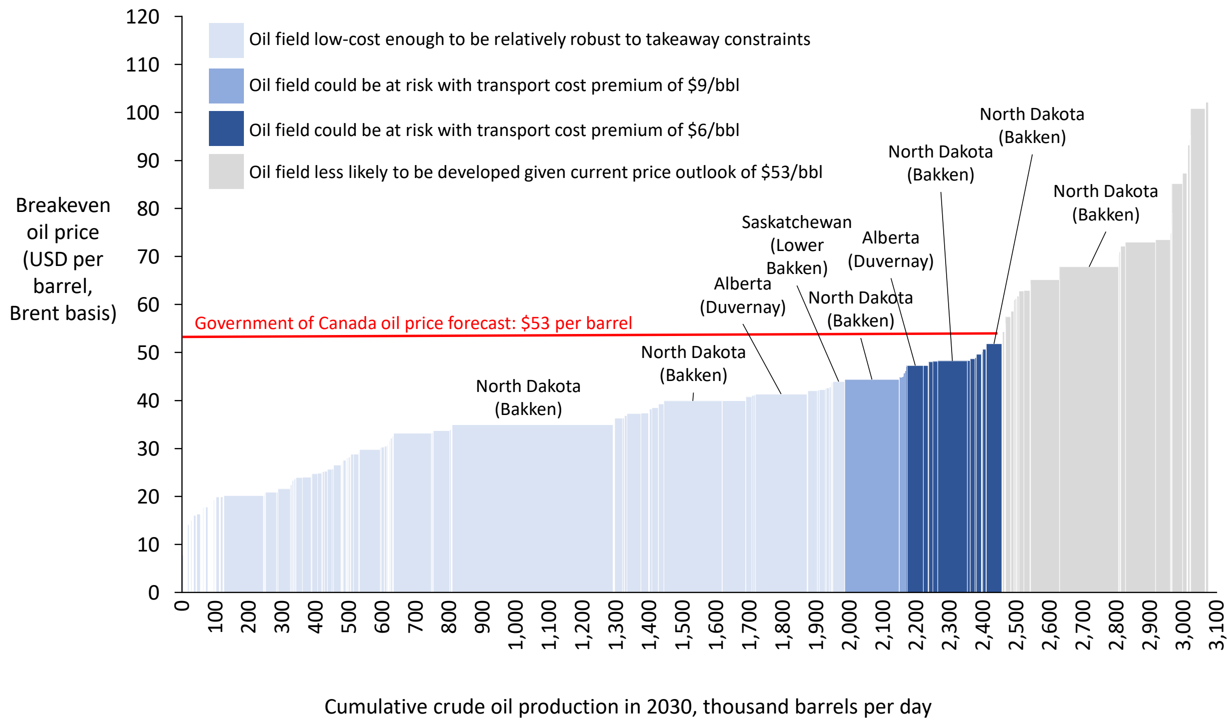
Indeed, the economics of oil in the greater Williston Basin may be challenging in the years ahead. The Government of Canada currently foresees crude oil prices to gradually

[49] Source: Nimana, B., Verma, A., Di Lullo, G., Rahman, Md. M., Canter, C. E., Olateju, B., Zhang, H., & Kumar, A. (2017). Life Cycle Analysis of Bitumen Transportation to Refineries by Rail and Pipeline. *Environmental Science & Technology*, 51(1), 680–691. https://doi.org/10.1021/acs.est.6b02889.

drift downwards towards $53 per barrel by the end of this decade (2030).[50] Oil fields that are only profitable ("break even") at prices just below this level – namely, between $53 per barrel and $47 per barrel ($53 minus the $6 extra for rail transportation) – would therefore not be able to afford an added $6 cost per barrel of transporting their oil to markets. A substantial number of oil projects in the greater Williston Basin are expected to break even in this range of $47 to $53 per barrel, and would therefore be put at risk by the added $6 per barrel in transportation costs. Figure 1, below, shows the sources of light crude oil production in the Canadian provinces of Alberta, British Columbia, Manitoba, and Saskatchewan, and US States of Montana and North Dakota that could potentially feed into the Enbridge mainline pipeline system, including Line 5. The oil fields colored in dark blue are the ones that would be put at risk by a transport cost premium of $6 per barrel. These are new oil fields, for example, in the Bakken formation of North Dakota and the Duvernay formation in Alberta. In total, the quantity of oil that would be put at risk, and ultimately stranded (not developed) by an added $6 per barrel in transportation costs (and assuming an oil price outlook of $53 per barrel) is 290,000 barrels per day. For reference, this is equivalent to about 64% of Line 5's expected crude oil throughput of 450,000 barrels per day.

[50] Canada Energy Regulator. (2021). *Energy Futures 2021: Consultation on Preliminary Results*.

**FIGURE 1. CRUDE OIL COST CURVE FOR GREATER WILLISTON BASIN LIGHT CRUDE**[51]




Therefore, were the Proposed Project not constructed and Line 5 not to be re-started, I estimate that about 290,000 barrels per day of greater Williston Basin light crude oil production would not be developed, due to the resulting increase in system-wide transportation costs. Note, however, that the actual amount of oil production at risk could actually be larger.

**Q: In the no-action scenario, where the existing line stops operating and the Proposed Project is not built, could more than 290,000 barrels per day of oil supply be stranded?**

A: My estimate of 290,000 barrels per day put at risk in the no-action scenario assumes that sufficient rail capacity exists to transport the oil carried by Line 5, and that it costs $6 per

[51] Source of cost curve: Rystad Energy. (2021). Cube Browser, Version 2.2. https://www.rystadenergy.com/Products/EnP-Solutions/UCube

barrel more than transporting oil by pipeline. However, when the capacity to move oil from oil fields to markets (whether by rail or pipeline) is constrained, firms that operate pipelines or rail lines can (and do) exert market power and increase their transportation charges or tariffs to capture additional profit. When they have done this in the recent past, the added cost of crude transportation compared to normal, average pipeline costs grows beyond the $6 per barrel difference in costs assumed here, to between roughly $9 per barrel and, in rare circumstances, as much as $27 per barrel on a temporary basis.[52]

Takeaway capacity for crude oil from the greater Williston Basin has been constrained in the past, and likely will be constrained in the coming years. Recent draft forecasts by the Canadian Energy Regulator, a government body, show that, even *with* the Line 5 pipeline (450,000 bpd crude capacity) *and* Line 3 pipeline (full capacity: 760,000 bpd, expanded from current capacity of 390,000 bpd), Western Canada will have only about 100,000 bpd of spare capacity in the system by 2030.[53] However, if *either* of those pipelines is not operational (and assuming continued delays in the Trans Mountain Pipeline expansion project to Vancouver, B.C.) oil transportation capacity would be insufficient. In that case, it is reasonable to expect that the no-action scenario could lead to added transportation charges of around $9 per barrel on a long-term basis.

An added charge of $9 per barrel for rail transport, instead of $6 per barrel, would have an even greater effect on oil supply. As shown in Figure 1, at a transport cost premium

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[52] The low end of this is taken from the following source: Heyes, A., Leach, A., & Mason, C. F. (2018). The economics of Canadian oil sands. Review of Environmental Economics and Policy, 12(2), 242–263. https://doi.org/10.1093/reep/rey006. The authors describe a discount for diluted bitumen, a heavier grade of oil, of $9 per barrel at the Hardisty hub, but that the difference between rail and pipeline shipping costs for bitumen is *less* than for other grades of oil, e.g. light crude, that do not require diluent. Therefore, a $9 per barrel up-charge is likely on the low end. Alternatively, the high end is calculated as the difference between the "healthy pipeline" and "persistent distressed discounts" case for MSW (light crude) in Chart 1 of Scotiabank (2018).

[53] Takeaway capacity from western Canada is described on slide 10 of: Canada Energy Regulator. (2021). Energy Futures 2021: Consultation on Preliminary Results.

of $9, and again assuming an oil price outlook of about $53 per barrel, much more oil is at risk (the added oil that becomes at-risk at $9 per barrel, as compared to $6 per barrel, is shown in a medium blue): about 450,000 bpd of crude oil production. In other words, it is conceivable that the full crude oil capacity of the Line 5 pipeline, 450,000 bpd, could be left undeveloped if Line 5 is not re-started.

**Q: In the no-action scenario, where the existing line stops operating and the Proposed Project is not built, could fewer than 290,000 barrels per day of oil supply be stranded?**

A: Yes, as I explain above, my central estimate is that 290,000 barrels per day will be stranded, but the figure could also be lower. One way that less oil could be stranded is if the long-term price of oil was expected to be much higher than the $53 per barrel figure I used here. I used that estimate, because, in my opinion, the Government of Canada's recent analysis of oil prices is the most up-to-date and relevant for the greater Williston Basin. A forecast of $53 per barrel is also similar to the outlook of oil consultancy Rystad Energy, which foresees the oil price at about $50 per barrel in the latter half of this decade. However, if the long-term outlook for the price of oil was to increase dramatically, e.g. to $100 per barrel, then differences of about $6 per barrel in transportation costs may not matter as much to how much oil is supplied in Figure 1, and so much less oil could be stranded. Or, if the no-action scenario were to lead to much less than a $6 per barrel increase in transportation cost, the amount of oil stranded could also be less.

Note, however, that less-extreme increases in the outlook for oil prices may not have much effect on my estimate of how much oil would be at risk. For example, the U.S.

Energy Information Administration has forecast oil prices to be about $73 per barrel,[54] which is higher than the $53 forecast from the Canada Energy Regulator. But while a price outlook of $73 would shift *which* exact oil fields are at risk (shifting up the cost curve in Figure 1), the same *number* of barrels – about 290,000 barrels – would be at risk.

**Q: Are your estimates of additional rail costs the same as what Michigan oil producers would expect to see if they were no longer able to use Line 5 to get their oil to market?**

A: No. These estimates of rail costs reflect the cost of transporting crude oil from the greater Williston Basin to markets. I have no reason to believe they would reflect the additional cost to Michigan producers who would no longer be able to use Line 5 and instead used rail transport to get their product to market, since that is a much smaller quantity of oil in a much more localized transportation market.

**Q: How much would the added cost of oil from the greater Williston Basin affect global GHG emissions?**

A: Put simply, shutting down the existing dual pipelines in the Straits and not building the Proposed Project would lead to less, and more costly, oil supplied from the greater Williston Basin over the long term. This outcome would affect global oil markets and consumption levels, because the long-term global price of oil is directly affected by how much it costs to develop the oil fields that will provide the added, or marginal, sources of supply at a given level of expected demand.[55] Since new sources of oil would be more costly than previously anticipated, the long-term oil price would rise, and oil consumers

[54] Brent crude oil price forecast in real dollars for 2030 from US EIA. (2021). *Annual Energy Outlook 2021*. U.S. Energy Information Administration. http://www.eia.gov/forecasts/aeo/

[55] For a discussion of these dynamics, see page 7 of Fattouh, B., Poudineh, R., & West, R. (2019). Energy transition, uncertainty, and the implications of change in the risk preferences of fossil fuels investors. The Oxford Institute for Energy Studies, or Erickson, P., van Asselt, H., Koplow, D., Lazarus, M., Newell, P., Oreskes, N., & Supran, G. (2020). Why fossil fuel producer subsidies matter. *Nature*, 578(7793), E1–E4. https://doi.org/10.1038/s41586-019-1920-x

would respond to the higher expected price by using less oil, such as by switching to other forms of lower-carbon transportation or by using more efficient vehicles. The effect of reductions in oil supply on oil price and consumption is well-established, even as it is also the subject of ongoing research and debate, as discussed in Hamilton (2009) and Caldara et al (2019).[56]

**Q: Why are the costs of oil from the greater Williston Basin so important?**

A: The costs of oil from the greater Williston Basin are especially important because this region is expected to be one of the major sources of the new, added supplies of oil in the years to come. In particular, the crude oil from these regions is expected to comprise at least 7% of the marginal, new sources of oil, based on my analysis of the costs and volumes of world oil supply in Rystad Energy's Ucube database.[57] An increase in the cost of oil from the greater Williston Basin would therefore have a proportional effect on the global marginal cost of supplying oil: namely, a $6 per barrel increase in the cost of oil from this region could increase the average *global* marginal cost of supplying oil by about $0.40 per barrel. (An increase of $6 per barrel in 7% of the marginal cost translates, via simple multiplication, to an average increase of $0.40 per barrel). That, in turn, would translate into an increase in global oil prices of about $0.29 per barrel.

**Q: Will that increase in oil prices have a significant impact on customers in Michigan?**

A: I have not conducted that analysis here, but it in my opinion it is unlikely that the effects of the price increase would be locally significant. Rather, the impacts of the per barrel price

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[56] Hamilton, J. D. (2009). Understanding crude oil prices. *The Energy Journal*, 30(2), 179–206. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol30-No2-9; Caldara, D., Cavallo, M., & Iacoviello, M. (2019). Oil price elasticities and oil price fluctuations. *Journal of Monetary Economics*, 103, 1–20. https://doi.org/10.1016/j.jmoneco.2018.08.004

[57] Rystad Energy. (2021). Cube Browser, Version 2.2. https://www.rystadenergy.com/Products/EnP-Solutions/UCube

increase would have global impacts. Even though the increase is small on the individual level ($0.29 per barrel of oil is less than 1 cent per gallon), that added cost would add up to globally significant effects on consumer behavior and oil consumption around the world, since it would lead to changes in how (and how many) people and goods are transported using oil.

**Q: If the Proposed Project were built, what is your overall estimate of the incremental GHG emissions compared to the no-action alternative?**

A: In total, assuming a $6 per barrel increase in transportation costs associated with rail transport of petroleum, I estimate that, compared to the no-action scenario, where the existing line stops operating and the Proposed Project is not built, building the Proposed Project would lead to a net, incremental increase in annual global oil consumption of about 150,000 bpd, equivalent to 27,000,000 metric tons $CO_2e$ per year from burning and producing that oil. Nearly all of this increase in oil consumption and GHG emissions would occur outside Michigan.

**Q: How did you calculate this estimate?**

A: This change in global oil price and oil consumption is calculated using a simple oil market model, parameterized by elasticities (long-run elasticity of crude oil supply of 0.6, long-run elasticity of crude oil demand of -0.3), a model that is described in more detail in my peer-reviewed, scientific work, including, most recently: Achakulwisut, P., Erickson, P., & Koplow, D. (2021). Effect of subsidies and regulatory exemptions on 2020–2030 oil and gas production and profits in the United States. *Environmental Research Letters*, 16(8), 084023, which is attached here as Exhibit ELP-7 (PAE-7).[58] I convert this change in oil

[58] Available at https://doi.org/10.1088/1748-9326/ac0a10 .

consumption to a change in GHG emissions from burning oil by assuming a global, reference GHG-intensity of crude oil of 502 kg $CO_2e$ per barrel, while also assuming that any oil now carried by rail instead of pipeline does so at an added GHG-intensity of 6 kg $CO_2e$ per barrel.

"Long-run" elasticities are intended to gauge effects over a period of time in which producers and consumers have time to make changes in their equipment or investment decisions, such as the decision of what kind of car to buy or whether or not to drill a new oil field. Over this time period – the next several years – the flexibility of decisions is greater than in the "short run," and hence the effects of a change in price are greater. The long-run elasticities of supply (0.6) and demand (-0.3) that I use here are the same as in my most recent peer-reviewed research. An elasticity of supply of 0.6 is consistent with a fairly "flat" oil supply curve characteristic of the current oil price outlook. (Were oil price outlooks to be much higher, e.g. over $100, the supply curve would be steeper, and the elasticity of supply lower.)

A long-run elasticity of demand, -0.3, is higher (in absolute value) than some prior reviews: Hamilton (2009) reported a range of -0.2 to -0.3. A higher value like -0.3, is commonly believed to be more consistent with the greater current availability of electric vehicles, and is still lower than an alternative, commonly used value of -0.5 as reported by Raimi (2019).[59]

**Q: What is the source of your assumption about the elasticity of supply and demand?**

A: My source for the elasticity of supply estimate of 0.6 is taken directly from the slope of the oil supply curve, as assembled by oil industry consultancy Rystad Energy, for prices in the

[59] Raimi, D. (2019). The Greenhouse Gas Impacts of Increased US Oil and Gas Production [Working Paper 19-03]. http://www.rff.org

$50 per barrel to $70 per barrel range, as described in Erickson *et al.* 2020. My source for the elasticity of demand is taken from Hamilton (2009).

**Q: Why did you choose these specific values and not others in the literature?**

A: The values I am using represent my expert judgment as to most reasonable values for the present situation, given current oil price outlooks and the expanding alternatives to oil in the transport sector, which is by far the largest sector using oil. These values are also well within the ranges used in other studies, and therefore represent mid-range values that should yield reasonable results for decision-makers. It would also be possible to use different values to get a sense of how the results could change.

**Q: Did you calculate the results using different values?**

A: Yes. I did a sensitivity analysis in which I varied elasticities of supply and demand to see how the results could vary. In the table below, I display how very different assumptions about elasticities of supply and demand could make my estimate of 27 million metric tons $CO_2e$ higher or lower. While I present this to show a wide range of potential outcomes, I find the lower elasticity of supply value of 0.1 to be extraordinarily unlikely, as that implies a very steep supply curve in which oil producers are very insensitive to price, a situation that only arises if long-term oil forecasts are very high, e.g. over $100 per barrel. In the more likely scenario – with higher elasticity of supply -- the incremental GHG emissions remain over 20 million metric tons $CO_2e$ even where assumptions regarding the elasticity of demand change.

**TABLE 3. INCREMENTAL GLOBAL GHG EMISSIONS (MILLION TONS $CO_2E$) RESULTING FROM THE PROPOSED PROJECT, USING DIFFERENT ELASTICITIES OF SUPPLY AND DEMAND**

| | | Long-run elasticity of global crude oil supply | | |
|---|---|---|---|---|
| | | 0.1 | **0.6** (best estimate) | 1 |
| Long-run elasticity of global crude oil demand | -0.2 | 4.2 million t $CO_2e$ | 20 million t $CO_2e$ | 27 million t $CO_2e$ |
| | **-0.3** (best estimate) | 4.8 million t $CO_2e$ | **27 million t $CO_2e$** | 38 million t $CO_2e$ |
| | -0.5 | 5.4 million t $CO_2e$ | 37 million t $CO_2e$ | 55 million t $CO_2e$ |

Values in **bold** are best estimates used in this testimony

**Q: Does this mean that your estimate of incremental GHG emissions could be lower?**

A: Yes, of course. As indicated in Table 3 above, my estimate of incremental emissions could be much lower if the elasticity of supply of oil was much lower, a situation that could arise if oil demand were to outpace oil supply in the years ahead and oil prices were to rise substantially, e.g. to well over $100 per barrel. I consider this outcome unlikely and, also, not very consistent with global goals to decarbonize the economy, the attainment of which would instead yield greatly reduced oil demand and, in turn, lower oil prices. As explained in my testimony above, my estimate could also be somewhat lower if the absence of Line 5 had less of an effect on oil transportation costs than in my central estimate.

**Q: Are there any other ways your estimate of incremental GHG emissions could be lower?**

A: Yes. Another way my estimate could be affected is if consumers, in response to slightly lower oil prices resulting from the Proposed Project (compared to the no-action scenario), were to increase their oil consumption at the expense of other fossil-based sources of energy, such as coal or gas-based electricity. I have not evaluated those effects, termed "cross-price" or substitution effects in the economic literature, because they involve different fuels than what would be handled by the Proposed Project and so are secondary considerations. These effects could reduce my incremental estimate of 27 million metric tons $CO_2e$ somewhat; however, as the global energy transition accelerates, the marginal source of the main substitute for oil – electricity – is no longer mainly fossil fuels, but instead primarily very low-carbon renewable power. This strong trend towards renewable power suggests that any shift away from electricity would have relatively minor effects on my incremental GHG emissions estimate.

**Q: How could your estimate of incremental GHG emissions be higher?**

A: My estimate of incremental GHG emissions could be somewhat greater if consumers were even more sensitive to oil prices in the future than they have been in the past (i.e., an elasticity of demand of -0.5 or more, as in Table 3) or if, as described above, the rail and pipeline takeaway capacity from the greater Williston Basin is even more constrained than I assume here (e.g., if either the Line 3 or Trans Mountain pipeline projects currently underway are not completed).

**Q: If the estimate could change, why should it be relied upon here?**

A: I believe my central estimate of 27,000,000 metric tons $CO_2e$ is a reasonable approximation of the incremental effect of the Proposed Project on global GHG emissions based on available information regarding supply and demand elasticities. The methods used above use standard GHG emissions accounting principles, and my specific approaches regarding pipelines and oil markets have been successfully scrutinized by the scientific peer review process several times for other projects. Furthermore, I have considered several possible uncertainties. Finally, in other contexts involving estimations of GHG emissions, courts have concluded that the inherent uncertainties in these types of estimations is no justification for failing to quantify these effects.[60]

**Q: What about the possibility that, if the Proposed Project is not built, the "no action" scenario is not the closing of Line 5, but instead that the existing, dual pipelines continue to operate for some limited amount of time?**

A: In such a case, then the concept of incremental emissions described above still applies, but the effect is essentially postponed by however many years the existing dual pipelines could continue to operate.

**Q: Have you estimated how this decrease in the quantity of oil consumed would impact customers in Michigan?**

A: No. My focus is on the global GHG emissions effect of the Line 5 pipeline. Michigan represents only about one-half of 1% of global oil consumption, so the GHG emissions effects inside Michigan are a small part of the overall GHG emissions effects of the Line 5 pipeline. Of course, the impact on Michigan's natural resources, as the result of all global GHG emissions, is significant, as discussed by other expert witnesses in this case.

**Q: Have you estimated changes in price, consumption, or incremental GHG emissions associated with the propane or butane handled by the Proposed Project?**

A: No. In contrast to the incremental emissions from increased consumption of crude oil that would result from constructing the Proposed Project (relative to the no-action scenario), which are driven by effects global markets, any incremental emissions from changes in propane and ethane markets would likely be more local, due to propane and ethane markets in the Eastern U.S. and Canada, including in Michigan.

[60] *See Ctr. for Biological Diversity v. Bernhardt*, 982 F.3d 723, 739–40 (9th Cir. 2020).

These effects are likely much smaller than for crude oil for three reasons: (1) the quantity of these NGLs handled by the pipeline is only 20% the volume of crude; (2) NGLs contain at least 35% less carbon per barrel than crude; and (3) the propensity for end-markets to increase their consumption of NGLs (relative to the no-action scenario) may be less than for crude oil, as consumers do not make as frequent decisions regarding home heating (a key source of propane use) as they do about how often and what kind of vehicle to drive.

For these reasons, I do not estimate the changes to price, consumption, or incremental GHG emissions associated with NGLs. I do note that the same fundamental market principles would apply as for oil: proceeding with the Proposed Project would, relative to the no-action scenario, would mean lower costs of producing NGLs from the greater Williston Basin, lower prices for these liquids, and therefore a (proportionally smaller) increase (again, relative to the no-action scenario) in their consumption.[61]

**Q: Have you estimated how the incremental GHG emissions caused by the Proposed Project would affect climate change, including in Michigan?**

A: No. Consistent with section III of this testimony ("Overview of climate change and the need for greenhouse gas emissions cuts"), the intent of global climate change policy is that substantial emission reductions are needed in all regions of the world and in all sectors. Accordingly, the change in warming or climate impacts that would result from actions in Michigan should be viewed in that context and not as isolated (and proportionally smaller) effects on global temperature.

[61] Lower-carbon alternatives to propane (e.g. for heating or for industrial equipment) and butane (e.g. for petrochemicals and plastic manufacturing) are becoming available.

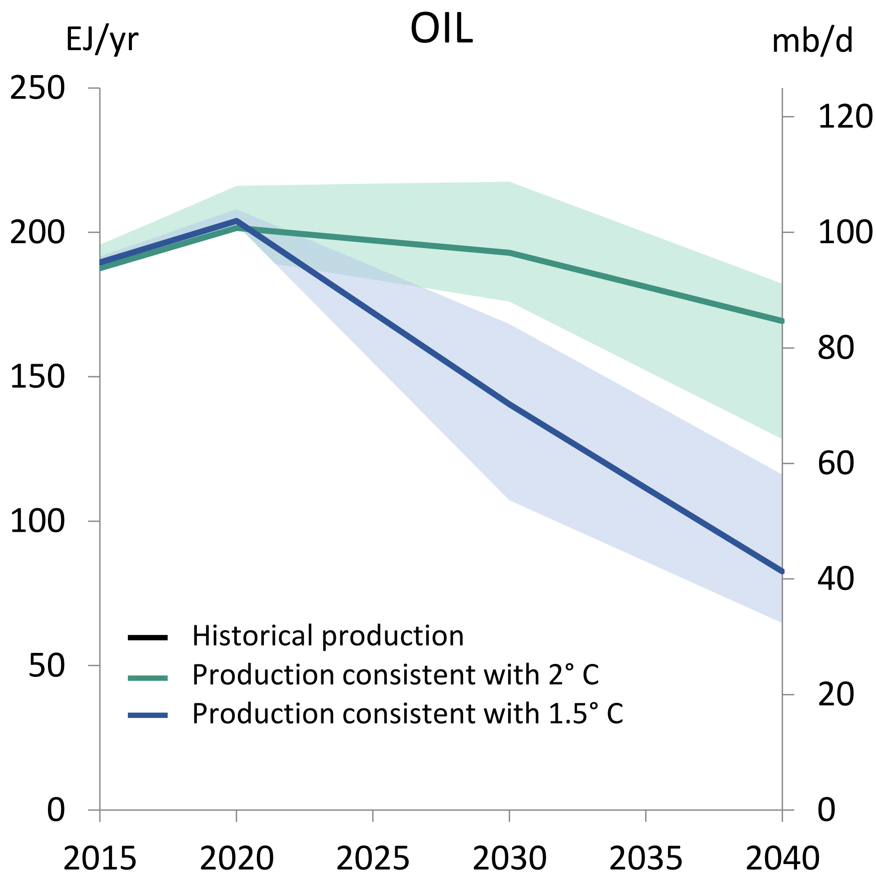
## VI. INCONSISTENCY OF THE PROPOSED PROJECT WITH INTERNATIONALLY AGREED CLIMATE LIMITS

**Q: Is Enbridge's Proposed Project generally consistent with international, national and state climate goals?**

A: No. Michigan's Governor Gretchen Whitmer has initiated the MI Healthy Climate Plan aimed at protecting public health and the environment, and helping to develop new clean energy jobs, by putting Michigan on a path towards becoming carbon-neutral, meaning net zero greenhouse gas emissions, by 2050. Further, the Governor has committed the State of Michigan to advance the goals of the Paris Agreement. As described in section III of this testimony, one of the goals of the Paris Agreement is "pursuing efforts" to limit global warming to 1.5°C above pre-industrial levels. To meet that goal with no or "limited" overshoot (exceedance) of the temperature limit, the Intergovernmental Panel on Climate Change (IPCC) has found that global emissions must reach zero by about the year 2050. Further, the IPCC has found that oil production and use must fall by an average of about 3% annually (for a total of 65%) between 2020 and 2050.

Analysis by international research organizations of the IPCC's emission-reduction pathways, published in partnership with the United Nations' Environment Program, has found that oil production needs to decline under both the 1.5 °C and 2 °C limits, as shown in Figure 2.

FIGURE 2. OIL PRODUCTION AND USE
CONSISTENT WITH 1.5 °C AND 2 °C LIMITS[62]




By contrast, maintaining oil production at recent levels for the next several decades is not consistent with meeting the warming goals of the Paris Agreement. Constructing long-lived oil infrastructure, such as pipelines, that helps lower the cost and investment risk of oil production – increasing oil use and emissions (as demonstrated in Section V of this testimony) is therefore at odds with the temperature and emissions goals of the Paris Agreement.

[62] Figure adapted from SEI, IISD, ODI, E3G, & UNEP. (2020). The Production Gap: Special Report 2020. http://productiongap.org/2020report. Green and blue bands show inter-quartile ranges across all scenarios analyzed by the Production Gap Report authors.

**Q: Besides the IPCC and the UN Environment Program, are there any other major international institutions that have pointed out the disconnect between further oil-related development and climate goals?**

A: Yes, the International Energy Agency (IEA), an intergovernmental organization, has similarly found that expanding oil production is inconsistent with reaching zero emissions by mid-century and limiting warming to 1.5°C. In its recent *Net Zero by 2050* report, the IEA found that there is "no need for investment in new fossil fuel supply" in their net-zero pathway.[63] More specifically, the IEA stated that "no new oil and natural gas fields are needed," which helps lead to a "contraction of oil and natural gas production."[64]

Constructing the Proposed Project and re-starting Line 5 would provide added certainty and low-cost takeaway capacity for new oil fields in the Bakken and Duvernay formations in Alberta, British Columbia, and Saskatchewan provinces of Canada, and in the states of North Dakota and Montana in the U.S. (*See* Figure 1). Developing new oil fields in these regions would be inconsistent with both the IPCC scenarios and the IEA's road map for reaching net zero by 2050, and would thus also be inconsistent with Michigan Governor Whitmer's commitment to align the state's policies with the Paris Agreement and with net zero emissions by 2050.

## SUMMARY OF TESTIMONY/CONCLUSIONS

**Q: Please summarize your conclusions.**

A: My testimony has three main conclusions.

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[63] Source: page 21 of IEA. (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector*. International Energy Agency. https://www.iea.org/reports/net-zero-by-2050

[64] Source: page 23 of IEA (2021).

First, as described in section IV of this testimony, the Proposed Project is associated with about 87 million metric tons carbon-dioxide equivalent ($CO_2e$) annually, the overwhelming majority of which are from the use, or combustion, of the oil and natural gas liquids transported by the Line 5 pipeline.

Second, as described in section V, compared to a no-action scenario, where the Line 5 pipeline no longer operates in the Straits, the Proposed Project would lead to an *increase* of about 27 million metric tons $CO_2e$ in global greenhouse gas emissions from the production and combustion of oil.

Third, as described in section VI, by enabling the continued, long-term production and combustion of oil, construction of the project would work against, and therefore be inconsistent with, the goals of the global Paris Agreement and Michigan's Healthy Climate Plan.

**Q: Does this conclude your testimony?**

A: Yes.

# Peter A. Erickson

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## Professional Summary

- Broad expertise in greenhouse gas emissions quantification, abatement and policy analysis. Published first-author research articles in prominent peer-reviewed journals, including *Climatic Change, Climate Policy, Energy Policy, Environmental Research Letters, Environmental Science and Technology, Nature, Nature Climate Change,* and *Nature Energy.*
- Over twenty years experience in environmental policy research and consulting, supported by funders such as United Nations Framework Convention on Climate Change European Commission, World Bank, U.S. EPA, Bloomberg Philanthropies, Energy Foundation, KR Foundation, Schmidt Family Foundation, C40 Cities, World Resources Institute, NRDC, SIDA, U.S. states of Washington and Oregon, Western Climate Initiative, City of Seattle, City of Chicago
- Outstanding skills in economic and financial analysis, modeling, writing, public speaking, project management, communication

## Professional Experience

**2008-Present STOCKHOLM ENVIRONMENT INSTITUTE – U.S., SEATTLE, WA**
**Scientist 2008-2011; Senior Scientist 2012-2021**

**Selected Projects and Research**

- **Oil market economics.** Leading long-term research into how supply and demand in oil markets interact, and with what $CO_2$ emissions implications. Major research publications in *Nature, Nature Climate Change, Nature Energy, Climatic Change*, and others. Popular commentary in the *New Yorker, Scientific American, Seattle Times*, *Salt Lake Tribune, Texas Tribune,* others.
- **Emissions implications of new fossil fuel supply infrastructure.** Researching the GHG implications and lock-in of investments in new infrastructure for supplying fossil fuels, such as oil pipelines, coal export facilities, and chemical facilities.
- **GHG emissions abatement potential of the world's cities.** Led a research effort, funded by Bloomberg Philanthropies, on the GHG emissions abatement potential of urban-scale policy levers worldwide.
- **Net emissions impact of the CDM.** Lead researcher for the UNFCCC's High Level Panel on the CDM Policy Dialogue focused on additionality and over- or under-crediting in the CDM. Contributed chapter to major research report.
- **Implications of international offsets on global climate mitigation.** Researched and modeled the supply and environmental efficacy of alternative sources and methods of crediting greenhouse gas offsets from developing countries.
- **Scenarios of domestic offset supply in a U.S. cap-and-trade system.** Lead researcher, with Michael Lazarus, on a partnership between SEI and the World Resources Institute on the economics and emissions implications of domestic greenhouse gas offsets.
- **Embodied emissions in international trade.** Led a research initiative on the embodied emissions in international trade and assessing opportunities to shift trade for both emissions and development benefits.

- **Emissions leakage and the CDM.** Conducted an assessment of the potential for the CDM to induce activity or emissions leakage in the cement, steel, and aluminum sectors.
- **King County (WA) consumption-based GHG inventory and GHG measurement framework**. Led effort to conduct geographic and consumption-based greenhouse gas inventories and recommend a new measurement framework for King County.
- **Role of behavior and consumption in global climate mitigation.** Developed a method to estimate the GHG reductions for a nation or community due to shifts in consumption behaviors. Working paper published summer 2012.
- **City of Seattle (WA) carbon neutral scenario analysis**. Contributing to a technical scenario analysis of how the Seattle community could reduce greenhouse gas emissions to near zero in the next few decades, with a focus on the buildings and transportation sectors.
- **State of Oregon consumption-based GHG inventory**. Peter was the project manager on this effort to develop a consumption-based (rather than production- or geographic-based) GHG inventory for the State of Oregon. Published in *Environmental Science and Technology* in 2012.
- **Europe deep GHG emissions reduction scenario.** Peter developed a deep greenhouse gas reduction scenario for the EU-27's transportation, buildings, and agriculture sectors – the deepest reduction scenario proposed EU-wide at the time of its publication.
- **Greenhouse gas mitigation potential in developing countries (US EPA).** Peter was the lead researcher on a study of greenhouse gas mitigation potential and policies in six developing countries for the U.S. EPA. Published as working paper, June 2009.
- **Industry greenhouse gas benchmarking**. Peter led an assessment of benchmarking as a policy tool for reducing industrial GHGs. Funded by the Washington Department of Ecology and the Energy Foundation.
- **GHG and green energy planning in Mongolia.** Researcher on alternative scenarios of Mongolia's energy development.

**2000-2008 CASCADIA CONSULTING GROUP, SEATTLE, WA**
Senior Associate (2006-2008); Associate (2002-'05); Project Assistant ('00-'01)

**Selected Projects - 2008**

- **Climate Change Policy Initiatives (Seattle City Council).** Peter led the development of a legislative agenda to address climate change
- **Energy Efficiency Policy Study (Seattle Office of Sustainability and Environment).** Led a study of energy efficiency policies for existing buildings in Seattle to support Mayor Greg Nickels' Green Building Task Force.
- **Carbon Footprint Calculator (Seattle Office of Sustainability and Environment)** Updated the City of Seattle's greenhouse gas footprint tool for businesses to include a greater focus on business supply chain (included upstream, embedded emissions) and year-to-year tracking.
- **Greenhouse Gas Inventory (Pierce County, Washington).** Oversaw Pierce County's greenhouse gas inventory process.

**Selected Projects – Pre-2008**

- **Carbon Footprint Calculator (Seattle Office of Sustainability and Environment)** Peter created the City of Seattle's greenhouse gas footprint tool for businesses
- **Other Carbon Footprint Calculators (Various clients).** Peter adapted the Seattle carbon footprint calculator for use by several other state and local jurisdictions
- **Oregon Waste Prevention Strategy (Oregon Department of Environmental Quality).** Peter contributed to research in support of DEQ's Waste Prevention Strategy.

- **Zero Waste Plan (City of Chicago).** Led several tasks of the development of a Zero Waste Plan for the City of Chicago.

## Committees

| | |
|---|---|
| **2015** | Compact of Mayors, City Mitigation Goals – Member of aggregation technical advisory group. |
| **2012-2014** | WRI GHG Protocol Mitigation Accounting Initiative. Member of the mitigation goals accounting technical working group. |
| **2010-2012** | ICLEI-US Community Greenhouse Gas Protocol. Member of the lifecycle technical advisory committee |

## Education

| | |
|---|---|
| **2007** | University of Washington, Seattle, Washington, USA. Courses in intermeditate micro-economics and macro-economics (non-matriculated). |
| **1994-1998** | Carleton College, Northfield, Minnesota, USA<br>B.A with major in geology and extensive studies in mathematics, studio art<br>*Magna Cum Laude, Phi Beta Kappa*, with distinction in major*;* GPA: 3.83 |

## Selected Recent (2009-2021) Publications

Achakulwisut, P., **Erickson, P.,** & Koplow, D. (2021). Effect of subsidies and regulatory exemptions on 2020-2030 oil and gas production and profits in the United States. *Environmental Research Letters*

Achakulwisut, P., & **Erickson, P.** (2021). Trends in fossil fuel extraction: Implications for a shared effort to align fossil fuel production with climate limits. Stockholm Environment Institute.

**Erickson, P.,** & Achakulwisut, P. (2021). Risks for New Natural Gas Developments in Appalachia. Ohio River Valley Institute.

SEI, IISD, ODI, E3G and UNEP (2020). The Production Gap: Special Report 2020. http://productiongap.org/ [I was a lead author of Chapter 2 and contributing author to other chapters.]

**Erickson, P.** and Lazarus, M. (2020). Examining Risks of New Oil and Gas Production in Canada. SEI report. Stockholm Environment Institute, US Center, Seattle. https://www.sei.org/publications/examining-risks-of-new-oil-and-gas-production-in-canada/

**Erickson, P**. et al. (2020). Why fossil fuel producer subsidies matter. *Nature* 578, E1–E4.

SEI, IISD, ODI, Climate Analytics, CICERO, & UNEP. (2019). The Production Gap Report 2019. Retrieved from http://productiongap.org/ [I was the lead author of Chapter 2 and contributing author to other chapters.]

Koski, J., Kartha, S., & **Erickson, P**. (2019). Principles for aligning US fossil fuel extraction with climate goals. https://www.sei.org/publications/principles-for-aligning-fossil-fuel-extraction-with-climate-limits/

Broekhoff, D., Piggot, G., & **Erickson, P**. (2019). Estimating consumption-based greenhouse gas emissions at the city scale [SEI Report]. https://www.sei.org/publications/consumption-based-greenhouse-gas-emissions-city-scale/

**Erickson, P**., Lazarus, M., & Piggot, G. (2018). Limiting fossil fuel production as the next big step in climate policy. *Nature Climate Change,* 8, 1037–1043. https://doi.org/10.1038/s41558-018-0337-0

**Erickson, P**., & Lazarus, M. (2018). Would constraining US fossil fuel production affect global CO2 emissions? A case study of US leasing policy. *Climatic Change*, 150, 29–42. https://doi.org/10.1007/s10584-018-2152-z

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**Erickson, P.** (2018). Confronting carbon lock-in: Canada's oil sands. (Discussion Brief). Seattle: Stockholm Environment Institute. Retrieved from https://www.sei.org/featured/continued-canadian-oil-sands-production-frustrate-global-climate-goals/

**Erickson, P.** (2018). Boom or Bust. *The New Yorker.* Retrieved from https://www.newyorker.com/magazine/2018/01/29/letters-from-the-january-29-2018-issue

**Erickson, P**. (2018). One of Trump's biggest scandals is happening in Utah. *Salt Lake Tribune*. Retrieved from https://www.sltrib.com/opinion/commentary/2018/03/08/commentary-one-of-trumps-biggest-scandals-is-happening-in-utah/

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**Erickson, P**., & Lazarus, M. (2018). Towards a climate test for industry: Assessing a gas-based methanol plant. Seattle, WA: Stockholm Environment Institute. Retrieved from https://www.sei.org/publications/assessing-gas-methanol-plant/

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Piggot, G., **Erickson, P**., van Asselt, H., & Lazarus, M. (2018). Swimming upstream: Addressing fossil fuel supply under the UNFCCC. *Climate Policy*, 18(9), 1189–1202. https://doi.org/10.1080/14693062.2018.1494535

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**Erickson, Peter** (2021). Direct testimony (written and oral) to Pollution Control Hearings Board for The State of Washington. Advocates For a Cleaner Tacoma; Sierra Club; Washington Environmental Council; Washington Physicians For Social Responsibility; Stand.Earth, Appellants, *v*. Puget Sound Clean Air Agency, Puget Sound Energy, Respondents. PCHB No. p19-087c.

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## Selected Recent (2009-2021) Presentations

**Erickson, Peter** (2021). *Can limiting oil and gas production help meet climate goals?* United Kingdom Climate Change Committee. London (remote presentation), April 27, 2021.

**Erickson, Peter** and Georgia Piggot (2021). *Opening remarks* at Virtual Forum on Fossil Fuel Supply And Climate Policy. September 15, 2020

**Erickson, Peter** (2020). *Examining risks of new oil and gas production in Canada*. Future of Oil and Canada's economy webinar, May 13, 2020.

**Erickson, Peter** (2020). *Closing the gap between fossil fuel production plans and climate goals.* American Association for the Advancement of Science annual conference, Seattle, WA . February 16, 2020.

**Erickson, Peter**, Ploy Achakulwisut, and Doug Koplow (2019*). How do subsidies affect oil drilling in the US?* Publish What You Pay webinar, November 7, 2019

**Erickson, Peter** (2019). *What might carbon neutrality mean for oil production?* CFEE Energy Summit: The Road to Carbon Neutrality. Napa, California. March 7-8, 2019

**Erickson, Peter**, Jess Koski, Sivan Kartha, Paelina DeStephano (2018). *Don't Count on It: Climate Limits Suggest a Wind-down of U.S. Oil and Gas Production.* Future Prospects for Oil & Gas in a Decarbonized World. American Geophysical Union (AGU) Annual conference, Washington, D.C., December 12, 2018.

**Erickson, Peter** (2018). *Limiting fossil fuel production: Could it be the next big step for decarbonization?* University of San Diego Tenth Annual Climate & Energy Law Symposium San Diego, November 9, 2018.

**Erickson, Peter** (2018). *Oil! Why limiting oil production can make good climate policy.* California Air Resources Board, Petroleum Transport Fuels Workshop, Sacramento, California. August 20, 2018

**Erickson, Peter** (2018). Opening remarks and panel moderator. Can limiting oil production make good climate policy? Global Climate Action Summit affiliate event. San Francisco, California. September 13, 2018.

**Erickson, Peter** (2018). Plenary panelist at Fossil Fuel Supply and Climate Policy: An International Conference. Oxford, UK. September 24.

**Erickson, Peter** (2018). *Avoiding carbon lock-in: Phasing out fossil fuels in the power sector*. ATA Insights webinar, July 19, 2018.

**Erickson, Peter** (2018). *Managing the decline of fossil fuel production: a missing piece of the climate policy puzzle*. Peter Wall Institute for Advanced Studies, University of British Columbia June 12, 2018.

**Erickson, Peter** (2018). *Oil! Why limiting oil production can make good climate policy*. Green California conference, Sacramento, California, February 28, 2018.

**Erickson, Peter** (2017). *National policies for low-carbon urban mobility (closing remarks).* Coalition for Urban Transitions / New Climate Economy side-event. UNFCCC COP 23, Bonn, Germany,

**Erickson, Peter** (2017). *Infrastructure and carbon lock-in: Could new infrastructure lock out a safe climate?* COP 23 Side-event: Infrastructure: Make it or break it for Paris implementation. UNFCCC COP 23, Bonn, Germany November 7, 2017.

**Erickson, Peter** (2017). How does Norway's tax system affect petroleum investment? Confronting the supply side of fossil fuels ¬– politics and economics. Svolvær, Norway, August 4, 2017.

**Erickson, Peter** (2016). *Moratoria on new fossil development: Example of U.S. federal-owned lands*. COP22 side event (Blue Zone): Fossil fuel supply & climate policy: Key steps to enhance ambition. UNFCCC COP 22, Marrakesh, Morocco. Nov 10, 2016

**Erickson, Peter** (2016). *Implications of phasing out U.S. federal leases for fossil fuel extraction, CO2 emissions, and* $2^{0}$ *C goals*. Workshop on the Economics of Controlling Fossil Fuel Supply, EDF, New York. October 21, 2016

**Erickson, Peter** (2016). *National urban development strategies*. New Climate Economy Research Partners Meeting. London. September 30, 2016

**Erickson, Peter** (2016). *Impact of phasing out U.S. fossil fuel leases on CO2 emissions and the 2°C goal.* Fossil fuel supply and climate policy: an international conference. Oxford, UK. Sept 27, 2016.

**Erickson, Peter** (2016). *The impact of ramping down federal oil leasing on CO2 emissions and* $2^{0}$ *C goals*. Dept of Interior Bureau of Ocean Energy Management (BOEM), Herndon, VA (via webinar) July 6, 2016

**Erickson, Peter** (2016). *The impact of ramping down federal coal and oil leasing on CO2 emissions and* $2^{0}$ *C goals*. Federal Coal Workshop: NYU, Washington, D.C. June 29, 2016

**Erickson, Peter** (2016). *What would "Keeping it in the Ground" do for fossil fuel markets and CO2 emissions*? House Briefing. Washington D.C. June 28, 2016

**Erickson, Peter** and Derik Broekhoff (2016). *What cities do best: Subnational integration and ideal roles for cities in climate action*. LEDS Global Partnership, 9 February, 2016.

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**Erickson, Peter** (2015). *Supply-side climate policy, carbon lock-in, and fossil fuel producer subsidies.* OCI / CAN Side Event: The Phase-out of Fossil Fuel Subsidies and a Paris Climate Deal". UNFCCC COP 21, Paris, 4 December, 2015

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**Erickson, Peter** (2015). *City mitigation opportunities.* Cities, Climate Action, and the Role of Philanthropy. London. September 30, 2015

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**Erickson, Peter** (2012). *Constructing benchmarks.* Session Chair: ICAP/NA2050 Workshop on Developing Industrial Benchmarks. New York, New York. September 24, 2012.

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**Erickson, Peter** (2010). *Issues in Defining Carbon Neutrality.* Carbon Neutral Unconference. www.worldchanging.com. Seattle. April 4th.

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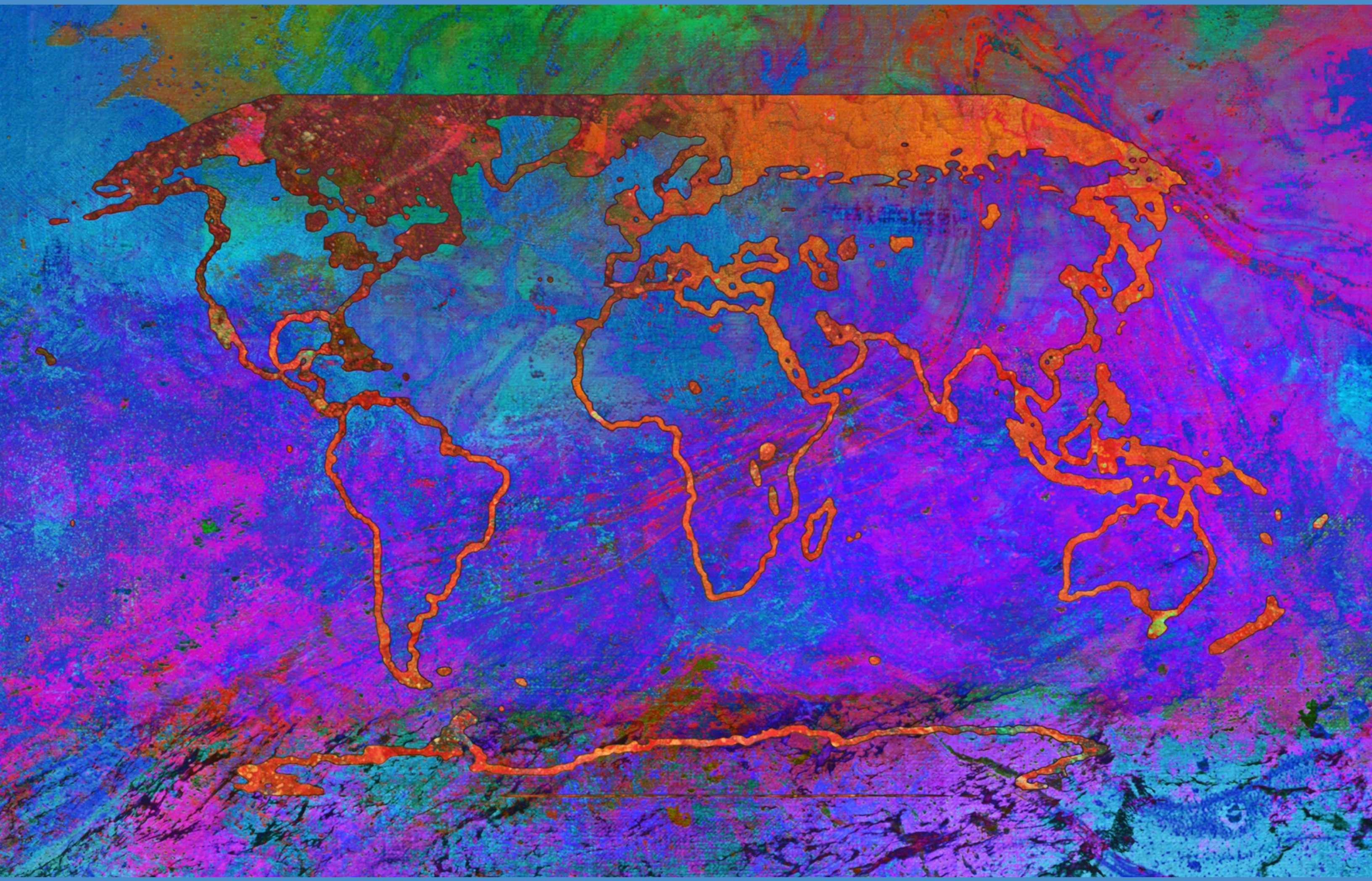
INTERGOVERNMENTAL PANEL ON climate change

# Climate Change 2021

## The Physical Science Basis

### Summary for Policymakers



WGI

Working Group I contribution to the
Sixth Assessment Report of the
Intergovernmental Panel on Climate Change

WMO UNEP

## Summary for Policymakers

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## Introduction

This Summary for Policymakers (SPM) presents key findings of the Working Group I (WGI) contribution to the IPCC's Sixth Assessment Report (AR6)[1] on the physical science basis of climate change. The report builds upon the 2013 Working Group I contribution to the IPCC's Fifth Assessment Report (AR5) and the 2018–2019 IPCC Special Reports[2] of the AR6 cycle and incorporates subsequent new evidence from climate science[3].

This SPM provides a high-level summary of the understanding of the current state of the climate, including how it is changing and the role of human influence, the state of knowledge about possible climate futures, climate information relevant to regions and sectors, and limiting human-induced climate change.

Based on scientific understanding, key findings can be formulated as statements of fact or associated with an assessed level of confidence indicated using the IPCC calibrated language[4].

The scientific basis for each key finding is found in chapter sections of the main Report, and in the integrated synthesis presented in the Technical Summary (hereafter TS), and is indicated in curly brackets. The AR6 WGI Interactive Atlas facilitates exploration of these key synthesis findings, and supporting climate change information, across the WGI reference regions[5].

[1] Decision IPCC/XLVI-2.

[2] The three Special reports are: 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 (SR1.5); Climate Change and Land: an IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL); IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC).

[3] The assessment covers scientific literature accepted for publication by 31 January 2021.

[4] 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%, and *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. In this Report, unless stated otherwise, square brackets [x to y] are used to provide the assessed *very likely* range, or 90% interval.

[5] The Interactive Atlas is available at https://interactive-atlas.ipcc.ch

## A. The Current State of the Climate

*Since AR5, improvements in observationally based estimates and information from paleoclimate archives provide a comprehensive view of each component of the climate system and its changes to date. New climate model simulations, new analyses, and methods combining multiple lines of evidence lead to improved understanding of human influence on a wider range of climate variables, including weather and climate extremes. The time periods considered throughout this Section depend upon the availability of observational products, paleoclimate archives and peer-reviewed studies.*

### A.1 It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.

{2.2, 2.3, Cross-Chapter Box 2.3, 3.3, 3.4, 3.5, 3.6, 3.8, 5.2, 5.3, 6.4, 7.3, 8.3, 9.2, 9.3, 9.5, 9.6, Cross-Chapter Box 9.1} **(Figure SPM.1, Figure SPM.2)**

**A.1.1** Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally caused by human activities. Since 2011 (measurements reported in AR5), concentrations have continued to increase in the atmosphere, reaching annual averages of 410 ppm for carbon dioxide ($CO_2$), 1866 ppb for methane ($CH_4$), and 332 ppb for nitrous oxide ($N_2O$) in 2019[6]. Land and ocean have taken up a near-constant proportion (globally about 56% per year) of $CO_2$ emissions from human activities over the past six decades, with regional differences (*high confidence*)[7]. {2.2, 5.2, 7.3, TS.2.2, Box TS.5}

**A.1.2** Each of the last four decades has been successively warmer than any decade that preceded it since 1850. Global surface temperature[8] in the first two decades of the 21st century (2001-2020) was 0.99 [0.84-1.10] °C higher than 1850-1900[9]. Global surface temperature was 1.09 [0.95 to 1.20] °C higher in 2011–2020 than 1850–1900, 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). 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 contributed approximately 0.1ºC to the updated estimate of warming in AR6[10].

[6] Other GHG concentrations in 2019 were: PFCs (109 ppt $CF_4$ equivalent); $SF_6$ (10 ppt); $NF_3$ (2 ppt); HFCs (237 ppt HFC-134a equivalent); other Montreal Protocol gases (mainly CFCs, HCFCs, 1032 ppt CFC-12 equivalent). Increases from 2011 are 19 ppm for $CO_2$, 63 ppb for $CH_4$ and 8 ppb for $N_2O$.

[7] Land and ocean are not substantial sinks for other GHGs.

[8] The term 'global surface temperature' is used in reference to both global mean surface temperature and global surface air temperature throughout this SPM. Changes in these quantities are assessed with *high confidence* to differ by at most 10% from one another, but conflicting lines of evidence lead to *low confidence* in the sign of any difference in long-term trend. {Cross-Section Box TS.1}

[9] The period 1850–1900 represents the earliest period of sufficiently globally complete observations to estimate global surface temperature and, consistent with AR5 and SR1.5, is used as an approximation for pre-industrial conditions.

[10] Since AR5, 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 additionally increased the estimate of global surface temperature change by approximately 0.1 ºC, but this increase does not represent additional physical warming since the AR5.

**A.1.3** The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019[11] is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is *likely* that well-mixed GHGs contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural 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. It is *very likely* that well-mixed GHGs were the main driver[12] of tropospheric warming since 1979, and *extremely likely* that human-caused stratospheric ozone depletion was the main driver of cooling of the lower stratosphere between 1979 and the mid-1990s.
{3.3, 6.4, 7.3, Cross-Section Box TS.1, TS.2.3} **(Figure SPM.2)**

**A.1.4** Globally averaged precipitation over land has *likely* increased since 1950, with a faster rate of increase since the 1980s (*medium confidence*). It is *likely* that human influence contributed to the pattern of observed precipitation changes since the mid-20th century, and *extremely likely* that human influence contributed to the pattern of observed changes in near-surface ocean salinity. Mid-latitude storm tracks have *likely* shifted poleward in both hemispheres since the 1980s, with marked seasonality in trends (*medium confidence*). For the Southern Hemisphere, human influence *very likely* contributed to the poleward shift of the closely related extratropical jet in austral summer.
{2.3, 3.3, 8.3, 9.2, TS.2.3, TS.2.4, Box TS.6}

**A.1.5** Human influence is *very likely* the main driver of the global retreat of glaciers since the 1990s and the decrease in Arctic sea ice area between 1979–1988 and 2010–2019 (about 40% in September and about 10% in March). There has been no significant trend in Antarctic sea ice area from 1979 to 2020 due to regionally opposing trends and large internal variability. Human influence *very likely* contributed to the decrease in Northern Hemisphere spring snow cover since 1950. It is *very likely* that human influence has contributed to the observed surface melting of the Greenland Ice Sheet over the past two decades, but there is only *limited evidence*, with *medium agreement*, of human influence on the Antarctic Ice Sheet mass loss.
{2.3, 3.4, 8.3, 9.3, 9.5, TS.2.5}

**A.1.6** It is *virtually certain* that the global upper ocean (0–700 m) has warmed since the 1970s and *extremely likely* that human influence is the main driver. It is *virtually certain* that human-caused $CO_2$ emissions are the main driver of current global acidification of the surface open ocean. There is *high confidence* that oxygen levels have dropped in many upper ocean regions since the mid-20th century, and *medium confidence* that human influence contributed to this drop.
{2.3, 3.5, 3.6, 5.3, 9.2, TS.2.4}

**A.1.7** 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.
{2.3, 3.5, 9.6, Cross-Chapter Box 9.1, Box TS.4}

**A.1.8** Changes in the land biosphere since 1970 are consistent with global warming: climate zones have shifted poleward in both hemispheres, and the growing season has on average lengthened by up to two days per decade since the 1950s in the Northern Hemisphere extratropics (*high confidence*).
{2.3, TS.2.6}

[11] The period distinction with A.1.2 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.

[12] Throughout this SPM, 'main driver' means responsible for more than 50% of the change.

# Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

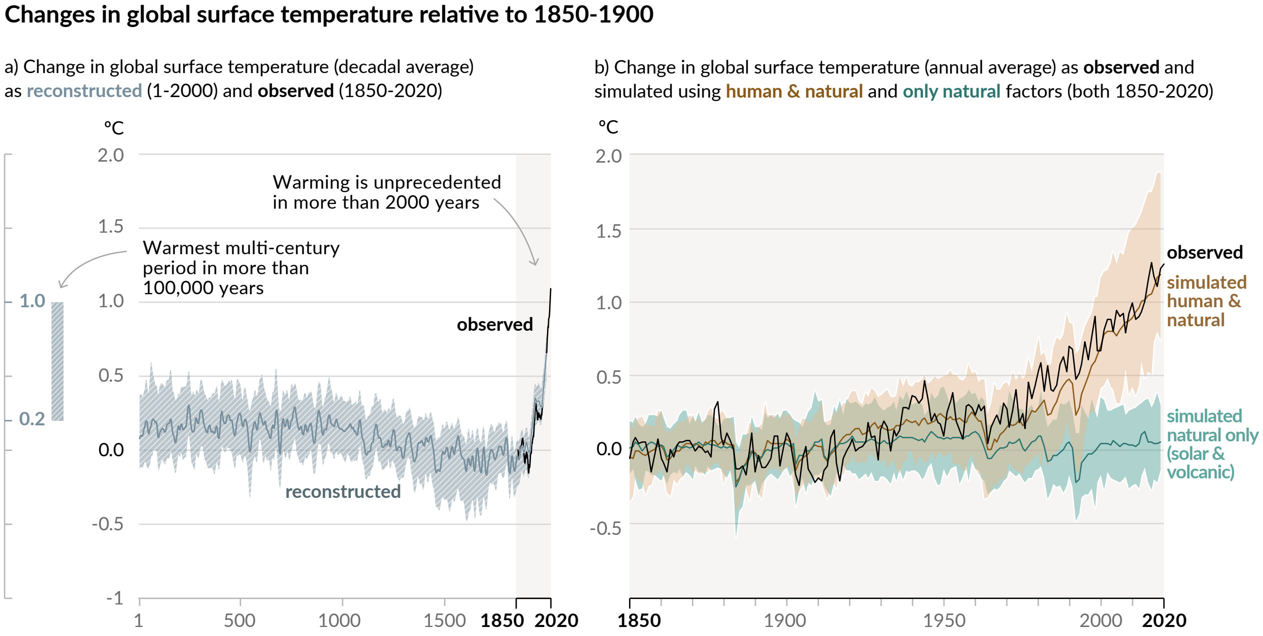



**Figure SPM.1: History of global temperature change and causes of recent warming.**

**Panel a): Changes in global surface temperature reconstructed from paleoclimate archives** (solid grey line, 1–2000) **and from direct observations** (solid black line, 1850–2020), both relative to 1850–1900 and decadally averaged. The vertical bar on the left shows the estimated temperature (*very likely* range) during the warmest multi-century period in at least the last 100,000 years, which occurred around 6500 years ago during the current interglacial period (Holocene). The Last Interglacial, around 125,000 years ago, is the next most recent candidate for a period of higher temperature. These past warm periods were caused by slow (multi-millennial) orbital variations. The grey shading with white diagonal lines shows the *very likely* ranges for the temperature reconstructions.

**Panel b): Changes in global surface temperature over the past 170 years** (black line) relative to 1850–1900 and annually averaged, compared to CMIP6 climate model simulations (see Box SPM.1) of the temperature response to both human and natural drivers (brown), and to only natural drivers (solar and volcanic activity, green). Solid coloured lines show the multi-model average, and coloured shades show the *very likely* range of simulations. (see Figure SPM.2 for the assessed contributions to warming).

{2.3.1, 3.3, Cross-Chapter Box 2.3, Cross-Section Box TS.1, Figure 1a, TS.2.2}

# Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling

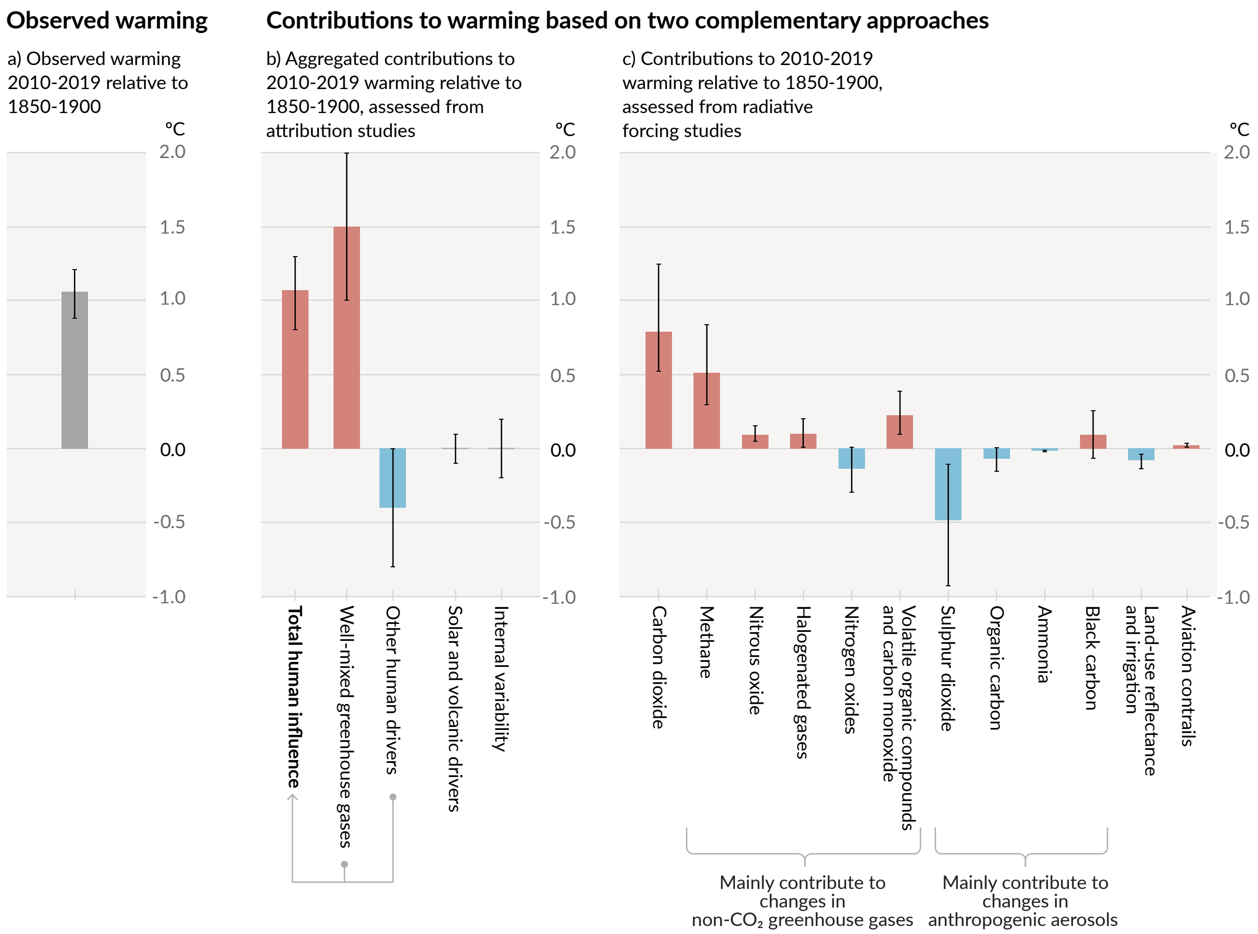



**Figure SPM.2: Assessed contributions to observed warming in 2010–2019 relative to 1850–1900.**

**Panel a): Observed global warming** (increase in global surface temperature) and its *very likely* range {3.3.1, Cross-Chapter Box 2.3}.

**Panel b): Evidence from attribution studies**, which synthesize information from climate models and observations. The panel shows temperature change attributed to total human influence, changes in well-mixed greenhouse gas concentrations, other human drivers due to aerosols, ozone and land-use change (land-use reflectance), solar and volcanic drivers, and internal climate variability. Whiskers show *likely* ranges {3.3.1}.

**Panel c): Evidence from the assessment of radiative forcing and climate sensitivity.** The panel shows temperature changes from individual components of human influence, including emissions of greenhouse gases, aerosols and their precursors; land-use changes (land-use reflectance and irrigation); and aviation contrails. Whiskers show *very likely* ranges. Estimates account for both direct emissions into the atmosphere and their effect, if any, on other climate drivers. For aerosols, both direct (through radiation) and indirect (through interactions with clouds) effects are considered. {6.4.2, 7.3}

## A.2 The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years.

{Cross-Chapter Box 2.1, 2.2, 2.3, 5.1} **(Figure SPM.1)**

**A.2.1** In 2019, atmospheric $CO_2$ concentrations were higher than at any time in at least 2 million years (*high confidence)*, and concentrations of $CH_4$ and $N_2O$ were higher than at any time in at least 800,000 years (*very high confidence*). Since 1750, increases in $CO_2$ (47%) and $CH_4$ (156%) concentrations far exceed, and increases in $N_2O$ (23%) are similar to, the natural multi-millennial changes between glacial and interglacial periods over at least the past 800,000 years (*very high confidence*).
{2.2, 5.1, TS.2.2}

**A.2.2** Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years (*high confidence*). Temperatures during the most recent decade (2011–2020) exceed those of the most recent multi-century warm period, around 6500 years ago[13] [0.2°C to 1°C relative to 1850–1900] (*medium confidence*). Prior to that, the next most recent warm period was about 125,000 years ago when the multi-century temperature [0.5°C to 1.5°C relative to 1850–1900] overlaps the observations of the most recent decade (*medium confidence*).
{Cross-Chapter Box 2.1, 2.3, Cross-Section Box TS.1} **(Figure SPM.1)**

**A.2.3** In 2011–2020, annual average Arctic sea ice area reached its lowest level since at least 1850 (*high confidence*). Late summer Arctic sea ice area was smaller than at any time in at least the past 1000 years (*medium confidence*). The global nature of glacier retreat, with almost all of the world's glaciers retreating synchronously, since the 1950s is unprecedented in at least the last 2000 years (*medium confidence*).
{2.3, TS.2.5}

**A.2.4** Global mean sea level has risen faster since 1900 than over any preceding century in at least the last 3000 years (*high confidence*). The global ocean has warmed faster over the past century than since the end of the last deglacial transition (around 11,000 years ago) (*medium confidence*). A long-term increase in surface open ocean pH occurred over the past 50 million years (*high confidence*), and surface open ocean pH as low as recent decades is unusual in the last 2 million years (*medium confidence*).
{2.3, TS.2.4, Box TS.4}

[13] As stated in section B.1, even under the very low emissions scenario SSP1-1.9, temperatures are assessed to remain elevated above those of the most recent decade until at least 2100 and therefore warmer than the century-scale period 6500 years ago.

## A.3 Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since AR5.

{2.3, 3.3, 8.2, 8.3, 8.4, 8.5, 8.6, Box 8.1, Box 8.2, Box 9.2, 10.6, 11.2, 11.3, 11.4, 11.6, 11.7, 11.8, 11.9, 12.3} **(Figure SPM.3)**

**A.3.1** It is *virtually certain* that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with *high confidence* that human-induced climate change is the main driver[14] of these changes. Some recent hot extremes observed over the past decade would have been *extremely unlikely* to occur without human influence on the climate system. Marine heatwaves have approximately doubled in frequency since the 1980s (*high confidence*), and human influence has *very likely* contributed to most of them since at least 2006.
{Box 9.2, 11.2, 11.3, 11.9, TS.2.4, TS.2.6, Box TS.10} **(Figure SPM.3)**

**A.3.2** The frequency and intensity of heavy precipitation events have increased since the 1950s over most land area for which observational data are sufficient for trend analysis (*high confidence*), and human-induced climate change is *likely* the main driver. Human-induced climate change has contributed to increases in agricultural and ecological droughts[15] in some regions due to increased land evapotranspiration[16] (*medium confidence*).
{8.2, 8.3, 11.4, 11.6, 11.9, TS.2.6, Box TS.10} **(Figure SPM.3)**

**A.3.3** Decreases in global land monsoon precipitation[17] from the 1950s to the 1980s are partly attributed to human-caused Northern Hemisphere aerosol emissions, but increases since then have resulted from rising GHG concentrations and decadal to multi-decadal internal variability (*medium confidence*). Over South Asia, East Asia and West Africa increases in monsoon precipitation due to warming from GHG emissions were counteracted by decreases in monsoon precipitation due to cooling from human-caused aerosol emissions over the 20th century (*high confidence*). Increases in West African monsoon precipitation since the 1980s are partly due to the growing influence of GHGs and reductions in the cooling effect of human-caused aerosol emissions over Europe and North America (*medium confidence*).
{2.3, 3.3, 8.2, 8.3, 8.4, 8.5, 8.6, Box 8.1, Box 8.2, 10.6, Box TS.13}

[14] Throughout this SPM, 'main driver' means responsible for more than 50% of the change.

[15] Agricultural and ecological drought (depending on the affected biome): a period with abnormal soil moisture deficit, which results from combined shortage of precipitation and excess evapotranspiration, and during the growing season impinges on crop production or ecosystem function in general. Observed changes in meteorological droughts (precipitation deficits) and hydrological droughts (streamflow deficits) are distinct from those in agricultural and ecological droughts and addressed in the underlying AR6 material (Chapter 11).

[16] The combined processes through which water is transferred to the atmosphere from open water and ice surfaces, bare soil, and vegetation that make up the Earth's surface.

[17] The global monsoon is defined as the area in which the annual range (local summer minus local winter) of precipitation is greater than 2.5 mm $day^{-1}$. Global land monsoon precipitation refers to the mean precipitation over land areas within the global monsoon.

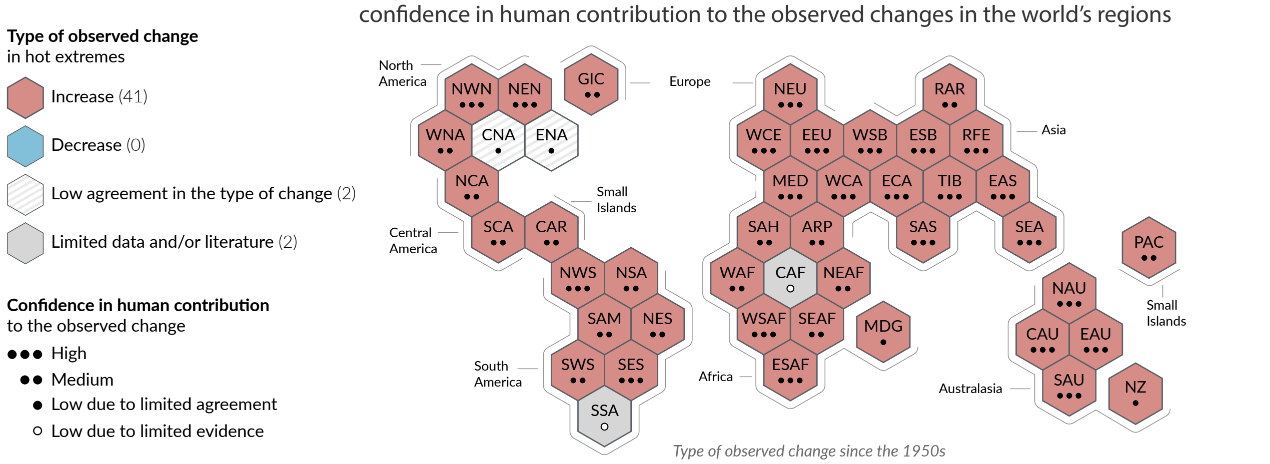
**A.3.4** It is *likely* that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades, and the latitude where tropical cyclones in the western North Pacific reach their peak intensity has shifted northward; these changes cannot be explained by internal variability alone (*medium confidence*). There is *low confidence* in long-term (multi-decadal to centennial) trends in the frequency of all-category tropical cyclones. Event attribution studies and physical understanding indicate that human-induced climate change increases heavy precipitation associated with tropical cyclones (*high confidence*) but data limitations inhibit clear detection of past trends on the global scale.
{8.2, 11.7, Box TS.10}

**A.3.5** Human influence has *likely* increased the chance of compound extreme events[18] since the 1950s. This includes increases in the frequency of concurrent heatwaves and droughts on the global scale (*high confidence*); fire weather in some regions of all inhabited continents (*medium confidence*); and compound flooding in some locations (*medium confidence*). {11.6, 11.7, 11.8, 12.3, 12.4, TS.2.6, Table TS.5, Box TS.10}

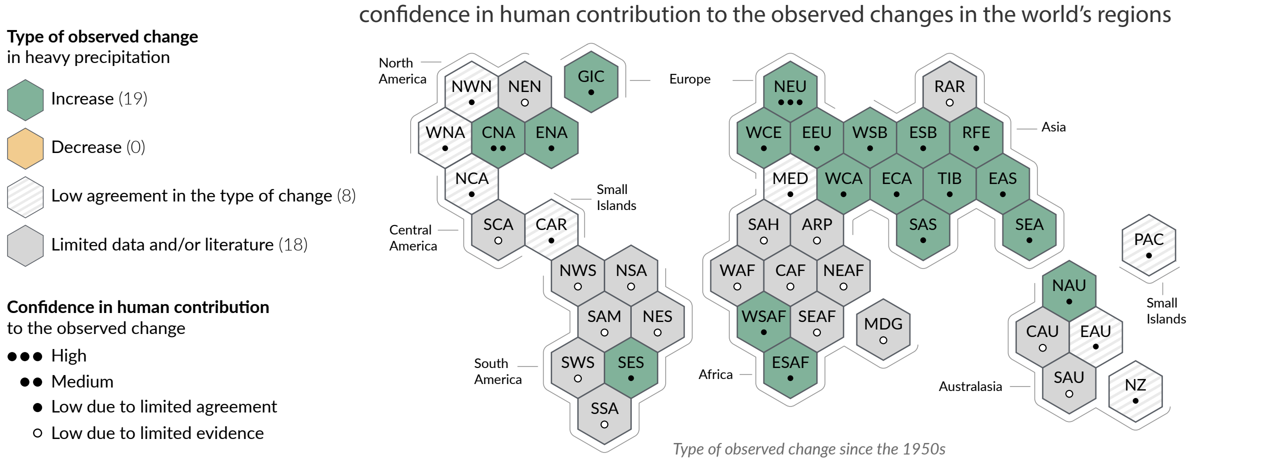
[18] Compound extreme events are the combination of multiple drivers and/or hazards that contribute to societal or environmental risk. Examples are concurrent heatwaves and droughts, compound flooding (e.g., a storm surge in combination with extreme rainfall and/or river flow), compound fire weather conditions (i.e., a combination of hot, dry, and windy conditions), or concurrent extremes at different locations.

# Climate change is already affecting every inhabited region across the globe with human influence contributing to many observed changes in weather and climate extremes

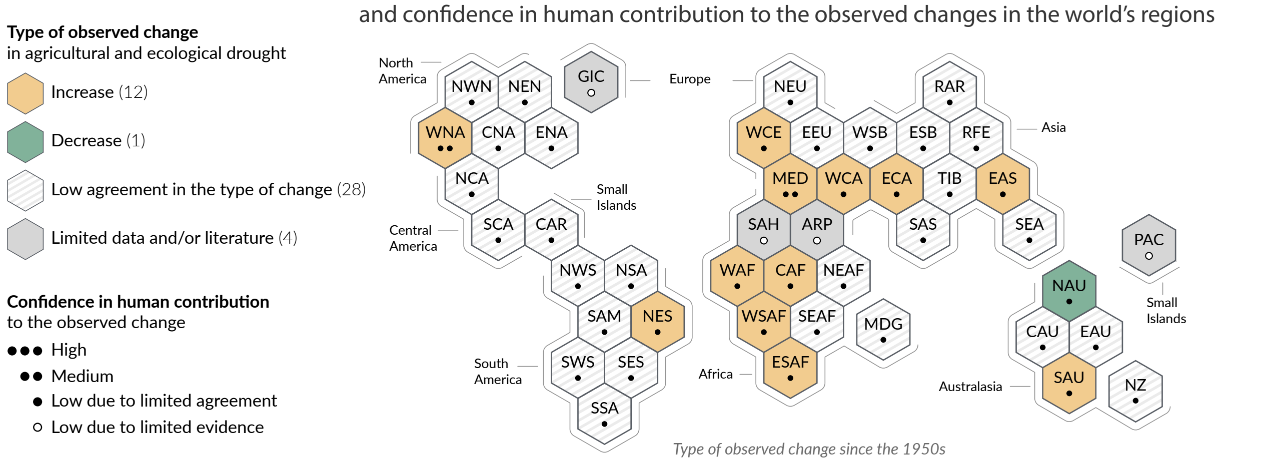
a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions




b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions




c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions




*Each hexagon corresponds to one of the IPCC AR6 WGI reference regions*

NWN *North-Western North America*

IPCC AR6 WGI reference regions: **North America:** ***NWN*** *(North-Western North America,* ***NEN*** *(North-Eastern North America),* ***WNA*** *(Western North America),* ***CNA*** *(Central North America),* ***ENA*** *(Eastern North America),* **Central America:** ***NCA*** *(Northern Central America),* ***SCA*** *(Southern Central America),* ***CAR*** *(Caribbean),* **South America:** ***NWS*** *(North-Western South America),* ***NSA*** *(Northern South America),* ***NES*** *(North-Eastern South America),* ***SAM*** *(South American Monsoon),* ***SWS*** *(South-Western South America),* ***SES*** *(South-Eastern South America),* ***SSA*** *(Southern South America),* **Europe:** ***GIC*** *(Greenland/Iceland),* ***NEU*** *(Northern Europe),* ***WCE*** *(Western and Central Europe),* ***EEU*** *(Eastern Europe),* ***MED*** *(Mediterranean),* **Africa:** ***MED*** *(Mediterranean),* ***SAH*** *(Sahara),* ***WAF*** *(Western Africa),* ***CAF*** *(Central Africa),* ***NEAF*** *(North Eastern Africa),* ***SEAF*** *(South Eastern Africa),* ***WSAF*** *(West Southern Africa),* ***ESAF*** *(East Southern Africa),* ***MDG*** *(Madagascar),* **Asia:** ***RAR*** *(Russian Arctic),* ***WSB*** *(West Siberia),* ***ESB*** *(East Siberia),* ***RFE*** *(Russian Far East),* ***WCA*** *(West Central Asia),* ***ECA*** *(East Central Asia),* ***TIB*** *(Tibetan Plateau),* ***EAS*** *(East Asia),* ***ARP*** *(Arabian Peninsula),* ***SAS*** *(South Asia),* ***SEA*** *(South East Asia),* **Australasia:** ***NAU*** *(Northern Australia),* ***CAU*** *(Central Australia),* ***EAU*** *(Eastern Australia),* ***SAU*** *(Southern Australia),* ***NZ*** *(New Zealand),* **Small Islands:** ***CAR*** *(Caribbean),* ***PAC*** *(Pacific Small Islands)*

**Figure SPM.3: Synthesis of assessed observed and attributable regional changes.**

The IPCC AR6 WGI inhabited regions are displayed as **hexagons** with identical size in their approximate geographical location (see legend for regional acronyms). All assessments are made for each region as a whole and for the 1950s to the present. Assessments made on different time scales or more local spatial scales might differ from what is shown in the figure. The **colours** in each panel represent the four outcomes of the assessment on observed changes. White and light grey striped hexagons are used where there is *low agreement* in the type of change for the region as a whole, and grey hexagons are used when there is limited data and/or literature that prevents an assessment of the region as a whole. Other colours indicate at least *medium confidence* in the observed change. The **confidence level** for the human influence on these observed changes is based on assessing trend detection and attribution and event attribution literature, and it is indicated by the number of dots: three dots for *high confidence*, two dots for *medium confidence* and one dot for *low confidence* (filled: limited agreement; empty: limited evidence).

**Panel a) For hot extremes,** the evidence is mostly drawn from changes in metrics based on daily maximum temperatures; regional studies using other indices (heatwave duration, frequency and intensity) are used in addition. Red hexagons indicate regions where there is at least *medium confidence* in an observed increase in hot extremes.

**Panel b) For heavy precipitation,** the evidence is mostly drawn from changes in indices based on one-day or five-day precipitation amounts using global and regional studies. Green hexagons indicate regions where there is at least *medium confidence* in an observed increase in heavy precipitation.

**Panel c) Agricultural and ecological droughts** are assessed based on observed and simulated changes in total column soil moisture, complemented by evidence on changes in surface soil moisture, water balance (precipitation minus evapotranspiration) and indices driven by precipitation and atmospheric evaporative demand. Yellow hexagons indicate regions where there is at least *medium confidence* in an observed increase in this type of drought and green hexagons indicate regions where there is at least *medium confidence* in an observed decrease in agricultural and ecological drought.

For all regions, table TS.5 shows a broader range of observed changes besides the ones shown in this figure. Note that SSA is the only region that does not display observed changes in the metrics shown in this figure, but is affected by observed increases in mean temperature, decreases in frost, and increases in marine heatwaves.

{11.9, Table TS.5, Box TS.10, Figure 1, Atlas 1.3.3, Figure Atlas.2}

## A.4 Improved knowledge of climate processes, paleoclimate evidence and the response of the climate system to increasing radiative forcing gives a best estimate of equilibrium climate sensitivity of 3°C with a narrower range compared to AR5. {2.2, 7.3, 7.4, 7.5, Box 7.2, Cross-Chapter Box 9.1, 9.4, 9.5, 9.6}

**A.4.1** Human-caused radiative forcing of 2.72 [1.96 to 3.48] W $m^{-2}$ in 2019 relative to 1750 has warmed the climate system. This warming is mainly due to increased GHG concentrations, partly reduced by cooling due to increased aerosol concentrations. The radiative forcing has increased by 0.43 W $m^{-2}$ (19%) relative to AR5, of which 0.34 W $m^{-2}$ is due to the increase in GHG concentrations since 2011. The remainder is due to improved scientific understanding and changes in the assessment of aerosol forcing, which include decreases in concentration and improvement in its calculation (*high confidence*).
{2.2, 7.3, TS.2.2, TS.3.1}

**A.4.2** Human-caused net positive radiative forcing causes an accumulation of additional energy (heating) in the climate system, partly reduced by increased energy loss to space in response to surface warming. The observed average rate of heating of the climate system increased from 0.50 [0.32 to 0.69] W $m^{-2}$ for the period 1971–2006[19], to 0.79 [0.52 to 1.06] W $m^{-2}$ for the period 2006–2018[20] (*high confidence*). Ocean warming accounted for 91% of the heating in the climate system, with land warming, ice loss and atmospheric warming accounting for about 5%, 3% and 1%, respectively (*high confidence*).
{7.2, Box 7.2, TS.3.1}

**A.4.3** Heating of the climate system has caused global mean sea level rise through ice loss on land and thermal expansion from ocean warming. Thermal expansion explained 50% of sea level rise during 1971–2018, while ice loss from glaciers contributed 22%, ice sheets 20% and changes in land water storage 8%. The rate of ice sheet loss increased by a factor of four between 1992–1999 and 2010–2019. Together, ice sheet and glacier mass loss were the dominant contributors to global mean sea level rise during 2006-2018. (*high confidence*)
{Cross-Chapter Box 9.1, 9.4, 9.5, 9.6}

**A.4.4** The equilibrium climate sensitivity is an important quantity used to estimate how the climate responds to radiative forcing. Based on multiple lines of evidence[21], the *very likely* range of equilibrium climate sensitivity is between 2°C (*high confidence*) and 5°C (*medium confidence*). The AR6 assessed best estimate is 3°C with a *likely* range of 2.5°C to 4°C (*high confidence*), compared to 1.5°C to 4.5°C in AR5, which did not provide a best estimate.
{7.4, 7.5, TS.3.2}

[19] cumulative energy increase of 282 [177 to 387] ZJ over 1971–2006 (1 ZJ = $10^{21}$ J).

[20] cumulative energy increase of 152 [100 to 205] ZJ over 2006–2018.

[21] Understanding of climate processes, the instrumental record, paleoclimates and model-based emergent constraints (see glossary).

## B. Possible Climate Futures

*A set of five new illustrative emissions scenarios is considered consistently across this report to explore the climate response to a broader range of greenhouse gas (GHG), land use and air pollutant futures than assessed in AR5. This set of scenarios drives climate model projections of changes in the climate system. These projections account for solar activity and background forcing from volcanoes. Results over the 21st century are provided for the near-term (2021–2040), mid-term (2041–2060) and long-term (2081–2100) relative to 1850–1900, unless otherwise stated.*

### Box SPM.1: Scenarios, Climate Models and Projections

**Box SPM.1.1:** This report assesses the climate response to five illustrative scenarios that cover the range of possible future development of anthropogenic drivers of climate change found in the literature. They start in 2015, and include scenarios[22] with high and very high GHG emissions (SSP3-7.0 and SSP5-8.5) and $CO_2$ emissions that roughly double from current levels by 2100 and 2050, respectively, scenarios with intermediate GHG emissions (SSP2-4.5) and $CO_2$ emissions remaining around current levels until the middle of the century, and scenarios with very low and low GHG emissions and $CO_2$ emissions declining to net zero around or after 2050, followed by varying levels of net negative $CO_2$ emissions[23] (SSP1-1.9 and SSP1-2.6) as illustrated in Figure SPM.4. Emissions vary between scenarios depending on socio-economic assumptions, levels of climate change mitigation and, for aerosols and non-methane ozone precursors, air pollution controls. Alternative assumptions may result in similar emissions and climate responses, but the socio-economic assumptions and the feasibility or likelihood of individual scenarios is not part of the assessment.
{TS.1.3, 1.6, Cross-Chapter Box 1.4} **(Figure SPM.4)**

**Box SPM.1.2:** This report assesses results from climate models participating in the Coupled Model Intercomparison Project Phase 6 (CMIP6) of the World Climate Research Programme. These models include new and better representation of physical, chemical and biological processes, as well as higher resolution, compared to climate models considered in previous IPCC assessment reports. This has improved the simulation of the recent mean state of most large-scale indicators of climate change and many other aspects across the climate system. Some differences from observations remain, for example in regional precipitation patterns. The CMIP6 historical simulations assessed in this report have an ensemble mean global surface temperature change within 0.2°C of the observations over most of the historical period, and observed warming is within the *very likely* range of the CMIP6 ensemble. However, some CMIP6 models simulate a warming that is either above or below the assessed *very likely* range of observed warming.
{1.5, Cross-Chapter Box 2.2, 3.3, 3.8, TS.1.2, Cross-Section Box TS.1} (Figure SPM.1 b, Figure SPM.2)

**Box SPM.1.3:** The CMIP6 models considered in this Report have a wider range of climate sensitivity than in CMIP5 models and the AR6 assessed *very likely* range, which is based on multiple lines of evidence. These CMIP6 models also show a higher average climate sensitivity than CMIP5 and the AR6 assessed best estimate. The higher CMIP6 climate sensitivity values compared to CMIP5 can be traced to an amplifying cloud feedback that is larger in CMIP6 by about 20%.
{Box 7.1, 7.3, 7.4, 7.5, TS.3.2}

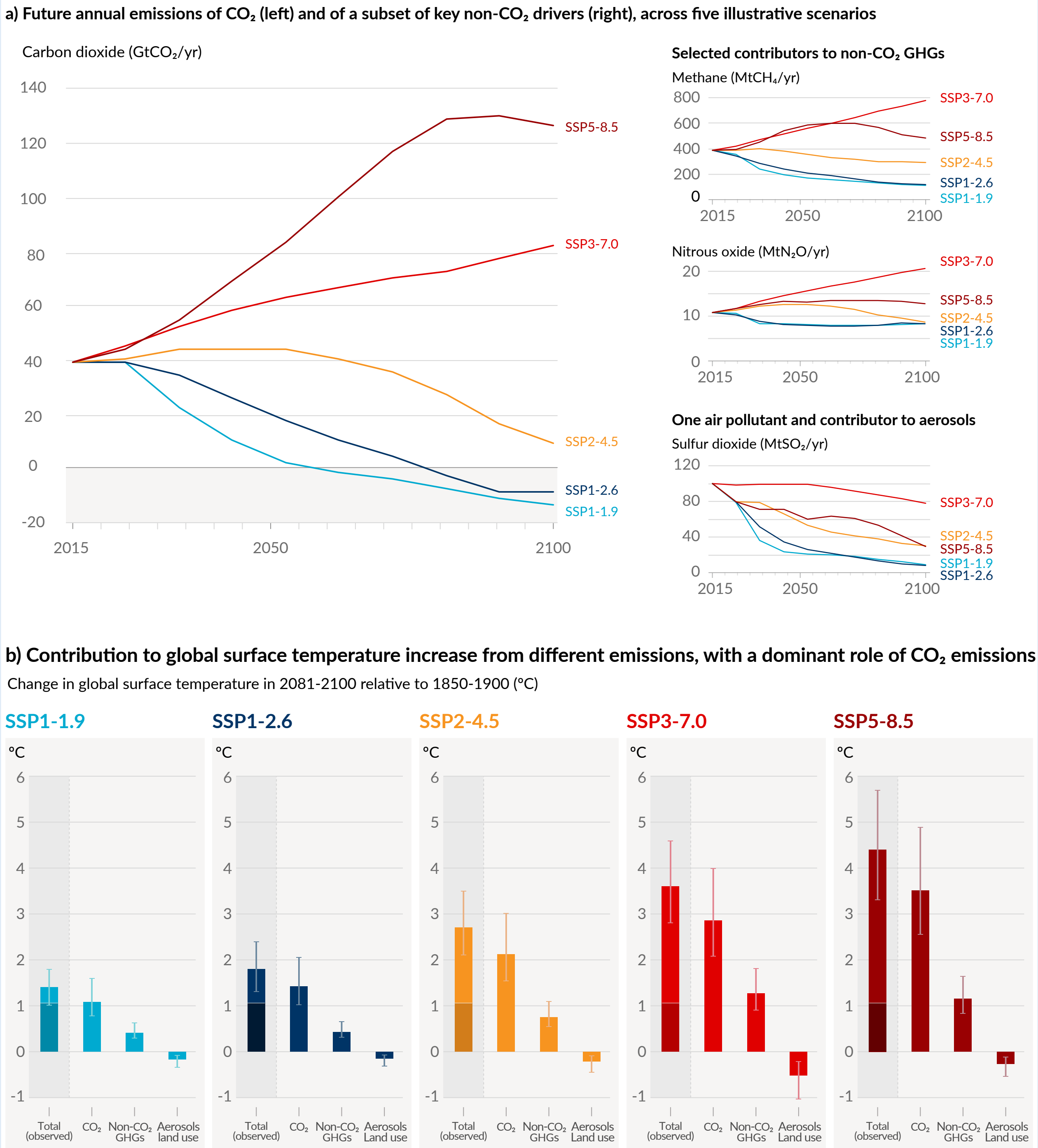
**Box SPM.1.4:** For the first time in an IPCC report, assessed future changes in global surface temperature, ocean warming and sea level are constructed by combining multi-model projections with observational constraints based on past simulated warming, as well as the AR6 assessment of climate sensitivity. For other quantities, such robust methods do not yet exist to constrain the projections. Nevertheless, robust projected

[22] Throughout this report, the five illustrative scenarios are referred to as SSPx-y, where 'SSPx' refers to the Shared Socio-economic Pathway or 'SSP' describing the socio-economic trends underlying the scenario, and 'y' refers to the approximate level of radiative forcing (in W $m^{-2}$) resulting from the scenario in the year 2100. A detailed comparison to scenarios used in earlier IPCC reports is provided in Section TS1.3 and 1.6 and 4.6. The SSPs that underlie the specific forcing scenarios used to drive climate models are not assessed by WGI. Rather, the SSPx-y labelling ensures traceability to the underlying literature in which specific forcing pathways are used as input to the climate models. IPCC is neutral with regard to the assumptions underlying the SSPs, which do not cover all possible scenarios. Alternative scenarios may be considered or developed.

[23] Net negative $CO_2$ emissions are reached when anthropogenic removals of $CO_2$ exceed anthropogenic emissions. {Glossary}

geographical patterns of many variables can be identified at a given level of global warming, common to all scenarios considered and independent of timing when the global warming level is reached. {1.6, Box 4.1, 4.3, 4.6, 7.5, 9.2, 9.6, Cross-Chapter Box 11.1, Cross-Section Box TS.1}

## Future emissions cause future additional warming, with total warming dominated by past and future $CO_2$ emissions




Total warming (observed warming to date in darker shade), warming from $CO_2$, warming from non-$CO_2$ GHGs and cooling from changes in aerosols and land use

**Figure SPM.4: Future anthropogenic emissions of key drivers of climate change and warming contributions by groups of drivers for the five illustrative scenarios used in this report.**

The five scenarios are SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5.

**Panel a) Annual anthropogenic (human-caused) emissions over the 2015–2100 period.** Shown are emissions trajectories for carbon dioxide ($CO_2$) from all sectors ($GtCO_2$/yr) (left graph) and for a subset of three key non-$CO_2$ drivers considered in the scenarios: methane ($CH_4$, $MtCH_4$/yr, top-right graph), nitrous oxide ($N_2O$, $MtN_2O$/yr, middle-right graph) and sulfur dioxide ($SO_2$, $MtSO_2$/yr, bottom-right graph, contributing to anthropogenic aerosols in panel b).

**Panel b) Warming contributions by groups of anthropogenic drivers and by scenario are shown as change in global surface temperature** (°C) in 2081–2100 relative to 1850–1900, with indication of the observed warming to date. Bars and whiskers represent median values and the *very likely* range, respectively. Within each scenario bar plot, the bars represent total global warming (°C; total bar) (see Table SPM.1) and warming contributions (°C) from changes in $CO_2$ ($CO_2$ bar), from non-$CO_2$ greenhouse gases (non-$CO_2$ GHGs bar; comprising well-mixed greenhouse gases and ozone) and net cooling from other anthropogenic drivers (aerosols and land-use bar; anthropogenic aerosols, changes in reflectance due to land-use and irrigation changes, and contrails from aviation; see Figure SPM.2, panel c, for the warming contributions to date for individual drivers). The best estimate for observed warming in 2010–2019 relative to 1850–1900 (see Figure SPM.2, panel a) is indicated in the darker column in the total bar. Warming contributions in panel b are calculated as explained in Table SPM.1 for the total bar. For the other bars the contribution by groups of drivers are calculated with a physical climate emulator of global surface temperature which relies on climate sensitivity and radiative forcing assessments.

{Cross-Chapter Box 1.4, 4.6, Figure 4.35, 6.7, Figure 6.18, 6.22 and 6.24, Cross-Chapter Box 7.1, 7.3, Figure 7.7, Box TS.7, Figures TS.4 and TS.15}

## B.1 Global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered. Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in $CO_2$ and other greenhouse gas emissions occur in the coming decades.

{2.3, Cross-Chapter Box 2.3, Cross-Chapter Box 2.4, 4.3, 4.4, 4.5} **(Figure SPM.1, Figure SPM.4, Figure SPM.8, Table SPM.1, Box SPM.1)**

**B.1.1** Compared to 1850–1900, global surface temperature averaged over 2081–2100 is *very likely* to be higher by 1.0°C to 1.8°C under the very low GHG emissions scenario considered (SSP1-1.9), by 2.1°C to 3.5°C in the intermediate scenario (SSP2-4.5) and by 3.3°C to 5.7°C under the very high GHG emissions scenario (SSP5-8.5)[24]. The last time global surface temperature was sustained at or above 2.5°C higher than 1850–1900 was over 3 million years ago (*medium confidence*).
{2.3, Cross-Chapter Box 2.4, 4.3, 4.5, Box TS.2, Box TS.4, Cross-Section Box TS.1} **(Table SPM.1)**

**Table SPM.1:** Changes in global surface temperature, which are assessed based on multiple lines of evidence, for selected 20-year time periods and the five illustrative emissions scenarios considered. Temperature differences relative to the average global surface temperature of the period 1850–1900 are reported in °C. This includes the revised assessment of observed historical warming for the AR5 reference period 1986–2005, which in AR6 is higher by 0.08 [–0.01 to 0.12] °C than in the AR5 (see footnote 10). Changes relative to the recent reference period 1995–2014 may be calculated approximately by subtracting 0.85°C, the best estimate of the observed warming from 1850–1900 to 1995–2014. {Cross-Chapter Box 2.3, 4.3, 4.4, Cross-Section Box TS.1}

[24] Changes in global surface temperature are reported as running 20-year averages, unless stated otherwise.

| | **Near term, 2021–2040** | | **Mid-term, 2041–2060** | | **Long term, 2081–2100** | |
|---|---|---|---|---|---|---|
| **Scenario** | Best estimate (°C) | *Very likely* range (°C) | Best estimate (°C) | *Very likely* range (°C) | Best estimate (°C) | *Very likely* range (°C) |
| **SSP1-1.9** | 1.5 | 1.2 to 1.7 | 1.6 | 1.2 to 2.0 | 1.4 | 1.0 to 1.8 |
| **SSP1-2.6** | 1.5 | 1.2 to 1.8 | 1.7 | 1.3 to 2.2 | 1.8 | 1.3 to 2.4 |
| **SSP2-4.5** | 1.5 | 1.2 to 1.8 | 2.0 | 1.6 to 2.5 | 2.7 | 2.1 to 3.5 |
| **SSP3-7.0** | 1.5 | 1.2 to 1.8 | 2.1 | 1.7 to 2.6 | 3.6 | 2.8 to 4.6 |
| **SSP5-8.5** | 1.6 | 1.3 to 1.9 | 2.4 | 1.9 to 3.0 | 4.4 | 3.3 to 5.7 |

**B.1.2** Based on the assessment of multiple lines of evidence, global warming of 2°C, relative to 1850–1900, would be exceeded during the 21st century under the high and very high GHG emissions scenarios considered in this report (SSP3-7.0 and SSP5-8.5, respectively). Global warming of 2°C would *extremely likely* be exceeded in the intermediate scenario (SSP2-4.5). Under the very low and low GHG emissions scenarios, global warming of 2°C is *extremely unlikely* to be exceeded (SSP1-1.9), or *unlikely* to be exceeded (SSP1-2.6)[25]. Crossing the 2°C global warming level in the mid-term period (2041–2060) is *very likely* to occur under the very high GHG emissions scenario (SSP5-8.5), *likely* to occur under the high GHG emissions scenario (SSP3-7.0), and *more likely than not* to occur in the intermediate GHG emissions scenario (SSP2-4.5)[26].
{4.3, Cross-Section Box TS.1} **(Table SPM.1, Figure SPM.4, Box SPM.1)**

**B.1.3** Global warming of 1.5°C relative to 1850-1900 would be exceeded during the 21st century under the intermediate, high and very high scenarios considered in this report (SSP2-4.5, SSP3-7.0 and SSP5-8.5, respectively). Under the five illustrative scenarios, in the near term (2021-2040), the 1.5°C global warming level is *very likely* to be exceeded under the very high GHG emissions scenario (SSP5-8.5), *likely* to be exceeded under the intermediate and high GHG emissions scenarios (SSP2-4.5 and SSP3-7.0), *more likely than not* to be exceeded under the low GHG emissions scenario (SSP1-2.6) and *more likely than not* to be reached under the very low GHG emissions scenario (SSP1-1.9)[27]. Furthermore, for the very low GHG emissions scenario (SSP1-1.9), it is *more likely than not* that global surface temperature would decline back to below 1.5°C toward the end of the 21st century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming.
{4.3, Cross-Section Box TS.1} **(Table SPM.1, Figure SPM.4)**

[25] SSP1-1.9 and SSP1-2.6 are scenarios that start in 2015 and have very low and low GHG emissions and $CO_2$ emissions declining to net zero around or after 2050, followed by varying levels of net negative $CO_2$ emissions.

[26] Crossing is defined here as having the assessed global surface temperature change, averaged over a 20-year period, exceed a particular global warming level.

[27] The AR6 assessment of when a given global warming level is first exceeded benefits from the consideration of the illustrative scenarios, the multiple lines of evidence entering the assessment of future global surface temperature response to radiative forcing, and the improved estimate of historical warming. The AR6 assessment is thus not directly comparable to the SR1.5 SPM, which reported likely reaching 1.5°C global warming between 2030 and 2052, from a simple linear extrapolation of warming rates of the recent past. When considering scenarios similar to SSP1-1.9 instead of linear extrapolation, the SR1.5 estimate of when 1.5°C global

**B.1.4** Global surface temperature in any single year can vary above or below the long-term human-induced trend, due to substantial natural variability[28]. The occurrence of individual years with global surface temperature change above a certain level, for example 1.5°C or 2ºC, relative to 1850–1900 does not imply that this global warming level has been reached[29].
{Cross-Chapter Box 2.3, 4.3, 4.4, Box 4.1, Cross-Section Box TS.1} **(Table SPM.1, Figure SPM.1, Figure SPM.8)**

**B.2 Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover and permafrost.** {4.3, 4.5, 4.6, 7.4, 8.2, 8.4, Box 8.2, 9.3, 9.5, Box 9.2, 11.1, 11.2, 11.3, 11.4, 11.6, 11.7, 11.9, Cross-Chapter Box 11.1, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11} **(Figure SPM.5, Figure SPM.6, Figure SPM.8)**

**B.2.1** It is *virtually certain* that the land surface will continue to warm more than the ocean surface (*likely* 1.4 to 1.7 times more). It is *virtually certain* that the Arctic will continue to warm more than global surface temperature, with *high confidence* above two times the rate of global warming.
{2.3, 4.3, 4.5, 4.6, 7.4, 11.1, 11.3, 11.9, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, Cross-Section Box TS.1, TS.2.6} **(Figure SPM.5)**

**B.2.2** With every additional increment of global warming, changes in extremes continue to become larger. For example, every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heatwaves (*very likely*), and heavy precipitation (*high confidence*), as well as agricultural and ecological droughts[30] in some regions (*high confidence*). Discernible changes in intensity and frequency of meteorological droughts, with more regions showing increases than decreases, are seen in some regions for every additional 0.5°C of global warming (*medium confidence*). Increases in frequency and intensity of hydrological droughts become larger with increasing global warming in some regions (*medium confidence*). There will be an increasing occurrence of some extreme events unprecedented in the observational record with additional global warming, even at 1.5°C of global warming. Projected percentage changes in frequency are higher for rarer events (*high confidence*).
{8.2, 11.2, 11.3, 11.4, 11.6, 11.9, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1, TS.2.6} **(Figure SPM.5, Figure SPM.6)**

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warming is first exceeded is close to the best estimate reported here.

[28] Natural variability refers to climatic fluctuations that occur without any human influence, that is, internal variability combined with the response to external natural factors such as volcanic eruptions, changes in solar activity and, on longer time scales, orbital effects and plate tectonics.

[29] The internal variability in any single year is estimated to be ± 0.25°C (5–95% range, *high confidence*).

[30] Projected changes in agricultural and ecological droughts are primarily assessed based on total column soil moisture. See footnote 15 for definition and relation to precipitation and evapotranspiration.

**B.2.3** Some mid-latitude and semi-arid regions, and the South American Monsoon region, are projected to see the highest increase in the temperature of the hottest days, at about 1.5 to 2 times the rate of global warming (*high confidence*). The Arctic is projected to experience the highest increase in the temperature of the coldest days, at about 3 times the rate of global warming (*high confidence*). With additional global warming, the frequency of marine heatwaves will continue to increase (*high confidence*), particularly in the tropical ocean and the Arctic *(medium confidence).*
{Box 9.2, 11.1, 11.3, 11.9, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1, 12.4, TS.2.4, TS.2.6} **(Figure SPM.6)**

**B.2.4** It is *very likely* that heavy precipitation events will intensify and become more frequent in most regions with additional global warming. At the global scale, extreme daily precipitation events are projected to intensify by about 7% for each 1°C of global warming (*high confidence*). The proportion of intense tropical cyclones (categories 4-5) and peak wind speeds of the most intense tropical cyclones are projected to increase at the global scale with increasing global warming (*high confidence*).
{8.2, 11.4, 11.7, 11.9, Cross-Chapter Box 11.1, Box TS.6, TS.4.3.1} **(Figure SPM.5, Figure SPM.6)**

**B.2.5** Additional warming is projected to further amplify permafrost thawing, and loss of seasonal snow cover, of land ice and of Arctic sea ice (*high confidence*). The Arctic is *likely* to be practically sea ice free in September[31] at least once before 2050 under the five illustrative scenarios considered in this report, with more frequent occurrences for higher warming levels. There is *low confidence* in the projected decrease of Antarctic sea ice.
{4.3, 4.5, 7.4, 8.2, 8.4, Box 8.2, 9.3, 9.5, 12.4, Cross-Chapter Box 12.1, Atlas.5, Atlas.6, Atlas.8, Atlas.9, Atlas.11, TS.2.5} **(Figure SPM.8)**

[31] monthly average sea ice area of less than 1 million $km^2$ which is about 15% of the average September sea ice area observed in 1979-1988

**With every increment of global warming, changes get larger in regional mean temperature, precipitation and soil moisture**

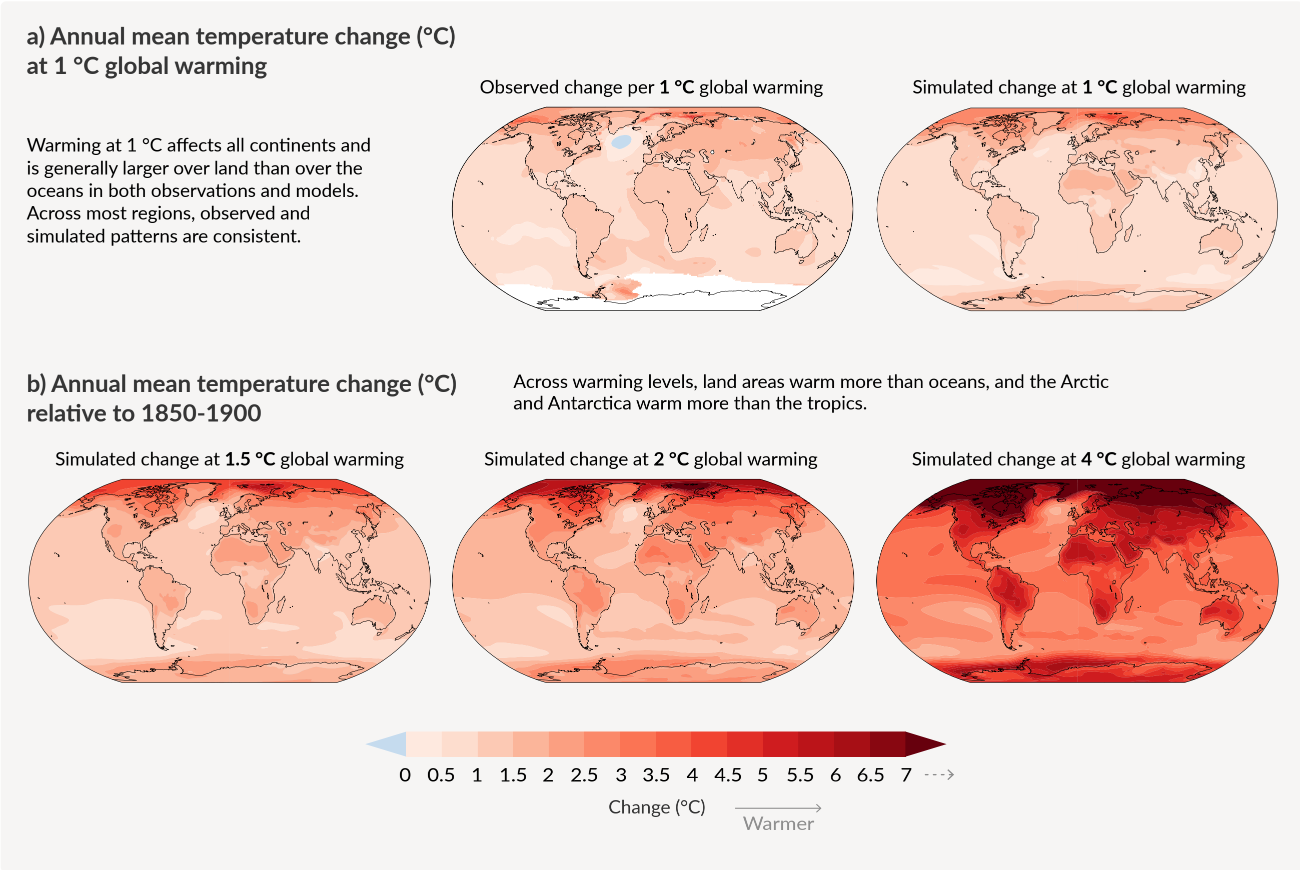
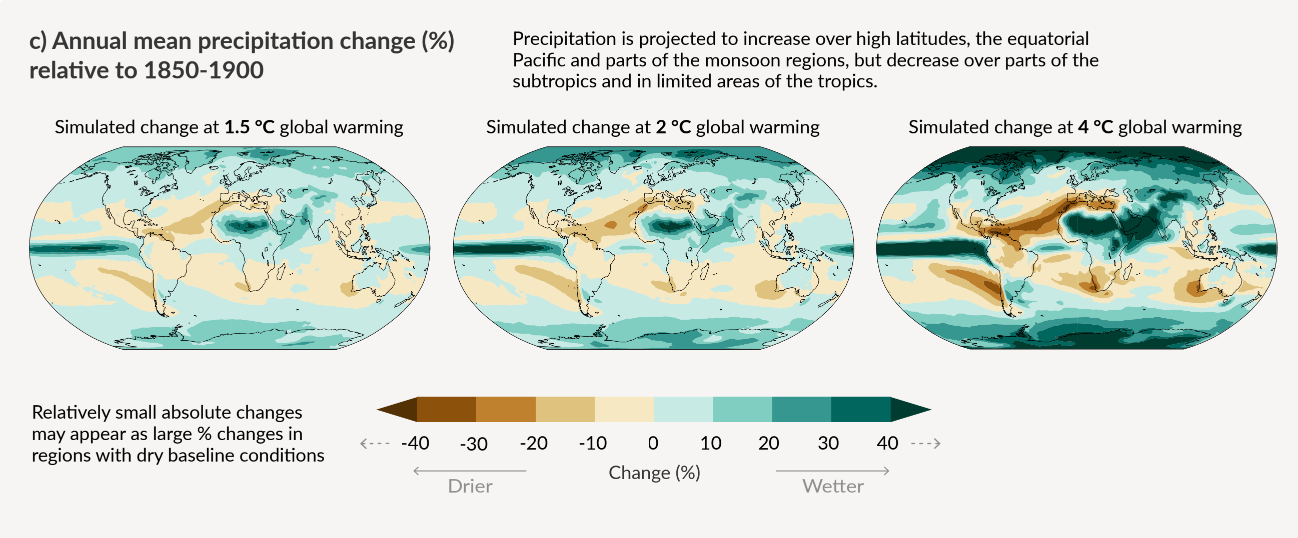
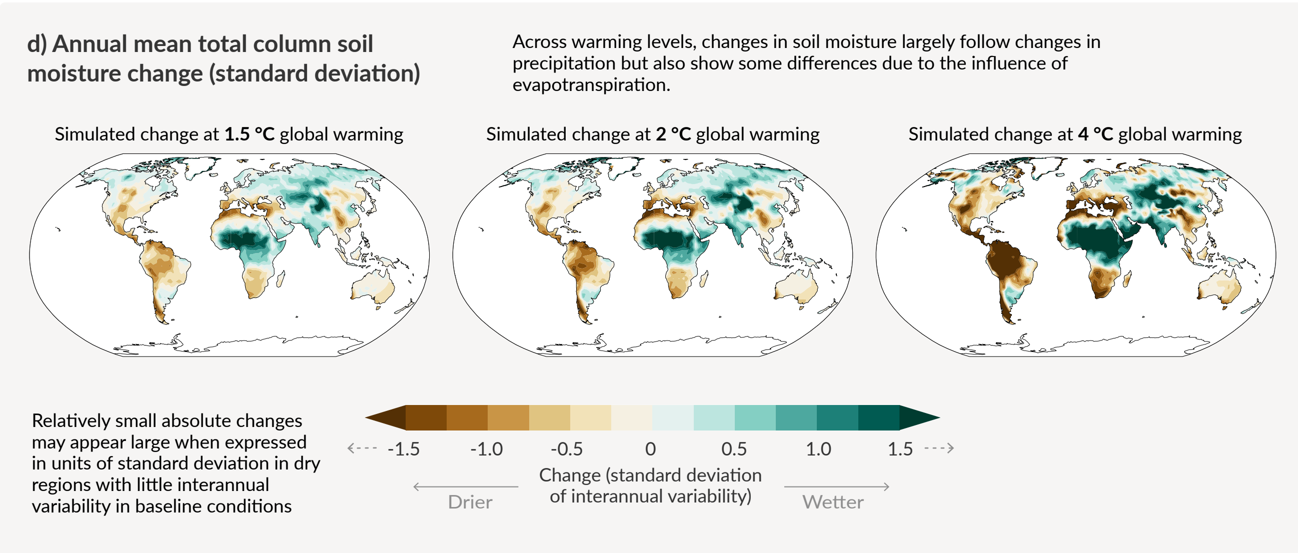



**Figure SPM.5: Changes in annual mean surface temperature, precipitation, and soil moisture.**

**Panel a) Comparison of observed and simulated annual mean surface temperature change.** The **left map** shows the observed changes in annual mean surface temperature in the period of 1850–2020 per °C of global warming (°C). The local (i.e., grid point) observed annual mean surface temperature changes are linearly regressed against the global surface temperature in the period 1850–2020. Observed temperature data are from Berkeley Earth, the dataset with the largest coverage and highest horizontal resolution. Linear regression is applied to all years for which data at the corresponding grid point is available. The regression method was used to take into account the complete observational time series and thereby reduce the role of internal variability at the grid point level. White indicates areas where time coverage was 100 years or less and thereby too short to calculate a reliable linear regression. The **right map** is based on model simulations and shows change in annual multi-model mean simulated temperatures at a global warming level of 1°C (20-year mean global surface temperature change relative to 1850–1900). The triangles at each end of the color bar indicate out-of-bound values, that is, values above or below the given limits.

**Panel b) Simulated annual mean temperature change (°C), panel c) precipitation change (%), and panel d) total column soil moisture change (standard deviation of interannual variability)** at global warming levels of 1.5°C, 2°C and 4°C (20-yr mean global surface temperature change relative to 1850–1900). Simulated changes correspond to CMIP6 multi-model mean change (median change for soil moisture) at the corresponding global warming level, i.e. the same method as for the right map in panel a).




In **panel c),** high positive percentage changes in dry regions may correspond to small absolute changes. In **panel d),** the unit is the standard deviation of interannual variability in soil moisture during 1850–1900. Standard deviation is a widely used metric in characterizing 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. In panel d), large changes in dry regions with little interannual variability in the baseline conditions can correspond to small absolute change. The triangles at each end of the color bars indicate out-of-bound values, that is, values above or below the given limits. Results from all models reaching the corresponding warming level in any of the five illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) are averaged. Maps of annual mean temperature and precipitation changes at a global warming level of 3°C are available in Figure 4.31 and Figure 4.32 in Section 4.6.

Corresponding maps of panels b), c) and d) including hatching to indicate the level of model agreement at grid-cell level are found in Figures 4.31, 4.32 and 11.19, respectively; as highlighted in CC-box Atlas.1, grid-cell level hatching is not informative for larger spatial scales (e.g., over AR6 reference regions) where the aggregated signals are less affected by small-scale variability leading to an increase in robustness.

{TS.1.3.2, Figure TS.3, Figure TS.5, Figure 1.14, 4.6.1, Cross-Chapter Box 11.1, Cross-Chapter Box Atlas.1}

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# Projected changes in extremes are larger in frequency and intensity with every additional increment of global warming

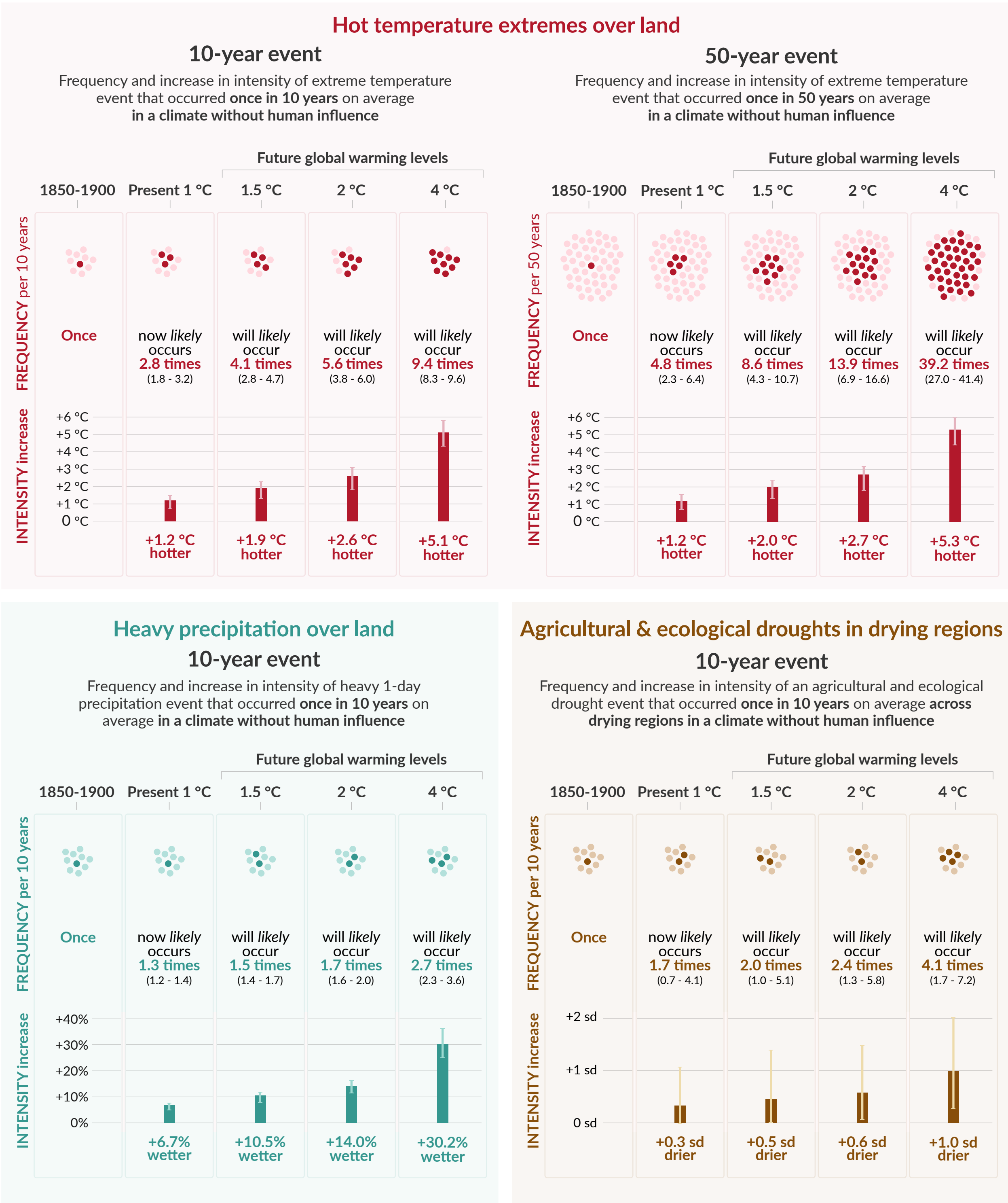


**Figure SPM.6: Projected changes in the intensity and frequency of hot temperature extremes over land, extreme precipitation over land, and agricultural and ecological droughts in drying regions.**

Projected changes are shown at global warming levels of 1°C, 1.5°C, 2°C, and 4°C and are relative to 1850-1900[9] representing a climate without human influence. The figure depicts frequencies and increases in intensity of 10- or 50-year extreme events from the base period (1850-1900) under different global warming levels.
**Hot temperature extremes** are defined as the daily maximum temperatures over land that were exceeded on average once in a decade (10-year event) or once in 50 years (50-year event) during the 1850–1900 reference period. **Extreme precipitation events** are defined as the daily precipitation amount over land that was exceeded on average once in a decade during the 1850–1900 reference period. **Agricultural and ecological drought events** are defined as the annual average of total column soil moisture below the 10th percentile of the 1850–1900 base period. These extremes are defined on model grid box scale. For hot temperature extremes and extreme precipitation, results are shown for the global land. For agricultural and ecological drought, results are shown for drying regions only, which correspond to the AR6 regions in which there is at least *medium confidence* in a projected increase in agricultural/ecological drought at the 2°C warming level compared to the 1850–1900 base period in CMIP6. These regions include W. North-America, C. North-America, N. Central-America, S. Central-America, Caribbean, N. South-America, N.E. South-America, South-American-Monsoon, S.W. South-America, S. South-America, West & Central-Europe, Mediterranean, W. Southern-Africa, E. Southern-Africa, Madagascar, E. Australia, S. Australia (Caribbean is not included in the calculation of the figure because of the too small number of full land grid cells). The non-drying regions do not show an overall increase or decrease in drought severity. Projections of changes in agricultural and ecological droughts in the CMIP5 multi-model ensemble differ from those in CMIP6 in some regions, including in part of Africa and Asia. Assessments on projected changes in meteorological and hydrological droughts are provided in Chapter 11. {11.6, 11.9}

In the **'frequency' section,** each year is represented by a dot. The dark dots indicate years in which the extreme threshold is exceeded, while light dots are years when the threshold is not exceeded. Values correspond to the medians (in bold) and their respective 5–95% range based on the multi-model ensemble from simulations of CMIP6 under different SSP scenarios. For consistency, the number of dark dots is based on the rounded-up median. In the **'intensity' section,** medians and their 5–95% range, also based on the multi-model ensemble from simulations of CMIP6, are displayed as dark and light bars, respectively. Changes in the intensity of hot temperature extremes and extreme precipitations are expressed as degree Celsius and percentage. As for agricultural and ecological drought, intensity changes are expressed as fractions of standard deviation of annual soil moisture.

{11.1, 11.3, 11.4, 11.6, Figure 11.12, Figure 11.15, Figure 11.6, Figure 11.7, Figure 11.18}

## B.3 Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events.

{4.3, 4.4, 4.5, 4.6, 8.2, 8.3, 8.4, 8.5, Box 8.2, 11.4, 11.6, 11.9, 12.4, Atlas.3} **(Figure SPM.5, Figure SPM.6)**

**B.3.1** There is strengthened evidence since AR5 that the global water cycle will continue to intensify as global temperatures rise (*high confidence*), with precipitation and surface water flows projected to become more variable over most land regions within seasons (*high confidence*) and from year to year (*medium confidence*). The average annual global land precipitation is projected to increase by 0–5% under the very low GHG emissions scenario (SSP1-1.9), 1.5-8% for the intermediate GHG emissions scenario (SSP2-4.5) and 1–13% under the very high GHG emissions scenario (SSP5-8.5) by 2081–2100 relative to 1995-2014 (*likely* ranges). Precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and limited areas in the tropics in SSP2-4.5, SSP3-7.0 and SSP5-8.5 (*very likely*). The portion of the global land experiencing detectable increases or decreases in seasonal mean precipitation is projected to increase (*medium confidence*). There is *high confidence* in an earlier onset of spring snowmelt, with higher peak flows at the expense of summer flows in snow-dominated regions globally.
{4.3, 4.5, 4.6, 8.2, 8.4, Atlas.3, TS.2.6, Box TS.6, TS.4.3} **(Figure SPM.5)**

**B.3.2** A warmer climate will intensify very wet and very dry weather and climate events and seasons, with implications for flooding or drought (*high confidence*), but the location and frequency of these events depend on projected changes in regional atmospheric circulation, including monsoons and mid-latitude storm tracks. It is *very likely* that rainfall variability related to the El Niño–Southern Oscillation is projected to be amplified by the second half of the 21st century in the SSP2-4.5, SSP3-7.0 and SSP5-8.5 scenarios.
{4.3, 4.5, 4.6, 8.2, 8.4, 8.5, 11.4, 11.6, 11.9, 12.4, TS.2.6, TS.4.2, Box TS.6} **(Figure SPM.5, Figure SPM.6)**

**B.3.3** Monsoon precipitation is projected to increase in the mid- to long term at global scale, particularly over South and Southeast Asia, East Asia and West Africa apart from the far west Sahel (*high confidence*). The monsoon season is projected to have a delayed onset over North and South America and West Africa (*high confidence*) and a delayed retreat over West Africa (*medium confidence*).
{4.4, 4.5, 8.2, 8.3, 8.4, Box 8.2, Box TS.13}

**B.3.4** A projected southward shift and intensification of Southern Hemisphere summer mid-latitude storm tracks and associated precipitation is *likely* in the long term under high GHG emissions scenarios (SSP3-7.0, SSP5-8.5), but in the near term the effect of stratospheric ozone recovery counteracts these changes (*high confidence*). There is *medium confidence* in a continued poleward shift of storms and their precipitation in the North Pacific, while there is *low confidence* in projected changes in the North Atlantic storm tracks.
{TS.4.2, 4.4, 4.5, 8.4, TS.2.3}

## B.4 Under scenarios with increasing $CO_2$ emissions, the ocean and land carbon sinks are projected to be less effective at slowing the accumulation of $CO_2$ in the atmosphere.

{4.3, 5.2, 5.4, 5.5, 5.6} **(Figure SPM.7)**

**B.4.1** While natural land and ocean carbon sinks are projected to take up, in absolute terms, a progressively larger amount of $CO_2$ under higher compared to lower $CO_2$ emissions scenarios, they become less effective, that is, the proportion of emissions taken up by land and ocean decrease with increasing cumulative $CO_2$ emissions. This is projected to result in a higher proportion of emitted $CO_2$ remaining in the atmosphere (*high confidence*).
{5.2, 5.4, Box TS.5} **(Figure SPM.7)**

**B.4.2** Based on model projections, under the intermediate scenario that stabilizes atmospheric $CO_2$ concentrations this century (SSP2-4.5), the rates of $CO_2$ taken up by the land and oceans are projected to decrease in the second half of the 21st century (*high confidence*). Under the very low and low GHG emissions scenarios (SSP1-1.9, SSP1-2.6), where $CO_2$ concentrations peak and decline during the 21st century, land and oceans begin to take up less carbon in response to declining atmospheric $CO_2$ concentrations (*high confidence*) and turn into a weak net source by 2100 under SSP1-1.9 (*medium confidence*). It is *very unlikely* that the combined global land and ocean sink will turn into a source by 2100 under scenarios without net negative emissions[32] (SSP2-4.5, SSP3-7.0, SSP5-8.5).
{4.3, 5.4, 5.5, 5.6, Box TS.5, TS.3.3}

**B.4.3** The magnitude of feedbacks between climate change and the carbon cycle becomes larger but also more uncertain in high $CO_2$ emissions scenarios (*very high confidence*). However, climate model projections show that the uncertainties in atmospheric $CO_2$ concentrations by 2100 are dominated by the differences between emissions scenarios (*high confidence*). Additional ecosystem responses to warming not yet fully included in climate models, such as $CO_2$ and $CH_4$ fluxes from wetlands, permafrost thaw and wildfires, would further increase concentrations of these gases in the atmosphere (*high confidence*).
{5.4, Box TS.5, TS.3.2}

[32] These projected adjustments of carbon sinks to stabilization or decline of atmospheric $CO_2$ are accounted for in calculations of remaining carbon budgets.

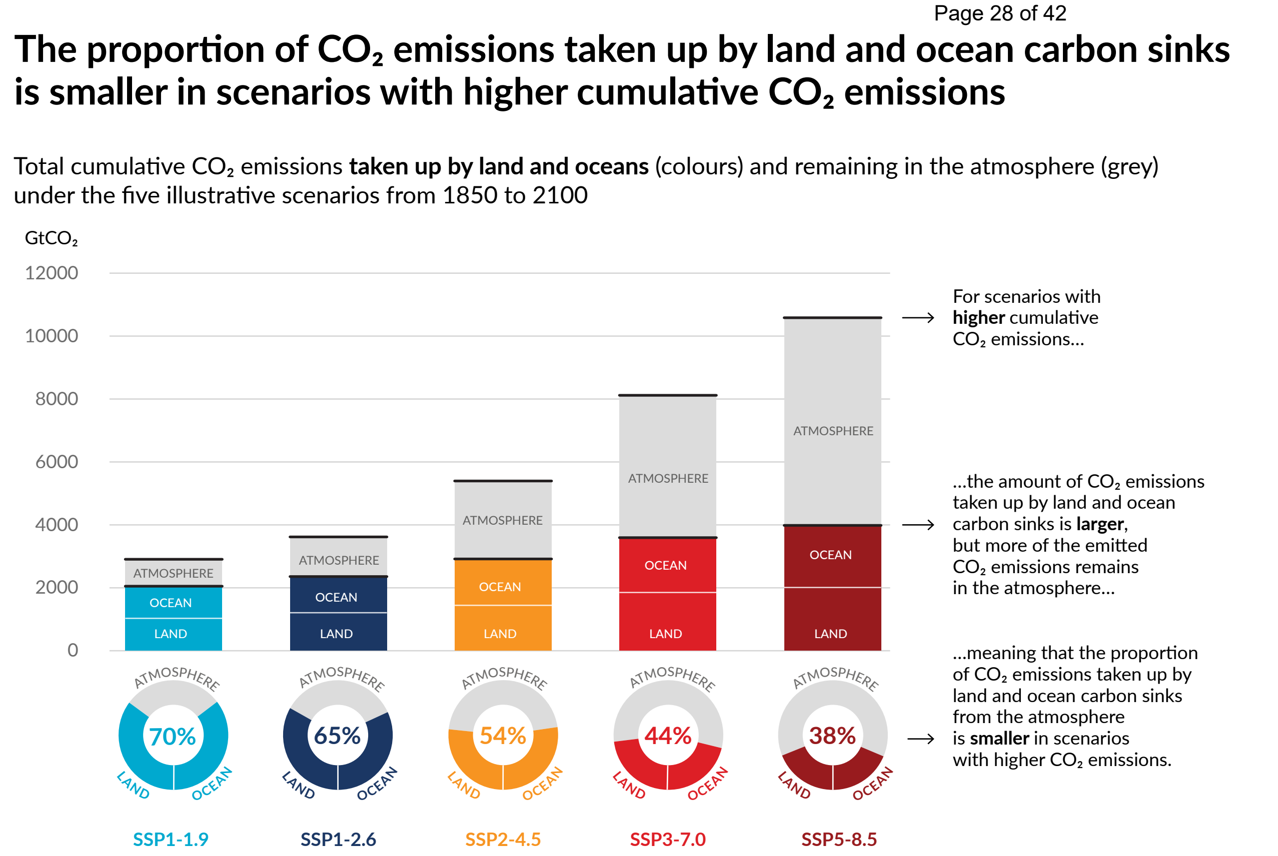



**Figure SPM.7: Cumulative anthropogenic CO2 emissions taken up by land and ocean sinks by 2100 under the five illustrative scenarios.**

The cumulative anthropogenic (human-caused) carbon dioxide ($CO_2$) emissions taken up by the land and ocean sinks under the five illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) are simulated from 1850 to 2100 by CMIP6 climate models in the concentration-driven simulations. Land and ocean carbon sinks respond to past, current and future emissions, therefore cumulative sinks from 1850 to 2100 are presented here. During the historical period (1850-2019) the observed land and ocean sink took up 1430 $GtCO_2$ (59% of the emissions).

The **bar chart** illustrates the projected amount of cumulative anthropogenic $CO_2$ emissions ($GtCO_2$) between 1850 and 2100 remaining in the atmosphere (grey part) and taken up by the land and ocean (coloured part) in the year 2100. The **doughnut chart** illustrates the proportion of the cumulative anthropogenic $CO_2$ emissions taken up by the land and ocean sinks and remaining in the atmosphere in the year 2100. Values in % indicate the proportion of the cumulative anthropogenic $CO_2$ emissions taken up by the combined land and ocean sinks in the year 2100. The overall anthropogenic carbon emissions are calculated by adding the net global land use emissions from CMIP6 scenario database to the other sectoral emissions calculated from climate model runs with prescribed $CO_2$ concentrations[33]. Land and ocean $CO_2$ uptake since 1850 is calculated from the net biome productivity on land, corrected for $CO_2$ losses due to land-use change by adding the land-use change emissions, and net ocean $CO_2$ flux.

{Box TS.5, Box TS.5, Figure 1, 5.2.1, Table 5.1, 5.4.5, Figure 5.25}

[33] The other sectoral emissions are calculated as the residual of the net land and ocean $CO_2$ uptake and the prescribed atmospheric $CO_2$ concentration changes in the CMIP6 simulations. These calculated emissions are net emissions and do not separate gross anthropogenic emissions from removals, which are included implicitly.

## B.5 Many changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets and global sea level.
{Cross-Chapter Box 2.4, 2.3, 4.3, 4.5, 4.7, 5.3, 9.2, 9.4, 9.5, 9.6, Box 9.4} **(Figure SPM.8)**

**B.5.1** Past GHG emissions since 1750 have committed the global ocean to future warming (*high confidence*). Over the rest of the 21st century, *likely* ocean warming ranges from 2–4 (SSP1-2.6) to 4–8 times (SSP5-8.5) the 1971–2018 change. Based on multiple lines of evidence, upper ocean stratification (*virtually certain*), ocean acidification (*virtually certain*) and ocean deoxygenation (*high confidence*) will continue to increase in the 21st century, at rates dependent on future emissions. Changes are irreversible on centennial to millennial time scales in global ocean temperature (*very high confidence*), deep ocean acidification (*very high confidence*) and deoxygenation (*medium confidence*).
{4.3, 4.5, 4.7, 5.3, 9.2, TS.2.4} **(Figure SPM.8)**

**B.5.2** Mountain and polar glaciers are committed to continue melting for decades or centuries (*very high confidence*). Loss of permafrost carbon following permafrost thaw is irreversible at centennial timescales (*high confidence*). Continued ice loss over the 21st century is *virtually certain* for the Greenland Ice Sheet and *likely* for the Antarctic Ice Sheet. There is *high confidence* that total ice loss from the Greenland Ice Sheet will increase with cumulative emissions. There is *limited evidence* for low-likelihood, high-impact outcomes (resulting from ice sheet instability processes characterized by deep uncertainty and in some cases involving tipping points) that would strongly increase ice loss from the Antarctic Ice Sheet for centuries under high GHG emissions scenarios[34]. {4.3, 4.7, 5.4, 9.4, 9.5, Box 9.4, Box TS.1, TS.2.5}

**B.5.3** It is *virtually certain* that global mean sea level will continue to rise over the 21st century. Relative to 1995-2014, the *likely* global mean sea level rise by 2100 is 0.28-0.55 m under the very low GHG emissions scenario (SSP1-1.9), 0.32-0.62 m under the low GHG emissions scenario (SSP1-2.6), 0.44-0.76 m under the intermediate GHG emissions scenario (SSP2-4.5), and 0.63-1.01 m under the very high GHG emissions scenario (SSP5-8.5), and by 2150 is 0.37-0.86 m under the very low scenario (SSP1-1.9), 0.46-0.99 m under the low scenario (SSP1-2.6), 0.66-1.33 m under the intermediate scenario (SSP2-4.5), and 0.98-1.88 m under the very high scenario (SSP5-8.5) (*medium confidence*)[35]. Global mean sea level rise above the *likely* range – approaching 2 m by 2100 and 5 m by 2150 under a very high GHG emissions scenario (SSP5-8.5) (*low confidence*) – cannot be ruled out due to deep uncertainty in ice sheet processes.
{4.3, 9.6, Box 9.4, Box TS.4} **(Figure SPM.8)**

**B.5.4** In the longer term, sea level is committed to rise for centuries to millennia due to continuing deep ocean warming and ice sheet melt, and will remain elevated for thousands of years (*high confidence*). Over the next 2000 years, global mean sea level will rise by about 2 to 3 m if warming is limited to 1.5°C, 2 to 6 m if limited to 2°C and 19 to 22 m with 5°C of warming, and it will continue to rise over subsequent millennia (*low confidence*). Projections of multi-millennial global mean sea level rise are consistent with reconstructed levels during past warm climate periods: *likely* 5–10 m higher than today around 125,000 years ago, when global temperatures were *very likely* 0.5°C–1.5°C higher than 1850–1900; and *very likely* 5–25 m higher roughly 3 million years ago, when global temperatures were 2.5°C–4°C higher (*medium confidence*).
{2.3, Cross-Chapter Box 2.4, 9.6, Box TS.2, Box TS.4, Box TS.9}

[34] Low-likelihood, high-impact outcomes are those whose probability of occurrence is low or not well known (as in the context of deep uncertainty) but whose potential impacts on society and ecosystems could be high. A tipping point is a critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly. {Cross-Chapter Box 1.3, 1.4, 4.7}

[35] To compare to the 1986–2005 baseline period used in AR5 and SROCC, add 0.03 m to the global mean sea level rise estimates. To compare to the 1900 baseline period used in Figure SPM.8, add 0.16 m.

## Human activities affect all the major climate system components, with some responding over decades and others over centuries

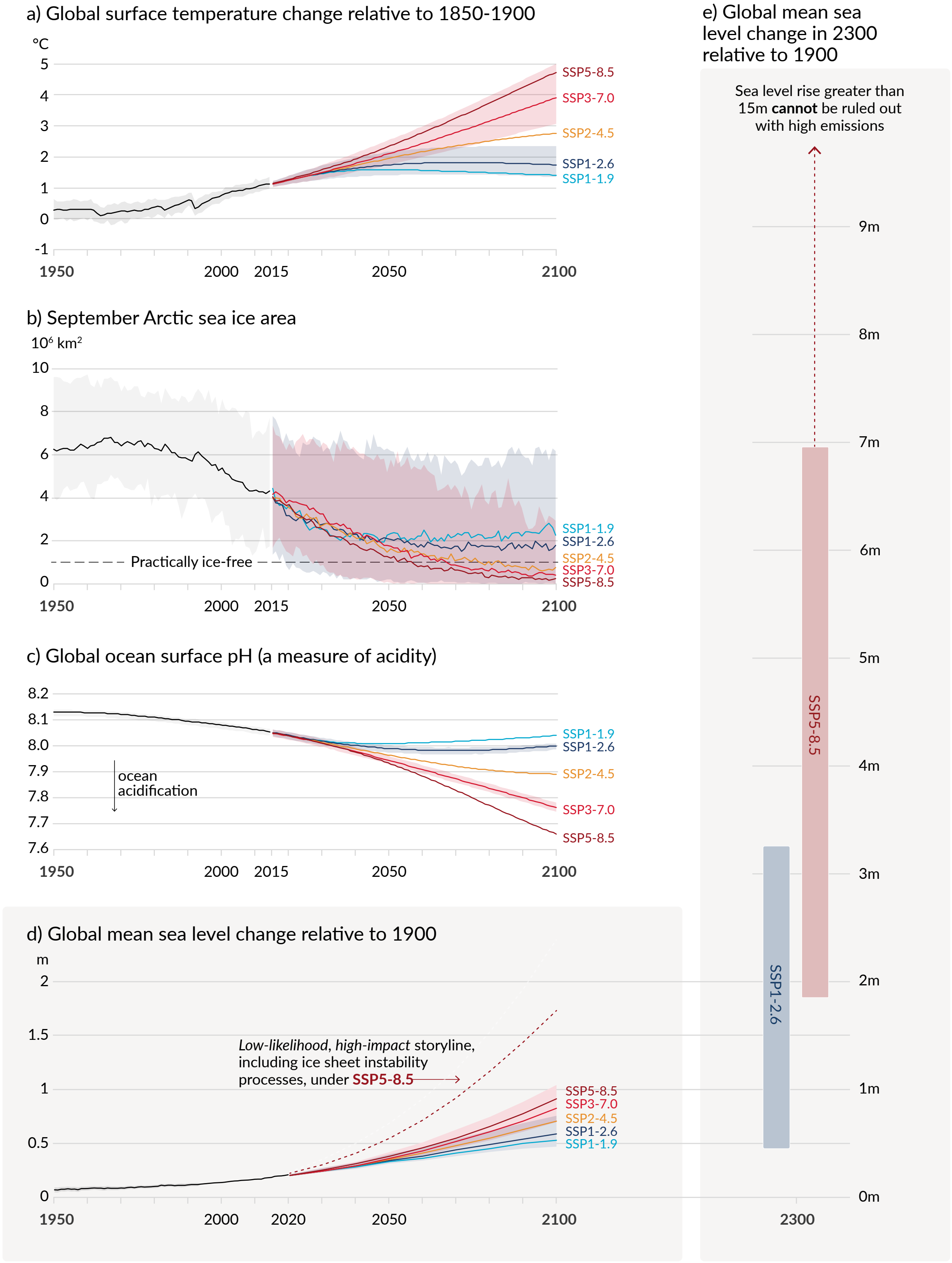


**Figure SPM.8: Selected indicators of global climate change under the five illustrative scenarios used in this report.**

The projections for each of the five scenarios are shown in colour. Shades represent uncertainty ranges – more detail is provided for each panel below. The black curves represent the historical simulations (panels a, b, c) or the observations (panel d). Historical values are included in all graphs to provide context for the projected future changes.

**Panel a) 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 (see Box SPM.1). Changes relative to 1850–1900 based on 20-year averaging periods are calculated by adding 0.85°C (the observed global surface temperature increase from 1850–1900 to 1995–2014) to simulated changes relative to 1995–2014. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0.

**Panel b) September Arctic sea ice area** in $10^6$ $km^2$ based on CMIP6 model simulations. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0. The Arctic is projected to be practically ice-free near mid-century under mid- and high GHG emissions scenarios.

**Panel c) Global ocean surface pH** (a measure of acidity) based on CMIP6 model simulations. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0.

**Panel d) Global mean sea level change** in meters relative to 1900. The historical changes are observed (from tide gauges before 1992 and altimeters afterwards), and the future changes are assessed consistently with observational constraints based on emulation of CMIP, ice sheet, and glacier models. *Likely* ranges are shown for SSP1-2.6 and SSP3-7.0. Only *likely* ranges are assessed for sea level changes due to difficulties in estimating the distribution of deeply uncertain processes. The dashed curve indicates the potential impact of these deeply uncertain processes. It shows the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice sheet processes that cannot be ruled out; because of *low confidence* in projections of these processes, this curve does not constitute part of a *likely* range. Changes relative to 1900 are calculated by adding 0.158 m (observed global mean sea level rise from 1900 to 1995–2014) to simulated and observed changes relative to 1995–2014.

**Panel e): Global mean sea level change at 2300** in meters relative to 1900. Only SSP1-2.6 and SSP5-8.5 are projected at 2300, as simulations that extend beyond 2100 for the other scenarios are too few for robust results. The 17th–83rd percentile ranges are shaded. The dashed arrow illustrates the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice sheet processes that cannot be ruled out.

Panels b) and c) are based on single simulations from each model, and so include a component of internal variability. Panels a), d) and e) are based on long-term averages, and hence the contributions from internal variability are small.

{Figure TS.8, Figure TS.11, Box TS.4 Figure 1, Box TS.4 Figure 1, 4.3, 9.6, Figure 4.2, Figure 4.8, Figure 4.11, Figure 9.27}

# C. Climate Information for Risk Assessment and Regional Adaptation

*Physical climate information addresses how the climate system responds to the interplay between human influence, natural drivers and internal variability. Knowledge of the climate response and the range of possible outcomes, including low-likelihood, high impact outcomes, informs climate services – the assessment of climate-related risks and adaptation planning. Physical climate information at global, regional and local scales is developed from multiple lines of evidence, including observational products, climate model outputs and tailored diagnostics.*

## C.1 Natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, with little effect on centennial global warming. These modulations are important to consider in planning for the full range of possible changes.

{1.4, 2.2, 3.3, Cross-Chapter Box 3.1, 4.4, 4.6, Cross-Chapter Box 4.1, 4.4, Box 7.2, 8.3, 8.5, 9.2, 10.3, 10.4, 10.6, 11.3, 12.5, Atlas.4, Atlas.5, Atlas.8, Atlas.9, Atlas.10, Cross-Chapter Box Atlas.2, Atlas.11}

**C.1.1** The historical global surface temperature record highlights that decadal variability has enhanced and masked underlying human-caused long-term changes, and this variability will continue into the future (*very high confidence*). For example, internal decadal variability and variations in solar and volcanic drivers partially masked human-caused surface global warming during 1998–2012, with pronounced regional and seasonal signatures (*high confidence*). Nonetheless, the heating of the climate system continued during this period, as reflected in both the continued warming of the global ocean (*very high confidence*) and in the continued rise of hot extremes over land (*medium confidence*).
{1.4, 3.3, Cross-Chapter Box 3.1, 4.4, Box 7.2, 9.2, 11.3, Cross-Section Box TS.1} **(Figure SPM.1)**

**C.1.2** Projected human caused changes in mean climate and climatic impact-drivers (CIDs)[36], including extremes, will be either amplified or attenuated by internal variability[37] (*high confidence*). Near-term cooling at any particular location with respect to present climate could occur and would be consistent with the global surface temperature increase due to human influence (*high confidence*).
{1.4, 4.4, 4.6, 10.4, 11.3, 12.5, Atlas.5, Atlas.10, Atlas.11, TS.4.2}

**C.1.3** Internal variability has largely been responsible for the amplification and attenuation of the observed human-caused decadal-to-multi-decadal mean precipitation changes in many land regions *(high confidence)*. At global and regional scales, near-term changes in monsoons will be dominated by the effects of internal variability (*medium confidence*). In addition to internal variability influence, near-term projected changes in precipitation at global and regional scales are uncertain because of model uncertainty and uncertainty in forcings from natural and anthropogenic aerosols (*medium confidence*).
{1.4, 4.4, 8.3, 8.5, 10.3, 10.4, 10.5, 10.6, Atlas.4, Atlas.8, Atlas.9, Atlas.10, Cross-Chapter Box Atlas.2, Atlas.11, TS.4.2, Box TS.6, Box TS.13}

[36] Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions. CID types include heat and cold, wet and dry, wind, snow and ice, coastal and open ocean.

[37] The main internal variability phenomena include El Niño–Southern Oscillation, Pacific Decadal variability and Atlantic Multi-decadal variability through their regional influence.

**C.1.4** Based on paleoclimate and historical evidence, it is *likely* that at least one large explosive volcanic eruption would occur during the 21st century[38]. Such an eruption would reduce global surface temperature and precipitation, especially over land, for one to three years, alter the global monsoon circulation, modify extreme precipitation and change many CIDs (*medium confidence*). If such an eruption occurs, this would therefore temporarily and partially mask human-caused climate change.
{4.4, Cross-Chapter Box 4.1, 2.2, 8.5, TS.2.1}

## C.2 With further global warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. Changes in several climatic impact-drivers would be more widespread at 2°C compared to 1.5°C global warming and even more widespread and/or pronounced for higher warming levels.

{8.2, 9.3, 9.5, 9.6, Box 10.3, Box 11.3, Box 11.4, 11.3, 11.4, 11.5, 11.6, 11.7, 11.9, 12.2, 12.3, 12.4, 12.5, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1} **(Table SPM.1, Figure SPM.9)**

**C.2.1** All regions[39] are projected to experience further increases in hot climatic impact-drivers (CIDs) and decreases in cold CIDs (*high confidence*). Further decreases are projected in permafrost, snow, glaciers and ice sheets, lake and Arctic sea ice (*medium* to *high confidence*)[40]. These changes would be larger at 2°C global warming or above than at 1.5°C (*high confidence*). For example, extreme heat thresholds relevant to agriculture and health are projected to be exceeded more frequently at higher global warming levels (*high confidence*).
{9.3, 9.5, 11.3, 11.9, 12.3, 12.4, 12.5, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, TS.4.3, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1} **(Table SPM.1, Figure SPM.9)**

**C.2.2** At 1.5°C global warming, heavy precipitation and associated flooding are projected to intensify and be more frequent in most regions in Africa and Asia (*high confidence*), North America (*medium* to *high confidence*)[40] and Europe (*medium confidence*). Also**,** more frequent and/or severe agricultural and ecological droughts are projected in a few regions in all continents except Asia compared to 1850–1900 (*medium confidence*); increases in meteorological droughts are also projected in a few regions (*medium confidence*). A small number of regions are projected to experience increases or decreases in mean precipitation (*medium confidence*).
**{**11.4, 11.5, 11.6, 11.9, Atlas.4, Atlas.5, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, TS.4.3} **(Table SPM.1)**

[38] Based on 2,500 year reconstructions, eruptions more negative than $-1$ W $m^{-2}$ occur on average twice per century.

[39] Regions here refer to the AR6 WGI reference regions used in this Report to summarize information in sub-continental and oceanic regions. Changes are compared to averages over the last 20–40 years unless otherwise specified. {1.4, 12.4, Atlas.1, Interactive Atlas}.

[40] The specific level of confidence or likelihood depends on the region considered. Details can be found in the Technical Summary and the underlying Report.

**C.2.3** At 2°C global warming and above, the level of confidence in and the magnitude of the change in droughts and heavy and mean precipitation increase compared to those at 1.5°C. Heavy precipitation and associated flooding events are projected to become more intense and frequent in the Pacific Islands and across many regions of North America and Europe (*medium* to *high confidence*)[40]. These changes are also seen in some regions in Australasia and Central and South America (*medium confidence*). Several regions in Africa, South America and Europe are projected to experience an increase in frequency and/or severity of agricultural and ecological droughts with *medium* to *high confidence*[40]; increases are also projected in Australasia, Central and North America, and the Caribbean with *medium confidence*. A small number of regions in Africa, Australasia, Europe and North America are also projected to be affected by increases in hydrological droughts, and several regions are projected to be affected by increases or decreases in meteorological droughts with more regions displaying an increase (*medium confidence*). Mean precipitation is projected to increase in all polar, northern European and northern North American regions, most Asian regions and two regions of South America (*high confidence*).
{11.4, 11.6, 11.9, 12.4, 12.5, Atlas.5, Atlas.7, Atlas.8, Atlas.9, Atlas.11, TS.4.3, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1} **(Table SPM.1, Figure SPM.5, Figure SPM.6, Figure SPM.9)**

**C.2.4** More CIDs across more regions are projected to change at 2°C and above compared to 1.5°C global warming (*high confidence*). Region-specific changes include intensification of tropical cyclones and/or extratropical storms (*medium confidence*), increases in river floods (*medium* to *high confidence*)[40], reductions in mean precipitation and increases in aridity (*medium* to *high confidence*)[40], and increases in fire weather (*medium* to *high confidence*)[40]. There is *low confidence* in most regions in potential future changes in other CIDs, such as hail, ice storms, severe storms, dust storms, heavy snowfall, and landslides.
{11.7, 11.9, 12.4, 12.5, Atlas.4, Atlas.6, Atlas.7, Atlas.8, Atlas.10, TS.4.3.1, TS.4.3.2, TS.5, Cross-Chapter Box, 11.1, Cross-Chapter Box 12.1} **(Table SPM.1, Figure SPM.9)**

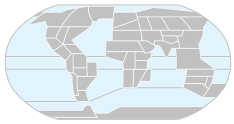
**C.2.5** It is *very likely* to *virtually certain*[40] that regional mean relative sea level rise will continue throughout the 21st century, except in a few regions with substantial geologic land uplift rates. Approximately two-thirds of the global coastline has a projected regional relative sea level rise within ±20% of the global mean increase (*medium confidence*). Due to relative sea level rise, extreme sea level events that occurred once per century in the recent past are projected to occur at least annually at more than half of all tide gauge locations by 2100 (*high confidence*). Relative sea level rise contributes to increases in the frequency and severity of coastal flooding in low-lying areas and to coastal erosion along most sandy coasts (*high confidence*).
{9.6, 12.4, 12.5, Box TS.4, TS.4.3, Cross-Chapter Box 12.1} **(Figure SPM.9)**

**C.2.6** Cities intensify human-induced warming locally, and further urbanization together with more frequent hot extremes will increase the severity of heatwaves (*very high confidence*). Urbanization also increases mean and heavy precipitation over and/or downwind of cities (*medium confidence*) and resulting runoff intensity (*high confidence*). In coastal cities, the combination of more frequent extreme sea level events (due to sea level rise and storm surge) and extreme rainfall/riverflow events will make flooding more probable (*high confidence*).
{8.2, Box 10.3, 11.3, 12.4, Box TS.14}

**C.2.7** Many regions are projected to experience an increase in the probability of compound events with higher global warming (*high confidence*). In particular, concurrent heatwaves and droughts are *likely* to become more frequent. Concurrent extremes at multiple locations become more frequent, including in crop-producing areas, at 2°C and above compared to 1.5°C global warming (*high confidence*).
{11.8, Box 11.3, Box 11.4, 12.3, 12.4, TS.4.3, Cross-Chapter Box 12.1} **(Table SPM.1)**

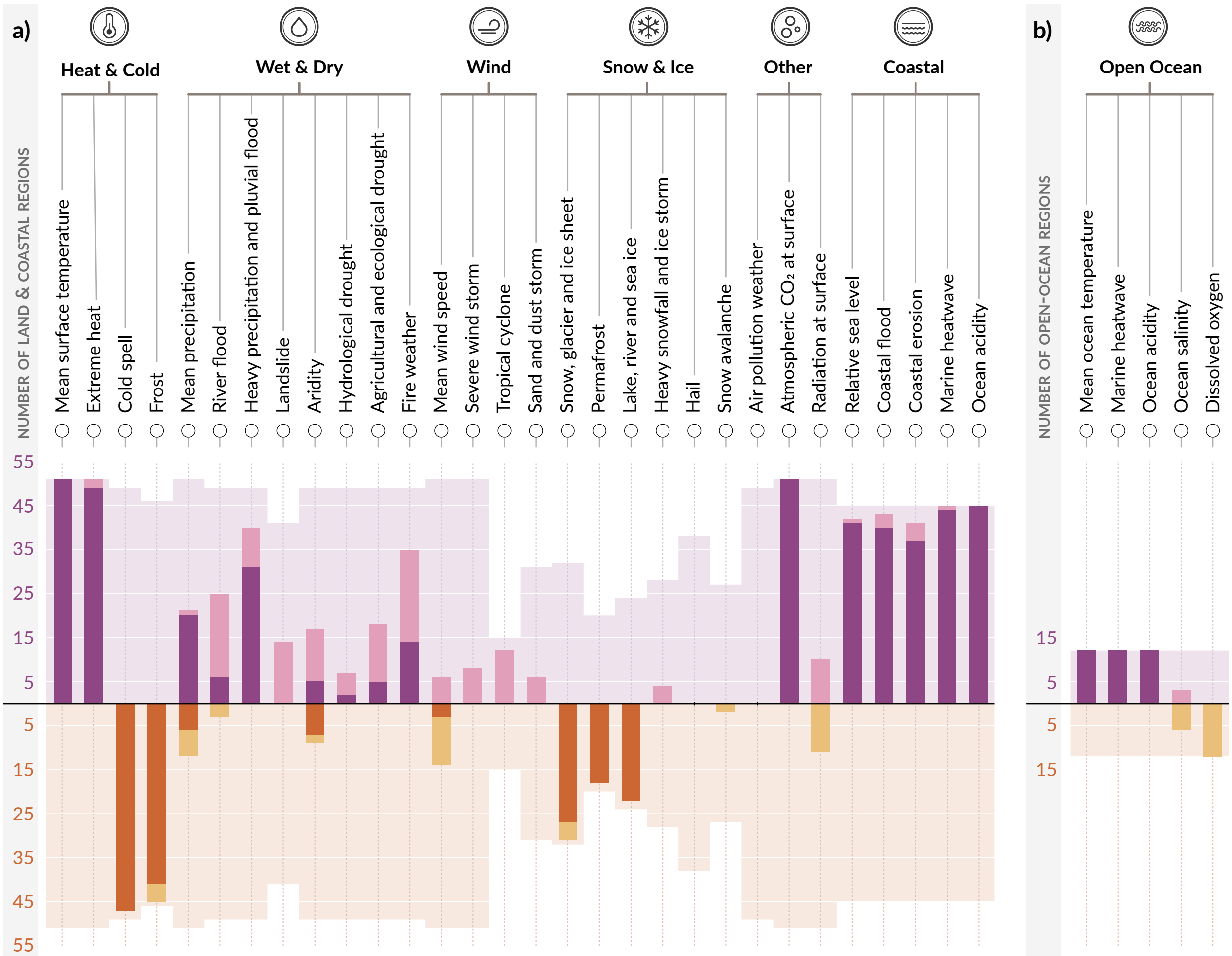
# Multiple climatic impact-drivers are projected to change in all regions of the world

**Climatic impact-drivers (CIDs)** are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions. The CIDs are grouped into seven types, which are summarized under the icons in the figure. All regions are projected to experience changes in at least 5 CIDs. Almost all (96%) are projected to experience changes in at least 10 CIDs and half in at least 15 CIDs. For many CIDs there is wide geographical variation in where they change and so each region are projected to experience a specific set of CID changes. Each bar in the chart represents a specific geographical set of changes that can be explored in the WGI Interactive Atlas.



interactive-atlas.ipcc.ch

**Number of land & coastal regions** (a) and **open-ocean regions** (b) where each **climatic impact-driver** (CID) is projected to **increase** or **decrease** with ***high** confidence* (dark shade) or ***medium** confidence* (light shade)




BAR CHART LEGEND
- Regions with ***high** confidence* **increase**
- Regions with ***medium** confidence* **increase**
- Regions with ***high** confidence* **decrease**
- Regions with ***medium** confidence* **decrease**

LIGHTER-SHADED 'ENVELOPE' LEGEND

The height of the lighter shaded 'envelope' behind each bar represents the maximum number of regions for which each CID is relevant. The envelope is symmetrical about the x-axis showing the maximum possible number of relevant regions for CID increase (upper part) or decrease (lower part).

ASSESSED FUTURE CHANGES

Changes refer to a 20–30 year period centred around 2050 and/or consistent with 2°C global warming compared to a similar period within 1960-2014 or 1850-1900.

**Figure SPM.9: Synthesis of the number of AR6 WGI reference regions where climatic impact-drivers are projected to change.**

A total of 35 climatic impact-drivers (CIDs) grouped into seven types are shown: heat and cold, wet and dry, wind, snow and ice, coastal, open ocean and other. For each CID, the bar in the graph below displays the number of AR6 WGI reference regions where it is projected to change. The **colours** represent the direction of change and the level of confidence in the change: purple indicates an increase while brown indicates a decrease; darker and lighter shades refer to *high* and *medium confidence*, respectively. Lighter background colours represent the maximum number of regions for which each CID is broadly relevant.

**Panel a)** shows the 30 CIDs relevant to the **land and coastal regions** while **panel b)** shows the 5 CIDs relevant to the **open ocean regions.** Marine heatwaves and ocean acidity are assessed for coastal ocean regions in panel a) and for open ocean regions in panel b). Changes refer to a 20–30 year period centred around 2050 and/or consistent with 2°C global warming compared to a similar period within 1960-2014, except for hydrological drought and agricultural and ecological drought which is compared to 1850-1900. Definitions of the regions are provided in Atlas.1 and the Interactive Atlas (see *interactive-atlas.ipcc.ch*).

{Table TS.5, Figure TS.22, Figure TS.25, 11.9, 12.2, 12.4, Atlas.1} **(Table SPM.1)**

## C.3 Low-likelihood outcomes, such as ice sheet collapse, abrupt ocean circulation changes, some compound extreme events and warming substantially larger than the assessed *very likely* range of future warming cannot be ruled out and are part of risk assessment.

{1.4, Cross-Chapter Box 1.3, Cross-Chapter Box 4.1, 4.3, 4.4, 4.8, 8.6, 9.2, Box 9.4, Box 11.2, 11.8, Cross-Chapter Box 12.1} **(Table SPM.1)**

**C.3.1** If global warming exceeds the assessed *very likely* range for a given GHG emissions scenario, including low GHG emissions scenarios, global and regional changes in many aspects of the climate system, such as regional precipitation and other CIDs, would also exceed their assessed *very likely* ranges (*high confidence*). Such low-likelihood high-warming outcomes are associated with potentially very large impacts, such as through more intense and more frequent heatwaves and heavy precipitation, and high risks for human and ecological systems particularly for high GHG emissions scenarios.
{Cross-Chapter Box 1.3, 4.3, 4.4, 4.8, Box 9.4, Box 11.2, Cross-Chapter Box 12.1, TS.1.4, Box TS.3, Box TS.4} **(Table SPM.1)**

**C.3.2** Low-likelihood, high-impact outcomes[34] could occur at global and regional scales even for global warming within the *very likely* range for a given GHG emissions scenario. The probability of low-likelihood, high impact outcomes increases with higher global warming levels (*high confidence*). Abrupt responses and tipping points of the climate system, such as strongly increased Antarctic ice sheet melt and forest dieback, cannot be ruled out (*high confidence*).
{1.4, 4.3, 4.4, 4.8, 5.4, 8.6, Box 9.4, Cross-Chapter Box 12.1, TS.1.4, TS.2.5, Box TS.3, Box TS.4, Box TS.9} **(Table SPM.1)**

**C.3.3** If global warming increases, some compound extreme events[18] with low likelihood in past and current climate will become more frequent, and there will be a higher likelihood that events with increased intensities, durations and/or spatial extents unprecedented in the observational record will occur (*high confidence*).
{11.8, Box 11.2, Cross-Chapter Box 12.1, Box TS.3, Box TS.9}

**C.3.4** The Atlantic Meridional Overturning Circulation is *very likely* to weaken over the 21st century for all emission scenarios. While there is *high confidence* in the 21st century decline, there is only *low confidence* in the magnitude of the trend. There is *medium confidence* that there will not be an abrupt collapse before 2100. If such a collapse were to occur, it would *very likely* cause abrupt shifts in regional weather patterns and water cycle, such as a southward shift in the tropical rain belt, weakening of the African and Asian monsoons and strengthening of Southern Hemisphere monsoons, and drying in Europe. {4.3, 8.6, 9.2, TS2.4, Box TS.3}

**C.3.5** Unpredictable and rare natural events not related to human influence on climate may lead to low-likelihood, high impact outcomes. For example, a sequence of large explosive volcanic eruptions within decades has occurred in the past, causing substantial global and regional climate perturbations over several decades. Such events cannot be ruled out in the future, but due to their inherent unpredictability they are not included in the illustrative set of scenarios referred to in this Report. {2.2, Cross-Chapter Box 4.1, Box TS.3} **(Box SPM.1)**

## D. Limiting Future Climate Change

*Since AR5, estimates of remaining carbon budgets have been improved by a new methodology first presented in SR1.5, updated evidence, and the integration of results from multiple lines of evidence. A comprehensive range of possible future air pollution controls in scenarios is used to consistently assess the effects of various assumptions on projections of climate and air pollution. A novel development is the ability to ascertain when climate responses to emissions reductions would become discernible above natural climate variability, including internal variability and responses to natural drivers.*

D.1 **From a physical science perspective, limiting human-induced 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. Strong, rapid and sustained reductions in $CH_4$ emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality.**
{3.3, 4.6, 5.1, 5.2, 5.4, 5.5, 5.6, Box 5.2, Cross-Chapter Box 5.1, 6.7, 7.6, 9.6} **(Figure SPM.10, Table SPM.2)**

**D.1.1** This Report reaffirms with *high confidence* the AR5 finding that there is a near-linear relationship between cumulative anthropogenic $CO_2$ emissions and the global warming they cause. Each 1000 $GtCO_2$ of cumulative $CO_2$ emissions is assessed to *likely* cause a 0.27°C to 0.63°C increase in global surface temperature with a best estimate of 0.45°C[41]. This is a narrower range compared to AR5 and SR1.5. This quantity is referred to as the transient climate response to cumulative $CO_2$ emissions (TCRE). This relationship implies that reaching net zero[42] anthropogenic $CO_2$ emissions is a requirement to stabilize human-induced global temperature increase at any level, but that limiting global temperature increase to a specific level would imply limiting cumulative $CO_2$ emissions to within a carbon budget[43]. {5.4, 5.5, TS.1.3, TS.3.3, Box TS.5} **(Figure SPM.10)**

[41] In the literature, units of °C per 1000 PgC are used, and the AR6 reports the TCRE *likely* range as 1.0°C to 2.3°C per 1000 PgC in the underlying report, with a best estimate of 1.65°C.

[42] condition in which anthropogenic carbon dioxide ($CO_2$) emissions are balanced by anthropogenic $CO_2$ removals over a specified period.

[43] The term carbon budget refers to the maximum amount of cumulative net global anthropogenic $CO_2$ emissions that would result in limiting global warming to a given level with a given probability, taking into account the effect of other anthropogenic climate forcers. This is referred to as the total carbon budget when expressed starting from the pre-industrial period, and as the remaining carbon budget when expressed from a recent specified date (see Glossary). Historical cumulative $CO_2$ emissions determine to a large degree warming to date, while future emissions cause future additional warming. The remaining carbon budget indicates how much $CO_2$ could still be emitted while keeping warming below a specific temperature level.

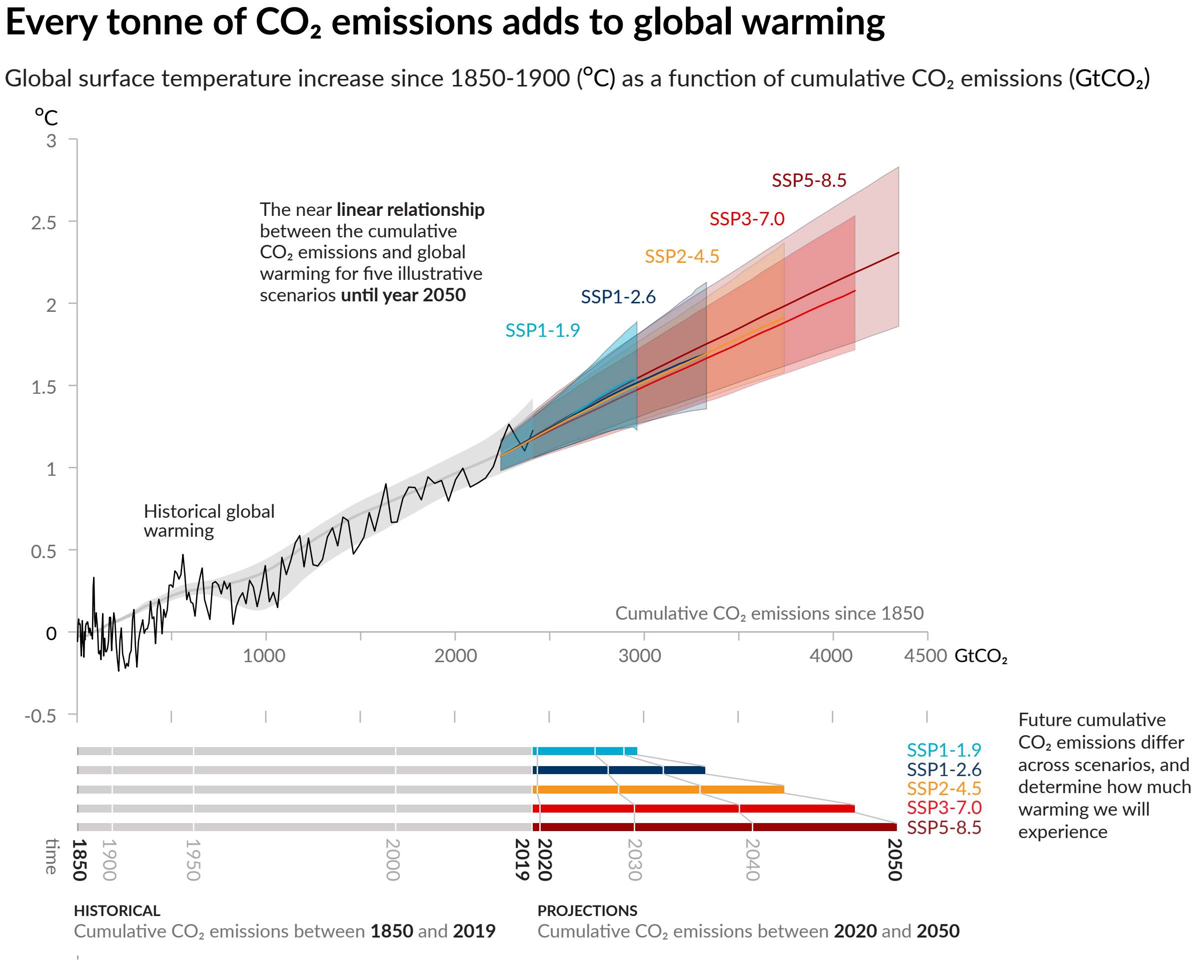



**Figure SPM.10: Near-linear relationship between cumulative CO2 emissions and the increase in global surface temperature.**

**Top panel:** Historical data (thin black line) shows observed global surface temperature increase in °C since 1850–1900 as a function of historical cumulative carbon dioxide ($CO_2$) emissions in $GtCO_2$ from 1850 to 2019. The grey range with its central line shows a corresponding estimate of the historical human-caused surface warming (see Figure SPM.2). Coloured areas show the assessed *very likely* range of global surface temperature projections, and thick coloured central lines show the median estimate as a function of cumulative $CO_2$ emissions from 2020 until year 2050 for the set of illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5, see Figure SPM.4). Projections use the cumulative $CO_2$ emissions of each respective scenario, and the projected global warming includes the contribution from all anthropogenic forcers. The relationship is illustrated over the domain of cumulative $CO_2$ emissions for which there is *high confidence* that the transient climate response to cumulative $CO_2$ emissions (TCRE) remains constant, and for the time period from 1850 to 2050 over which global $CO_2$ emissions remain net positive under all illustrative scenarios as there is *limited evidence* supporting the quantitative application of TCRE to estimate temperature evolution under net negative $CO_2$ emissions.

**Bottom panel:** Historical and projected cumulative $CO_2$ emissions in $GtCO_2$ for the respective scenarios.

{Figure TS.18, Figure 5.31, Section 5.5}

**D.1.2** Over the period 1850–2019, a total of 2390 ± 240 (*likely* range) $GtCO_2$ of anthropogenic $CO_2$ was emitted. Remaining carbon budgets have been estimated for several global temperature limits and various levels of probability, based on the estimated value of TCRE and its uncertainty, estimates of historical warming, variations in projected warming from non-$CO_2$ emissions, climate system feedbacks such as emissions from thawing permafrost, and the global surface temperature change after global anthropogenic $CO_2$ emissions reach net zero.
{5.1, 5.5, Box 5.2, TS.3.3} **(Table SPM.2)**

**Table SPM.2:** **Estimates of historical $CO_2$ emissions and remaining carbon budgets.** Estimated remaining carbon budgets are calculated from the beginning of 2020 and extend until global net zero $CO_2$ emissions are reached. They refer to $CO_2$ emissions, while accounting for the global warming effect of non-$CO_2$ emissions. Global warming in this table refers to human-induced global surface temperature increase, which excludes the impact of natural variability on global temperatures in individual years. {Table TS.3, Table 3.1, Table 5.1, Table 5.7, Table 5.8, 5.5.1, 5.5.2, Box 5.2}

| Global warming between 1850–1900 and 2010–2019 *(°C)* | Historical cumulative $CO_2$ emissions from 1850 to 2019 *($GtCO_2$)* |
|---|---|
| 1.07 (0.8–1.3; *likely* range) | 2390 (± 240; *likely* range) |

| Approximate global warming relative to 1850–1900 until temperature limit *(°C)**(1) | Additional global warming relative to 2010–2019 until temperature limit *(°C)* | Estimated remaining carbon budgets from the beginning of 2020 *($GtCO_2$)*<br>*Likelihood of limiting global warming to temperature limit*(2)* | | | | | Variations in reductions in non-$CO_2$ emissions*(3) |
|---|---|---|---|---|---|---|---|
| | | *17%* | *33%* | *50%* | *67%* | *83%* | |
| 1.5 | 0.43 | 900 | 650 | 500 | 400 | 300 | Higher or lower reductions in accompanying non-$CO_2$ emissions can increase or decrease the values on the left by 220 $GtCO_2$ or more |
| 1.7 | 0.63 | 1450 | 1050 | 850 | 700 | 550 | |
| 2.0 | 0.93 | 2300 | 1700 | 1350 | 1150 | 900 | |

*(1) Values at each 0.1°C increment of warming are available in Tables TS.3 and 5.8.
*(2) This likelihood is based on the uncertainty in transient climate response to cumulative $CO_2$ emissions (TCRE) and additional Earth system feedbacks, and provides the probability that global warming will not exceed the temperature levels provided in the two left columns. Uncertainties related to historical warming (±550 $GtCO_2$) and non-$CO_2$ forcing and response (±220 $GtCO_2$) are partially addressed by the assessed uncertainty in TCRE, but uncertainties in recent emissions since 2015 (±20 $GtCO_2$) and the climate response after net zero $CO_2$ emissions are reached (±420 $GtCO_2$) are separate.
*(3) Remaining carbon budget estimates consider the warming from non-$CO_2$ drivers as implied by the scenarios assessed in SR1.5. The Working Group III Contribution to AR6 will assess mitigation of non-$CO_2$ emissions.

**D.1.3** Several factors that determine estimates of the remaining carbon budget have been re-assessed, and updates to these factors since SR1.5 are small. When adjusted for emissions since previous reports, estimates of remaining carbon budgets are therefore of similar magnitude compared to SR1.5 but larger compared to AR5 due to methodological improvements[44].
{5.5, Box 5.2, TS.3.3} **(Table SPM.2)**

**D.1.4** Anthropogenic $CO_2$ removal (CDR) has the potential to remove $CO_2$ from the atmosphere and durably store it in reservoirs (*high confidence*). CDR aims to compensate for residual emissions to reach net zero $CO_2$ or net zero GHG emissions or, if implemented at a scale where anthropogenic removals exceed anthropogenic emissions, to lower surface temperature. CDR methods can have potentially wide-ranging effects on biogeochemical cycles and climate, which can either weaken or strengthen the potential of these methods to remove $CO_2$ and reduce warming, and can also influence water availability and quality, food production and biodiversity[45] (*high confidence*).
{5.6, Cross-Chapter Box 5.1, TS.3.3}

**D.1.5** Anthropogenic $CO_2$ removal (CDR) leading to global net negative emissions would lower the atmospheric $CO_2$ concentration and reverse surface ocean acidification (*high confidence*). Anthropogenic $CO_2$ removals and emissions are partially compensated by $CO_2$ release and uptake respectively, from or to land and ocean carbon pools (*very high confidence*). CDR would lower atmospheric $CO_2$ by an amount approximately equal to the increase from an anthropogenic emission of the same magnitude (*high confidence*). The atmospheric $CO_2$ decrease from anthropogenic $CO_2$ removals could be up to 10% less than the atmospheric $CO_2$ increase from an equal amount of $CO_2$ emissions, depending on the total amount of CDR (*medium confidence*). {5.3, 5.6, TS.3.3}

**D.1.6** If global net negative $CO_2$ emissions were to be achieved and be sustained, the global $CO_2$-induced surface temperature increase would be gradually reversed but other climate changes would continue in their current direction for decades to millennia (*high confidence*). For instance, it would take several centuries to millennia for global mean sea level to reverse course even under large net negative $CO_2$ emissions (*high confidence*).
{4.6, 9.6, TS.3.3}

**D.1.7** In the five illustrative scenarios, simultaneous changes in $CH_4$, aerosol and ozone precursor emissions, that also contribute to air pollution, lead to a net global surface warming in the near and long-term (*high confidence*). In the long term, this net warming is lower in scenarios assuming air pollution controls combined with strong and sustained $CH_4$ emission reductions (*high confidence*). In the low and very low GHG emissions scenarios, assumed reductions in anthropogenic aerosol emissions lead to a net warming, while reductions in $CH_4$ and other ozone precursor emissions lead to a net cooling. Because of the short lifetime of both $CH_4$ and aerosols, these climate effects partially counterbalance each other and reductions in $CH_4$ emissions also contribute to improved air quality by reducing global surface ozone (*high confidence*).
{6.7, Box TS.7} **(Figure SPM.2, Box SPM.1)**

[44] Compared to AR5, and when taking into account emissions since AR5, estimates in AR6 are about 300–350 $GtCO_2$ larger for the remaining carbon budget consistent with limiting warming to 1.5°C; for 2°C, the difference is about 400–500 $GtCO_2$.

[45] Potential negative and positive effects of CDR for biodiversity, water and food production are methods-specific, and are often highly dependent on local context, management, prior land use, and scale. IPCC Working Groups II and III assess the CDR potential, and ecological and socio-economic effects of CDR methods in their AR6 contributions.

**D.1.8** Achieving global net zero $CO_2$ emissions is a requirement for stabilizing $CO_2$-induced global surface temperature increase, with anthropogenic $CO_2$ emissions balanced by anthropogenic removals of $CO_2$. This is different from achieving net zero GHG emissions, where metric-weighted anthropogenic GHG emissions equal metric-weighted anthropogenic GHG removals. For a given GHG emission pathway, the pathways of individual greenhouse gases determine the resulting climate response[46], whereas the choice of emissions metric[47] used to calculate aggregated emissions and removals of different GHGs affects what point in time the aggregated greenhouse gases are calculated to be net zero. Emissions pathways that reach and sustain net zero GHG emissions defined by the 100-year global warming potential are projected to result in a decline in surface temperature after an earlier peak (*high confidence*).
{4.6, 7.6, Box 7.3, TS.3.3}

**D.2 Scenarios with very low or low GHG emissions (SSP1-1.9 and SSP1-2.6) lead within years to discernible effects on greenhouse gas and aerosol concentrations, and air quality, relative to high and very high GHG emissions scenarios (SSP3-7.0 or SSP5-8.5). Under these contrasting scenarios, discernible differences in trends of global surface temperature would begin to emerge from natural variability within around 20 years, and over longer time periods for many other climatic impact-drivers (*high confidence*).** {4.6, Cross-Chapter Box 6.1, 6.6, 6.7, 9.6, Cross-Chapter Box 11.1, 11.2, 11.4, 11.5, 11.6, 12.4, 12.5} **(Figure SPM.8, Figure SPM.10)**

**D.2.1** Emissions reductions in 2020 associated with measures to reduce the spread of COVID-19 led to temporary but detectible effects on air pollution (*high confidence*), and an associated small, temporary increase in total radiative forcing, primarily due to reductions in cooling caused by aerosols arising from human activities (*medium confidence*). Global and regional climate responses to this temporary forcing are, however, undetectable above natural variability (*high confidence*). Atmospheric $CO_2$ concentrations continued to rise in 2020, with no detectable decrease in the observed $CO_2$ growth rate (*medium confidence*)[48].
{Cross-Chapter Box 6.1, TS.3.3}

**D.2.2** Reductions in GHG emissions also lead to air quality improvements. However, in the near term[49], even in scenarios with strong reduction of GHGs, as in the low and very low GHG emission scenarios (SSP1-2.6 and SSP1-1.9), these improvements are not sufficient in many polluted regions to achieve air quality guidelines specified by the World Health Organization (*high confidence*). Scenarios with targeted reductions of air pollutant emissions lead to more rapid improvements in air quality within years compared to reductions in GHG emissions only, but from 2040, further improvements are projected in scenarios that combine efforts to reduce air pollutants as well as GHG emissions with the magnitude of the benefit varying between regions (*high confidence*). {6.6, 6.7, Box TS.7}.

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[46] A general term for how the climate system responds to a radiative forcing (see Glossary).

[47] The choice of emissions metric depends on the purposes for which gases or forcing agents are being compared. This report contains updated emission metric values and assesses new approaches to aggregating gases.

[48] For other GHGs, there was insufficient literature available at the time of the assessment to assess detectable changes in their atmospheric growth rate during 2020.

[49] Near term: (2021–2040)

**D.2.3** Scenarios with very low or low GHG emissions (SSP1-1.9 and SSP1-2.6) would have rapid and sustained effects to limit human-caused climate change, compared with scenarios with high or very high GHG emissions (SSP3-7.0 or SSP5-8.5), but early responses of the climate system can be masked by natural variability. For global surface temperature, differences in 20-year trends would *likely* emerge during the near term under a very low GHG emission scenario (SSP1-1.9), relative to a high or very high GHG emission scenario (SSP3-7.0 or SSP5-8.5). The response of many other climate variables would emerge from natural variability at different times later in the 21st century (*high confidence*).
{4.6, Cross-Section Box TS.1} **(Figure SPM.8, Figure SPM.10)**

**D.2.4** Scenarios with very low and low GHG emissions (SSP1-1.9 and SSP1-2.6) would lead to substantially smaller changes in a range of CIDs[36] beyond 2040 than under high and very high GHG emissions scenarios (SSP3-7.0 and SSP5-8.5). By the end of the century, scenarios with very low and low GHG emissions would strongly limit the change of several CIDs, such as the increase in the frequency of extreme sea level events, heavy precipitation and pluvial flooding, and exceedance of dangerous heat thresholds, while limiting the number of regions where such exceedances occur, relative to higher GHG emissions scenarios (*high confidence*). Changes would also be smaller in very low compared to low emissions scenarios, as well as for intermediate (SSP2-4.5) compared to high or very high emissions scenarios (*high confidence*). {9.6, Cross-Chapter Box 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 11.9, 12.4, 12.5, TS.4.3}

Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II

# 21 Midwest

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On the Web: https://nca2018.globalchange.gov/chapter/midwest

Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II

# 21 Midwest

Carson, Wisconsin

## Key Message 1

### Agriculture

The Midwest is a major producer of a wide range of food and animal feed for national consumption and international trade. Increases in warm-season absolute humidity and precipitation have eroded soils, created favorable conditions for pests and pathogens, and degraded the quality of stored grain. Projected changes in precipitation, coupled with rising extreme temperatures before mid-century, will reduce Midwest agricultural productivity to levels of the 1980s without major technological advances.

## Key Message 2

### Forestry

Midwest forests provide numerous economic and ecological benefits, yet threats from a changing climate are interacting with existing stressors such as invasive species and pests to increase tree mortality and reduce forest productivity. Without adaptive actions, these interactions will result in the loss of economically and culturally important tree species such as paper birch and black ash and are expected to lead to the conversion of some forests to other forest types or even to non-forested ecosystems by the end of the century. Land managers are beginning to manage risk in forests by increasing diversity and selecting for tree species adapted to a range of projected conditions.

## Key Message 3

### Biodiversity and Ecosystems

The ecosystems of the Midwest support a diverse array of native species and provide people with essential services such as water purification, flood control, resource provision, crop pollination, and recreational opportunities. Species and ecosystems, including the important freshwater resources of the Great Lakes, are typically most at risk when climate stressors, like temperature increases, interact with land-use change, habitat loss, pollution, nutrient inputs, and nonnative invasive species. Restoration of natural systems, increases in the use of green infrastructure, and targeted conservation efforts, especially of wetland systems, can help protect people and nature from climate change impacts.

## Key Message 4

### Human Health

Climate change is expected to worsen existing health conditions and introduce new health threats by increasing the frequency and intensity of poor air quality days, extreme high temperature events, and heavy rainfalls; extending pollen seasons; and modifying the distribution of disease-carrying pests and insects. By mid-century, the region is projected to experience substantial, yet avoidable, loss of life, worsened health conditions, and economic impacts estimated in the billions of dollars as a result of these changes. Improved basic health services and increased public health measures—including surveillance and monitoring—can prevent or reduce these impacts.

## Key Message 5

### Transportation and Infrastructure

Storm water management systems, transportation networks, and other critical infrastructure are already experiencing impacts from changing precipitation patterns and elevated flood risks. Green infrastructure is reducing some of the negative impacts by using plants and open space to absorb storm water. The annual cost of adapting urban storm water systems to more frequent and severe storms is projected to exceed $500 million for the Midwest by the end of the century.

## Key Message 6

### Community Vulnerability and Adaptation

At-risk communities in the Midwest are becoming more vulnerable to climate change impacts such as flooding, drought, and increases in urban heat islands. Tribal nations are especially vulnerable because of their reliance on threatened natural resources for their cultural, subsistence, and economic needs. Integrating climate adaptation into planning processes offers an opportunity to better manage climate risks now. Developing knowledge for decision-making in cooperation with vulnerable communities and tribal nations will help to build adaptive capacity and increase resilience.

## Executive Summary

The Midwest is home to over 60 million people, and its active economy represents 18% of the U.S. gross domestic product.[1] The region is probably best known for agricultural production. Increases in growing-season temperature in the Midwest are projected to be the largest contributing factor to declines in the productivity of U.S. agriculture.[2] Increases in humidity in spring through mid-century[3,4] are expected to increase rainfall, which will increase the potential for soil erosion[5,6] and further reduce planting-season workdays due to waterlogged soil.[7]

Forests are a defining characteristic of many landscapes within the Midwest, covering more than 91 million acres. However, a changing climate, including an increased frequency of late-growing-season drought conditions, is worsening the effects of invasive species, insect pests, and plant disease as trees experience periodic moisture stress. Impacts from human activities, such as logging, fire suppression, and agricultural expansion, have lowered the diversity of the Midwest's forests from the pre-Euro-American settlement period. Natural resource managers are taking steps to address these issues by increasing the diversity of trees and introducing species suitable for a changing climate.[8]

The Great Lakes play a central role in the Midwest and provide an abundant freshwater resource for water supplies, industry, shipping, fishing, and recreation, as well as a rich and diverse ecosystem. These important ecosystems are under stress from pollution, nutrient and sediment inputs from agricultural systems, and invasive species.[9,10] Lake surface temperatures are increasing,[11,12] lake ice cover is declining,[12,13,14] the seasonal stratification of temperatures in the lakes is occurring earlier in the year,[15] and summer evaporation rates are increasing.[13,16] Increasing storm impacts and declines in coastal water quality can put coastal communities at risk. While several coastal communities have expressed willingness to integrate climate action into planning efforts, access to useful climate information and limited human and financial resources constrain municipal action.

Land conversion, and a wide range of other stressors, has already greatly reduced biodiversity in many of the region's prairies, wetlands, forests, and freshwater systems. Species are already responding to changes that have occurred over the last several decades,[17,18,19] and rapid climate change over the next century is expected to cause or further amplify stress in many species and ecological systems in the Midwest.[20,21,22] The loss of species and the degradation of ecosystems have the potential to reduce or eliminate essential ecological services such as flood control, water purification, and crop pollination, thus reducing the potential for society to successfully adapt to ongoing changes. However, understanding these relationships also highlights important climate adaptation strategies. For example, restoring systems like wetlands and forested floodplains and implementing agricultural best management strategies that increase vegetative cover (cover crops and riparian buffers) can help reduce flooding risks and protect water quality.[23,24,25]

Midwestern populations are already experiencing adverse health impacts from climate change, and these impacts are expected to worsen in the future.[26,27] In the absence of mitigation, ground-level ozone concentrations are projected to increase across most of the Midwest, resulting in an additional 200–550 premature deaths in the region per year by 2050.[28] Exposure to high temperatures impacts workers' health, safety, and productivity.[29] Currently, days over 100°F in Chicago are rare. However, they could become increasingly more common by late century in both the lower and higher scenarios (RCP4.5 and RCP8.5).

The Midwest also has vibrant manufacturing, retail, recreation/tourism, and service sectors. The region's highways, railroads, airports, and navigable rivers are major modes for commerce activity. Increasing precipitation, especially heavy rain events, has increased the overall flood risk, causing disruption to transportation and damage to property and infrastructure. Increasing use of green infrastructure (including nature-based approaches, such as wetland restoration, and innovations like permeable pavements) and better engineering practices are beginning to address these issues.

**Conservation Practices Reduce Impact of Heavy Rains**

Integrating strips of native prairie vegetation into row crops has been shown to reduce sediment and nutrient loss from fields, as well as improve biodiversity and the delivery of ecosystem services.[33] Iowa State University's STRIPS program is actively conducting research into this agricultural conservation practice.[34] The inset shows a close-up example of a prairie vegetation strip. *From Figure 21.2 (Photo credits: [main photo] Lynn Betts, [inset] Farnaz Kordbacheh)*.

Citizens and stakeholders value their health and the well-being of their communities—all of which are at risk from increased flooding, increased heat, and lower air and water quality under a changing climate.[30,31] To better prevent and respond to these impacts, scholars and practitioners highlight the need to engage in risk-driven approaches that not only focus on assessing vulnerabilities but also include effective planning and implementation of adaptation options.[32]

The photo shows Menominee Tribal Enterprises staff creating opportunity from adversity by replanting a forest opening caused by oak wilt disease with a diverse array of tree and understory plant species that are expected to fare better under future climate conditions. *From Figure 21.4 (Photo credit: Kristen Schmitt)*.

## Background

The Midwest is home to more than 60 million people, and its active economy represents 18% of the U.S. gross domestic product.[1] In this report, the Midwest covers Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin. The region is probably best known for agricultural production. Trends toward warmer, wetter, and more humid conditions provide challenges for field work, increase disease and pest pressure, and reduce yields to an extent that these challenges can be only partially overcome by technology.[35] The Midwest contains large tracts of federal, state, and private forests and preserves that provide significant economic and ecological benefits to the region. However, as a changing climate results in shifting precipitation patterns, altered disturbance regimes, and increased frequency of late-growing-season moisture stress, the effects of existing stressors such as invasive species, insect pests, and plant disease are amplified.[36] Natural resource managers are taking steps to address these issues by increasing the diversity of trees and introducing species suitable for a changing climate.[8]

The Midwest also has vibrant manufacturing, retail, recreation/tourism, and service sectors. The region's highways, railroads, airports, and navigable rivers are major modes for commercial activity. Increasing precipitation, especially heavy rain events, has increased the overall flood risk, causing disruption to transportation and damage to property and infrastructure (e.g., Winters et al. 2015[37]). Increasing use of green infrastructure (including nature-based approaches, such as wetland restoration, and innovations like permeable pavements) and better engineering practices are beginning to address these issues (e.g., City of Chicago 2015[38]).

Tourism and outdoor recreation are major economic activities that may be affected by climate change, particularly in coastal towns that are at risk from algal bloom impacts and in areas that host winter sports that are especially vulnerable to warming winters. For example, ice fishing was limited due to mild temperatures in the winters of 2015–2016 and 2016–2017, and the American Birkebeiner cross-country ski race in Wisconsin was cancelled due to a lack of snow in February 2017. Portions of Michigan, Wisconsin, and Minnesota contain ceded territory of many tribes, and these are used for hunting, fishing, and gathering native plants, all of which play vital roles in maintaining cultural heritage. Projected changes in climate and ecosystems will have strong impacts on these activities.[39]

The Great Lakes play a central role in the Midwest and provide an abundant freshwater resource for water supplies, industry, shipping, fishing, and recreation, as well as a rich and diverse ecosystem. The same can be said for the upper Mississippi, lower Missouri, Illinois, and Ohio River systems. Episodes of widespread heavy rains in recent years have led to flooding, soil erosion, and water quality issues from nutrient runoff into those systems.[10] Land managers are beginning to change some of their practices (such as increasing the use of cover crops) to better manage excess surface water.[40]

Citizens and stakeholders in the Midwest value their health and the well-being of their communities—all of which are at risk from increased flooding, increased heat, and lower air and water quality under a changing climate.[30,31]

## Energy in the Midwest

The Midwest is a major consumer of coal. In 2015, coal provided 56% of the electricity consumed in the region, and the eight states in the region accounted for 32% of the Nation's coal consumption (in BTUs). Coal's share of electricity production is declining in the Midwest, following the national trend (Ch. 4: Energy, Figure 4.3). In 2008, coal accounted for more than 70% of electricity consumption in the Midwest. Wind power is a small but growing source of electricity for the region. Iowa leads the Nation in per capita consumption of wind power, with wind providing over 30% of the state's electrical needs in 2015.[41]

Renewable energy is expanding in the Midwest. As part of a campus-wide initiative to transition to renewable energy sources, in 2017, Michigan State University established five solar carports that have an estimated annual production of 15,000 megawatt hours, representing about 5% of electricity use on campus (Figure 21.1). In addition to reducing carbon emissions, this investment is expected to save the university $10 million over 25 years.[42]

**Solar Charging Stations**

**Figure 21.1:** Solar carports were recently installed on the Michigan State University campus. Photo credit: David Rothstein.

## What Is New in NCA4

Two new Key Messages are introduced (Key Messages 3 and 6). Key Message 3 recognizes the important role that ecosystems of the Midwest play in supporting a diverse array of species and providing important benefits such as flood control, crop pollination, and outdoor recreation. Key Message 6 addresses how at-risk communities in the Midwest are becoming more vulnerable to climate change impacts and how they are working to build adaptive capacity. Tribal nations are especially vulnerable because of their reliance on threatened natural resources for their cultural, subsistence, and economic needs. The four remaining Key Messages address improvements in the understanding of risks and responses to climate change since NCA3. Key Message 1 on agriculture provides more specificity about the risk to agriculture by stating that agricultural productivity (the ratio of outputs to inputs) is projected to decline by 2050 to levels of the 1980s (that is, yields may increase but at the cost of substantial increases in inputs). Key Message 2 on forestry illustrates the progress foresters and land managers have made in climate adaptation through their efforts to incorporate climate change risks into management decision-making. Key Message 5 on transportation and infrastructure highlights a growing interest in green infrastructure—the use of plants and open space in storm water management—as an option for adapting to more frequent episodes of extreme precipitation. Finally, Key Message 4 on human health identifies specific health impacts by naming expected changes in magnitude and occurrence of extreme events, exposures, and economic impacts. The message explicitly states public health actions that can be implemented to avoid or reduce the health impacts.

## Key Message 1

### Agriculture

**The Midwest is a major producer of a wide range of food and animal feed for national consumption and international trade. Increases in warm-season absolute humidity and precipitation have eroded soils, created favorable conditions for pests and pathogens, and degraded the quality of stored grain. Projected changes in precipitation, coupled with rising extreme temperatures before mid-century, will reduce Midwest agricultural productivity to levels of the 1980s without major technological advances.**

#### Recent Agriculturally Important Trends

The two main commodity crops in the Midwest are corn and soybeans, which are grown on 75% of the arable land. Wheat and oats are important crops grown on fewer acres. An increasing number of niche but higher-value crops (such as apples, grapes, cherries, cranberries, blueberries, and pumpkins) also are grown in the region.[43]

Over the past 30 years, increased rainfall from April to June has been the most impactful climate trend for agriculture in the Midwest,[3] providing a favorable supply of soil moisture while also reducing flexibility for timing of spring planting and increasing soil erosion.[44] In addition, wet conditions at the end of the growing season can create elevated levels of mold, fungus, and toxins.[45] The last spring frost has occurred earlier, causing the frost-free season to increase by an average of nine days since 1901.[46] However, daily maximum temperatures in summer in the Midwest have not followed the upward global trend, in part due to higher early summer rainfall on deep, water-holding soils,[47] thereby avoiding plant stress detrimental to crops. The avoidance of heat stress and longer growing seasons have favored production in some parts of and some years in the Midwest.

Daily minimum temperatures have increased in all seasons due to increasing humidity.[48,49] Elevated growing-season minimum daily temperatures are considered a factor in reducing grain weight in corn due to increased nighttime plant respiration.[50] Warming winters have increased the survival and reproduction of existing insect pests[51] and already are enabling a northward range expansion of new insect pests and crop pathogens into the Midwest.[52]

A contributing factor underpinning Midwest growing-season trends in both temperature and precipitation is the increase in water vapor (absolute humidity):[49,53] higher humidity decreases the day–night temperature range and increases warm-season precipitation. Rising humidity also leads to longer dew periods and high moisture conditions that favor many agricultural pests and pathogens for both growing plants and stored grain.

#### Projected Trends and Agricultural Impacts

Warm-season temperatures are projected to increase more in the Midwest than any other region of the United States.[54] The frost-free season is projected to increase 10 days by early this century (2016–2045), 20 days by mid-century (2036–2065), and possibly a month by late century (2070–2099) compared to the period 1976–2005 according to the higher scenario (RCP8.5).[46]

By the middle of this century (2036–2065), 1 year out of 10 is projected to have a 5-day period that is an average of 13°F warmer than a comparable period at the end of last century (1976–2005).[54] Current average annual 5-day maximum temperature values range from about 88°F in Northern Minnesota to 97°F in Southern Missouri. Tables 21.1 and 21.2 show that by mid-century under the higher scenario (RCP8.5), 5-day maximum temperatures are projected to have moved further above optimum conditions for many crops and closer to the reproductive failure temperature, especially for corn in the southern half of the Midwest. Higher growing-season temperatures also shorten phenological stages in crops (for example, the grain fill period for corn).[35,50] Under these temperatures, overall yield trends will be reduced because of periodic pollination failures and reduced grain fill during other years.

Increases in humidity in spring through mid-century[3,4] are expected to increase rainfall, which will increase the potential for soil erosion[5,6] and further reduce planting-season workdays due to waterlogged soil.[7] As an example, for the Cedar River Basin in Iowa, the 100-year flood (1% chance of occurring in a given year) of the 20th century is projected to be a 25-year flood (4% chance per year) in the 21st century,[55] with associated increased frequency of flooding of agricultural land.

Increased spring precipitation and higher temperatures and humidity are expected to increase the number and intensity of fungus and disease outbreaks[56,57] and the prevalence of bacterial plant diseases,[58] such as bacterial spot in pumpkin and squash.[59] Increased precipitation and soil moisture in a warmer climate also lead to increased loss of soil carbon[60] and degraded surface water quality due to loss of soil particles and nutrients.[61,62] Transitions from extremes of drought to floods, in particular, increase nitrogen levels in rivers[63] and lead to harmful algal blooms.

Current understanding of drought in the Midwest is that human activity has not been a major component in historical droughts, and it remains uncertain how droughts will behave in the future. However, future projections show that Midwest surface soil moisture likely will transition from excessive levels in spring due to increased precipitation to insufficient levels in summer driven by higher temperatures, causing more moisture to be lost through evaporation.[64]

**Average Annual 5-Day Maximum Temperature**

| Geographic Area | Modeled Historical (1976–2005) | Mid-21st Century (2036–2065) for Lower Scenario (RCP4.5) | Mid-21st Century (2036–2065) for Higher Scenario (RCP8.5) |
|---|---|---|---|
| Northern Minnesota | 88°F | 93°F | 95°F |
| Southern Missouri | 97°F | 102°F | 103°F |

**Table 21.1:** These modeled historical and projected average annual 5-day maximum temperatures illustrate the temperature increases projected for the middle of this century across the Midwest. Sources: NOAA NCEI and CICS-NC.

**Optimum and Failure Temperatures for Vegetative Growth and Reproduction**

| Crop | Optimum Growth | Failure for Growth | Optimum Reproduction | Failure for Reproduction |
|---|---|---|---|---|
| Corn | 80°F | 105°F | 67°F | 95°F |
| Soybean | 86°F | 101°F | 72°F | 102°F |

**Table 21.2:** This table shows the temperatures at which corn and soybeans reach optimum growth and reproduction as well as the temperatures at which growth and reproduction fail.[50]

Projections of mid-century yields of commodity crops[65,66] show declines of 5% to over 25% below extrapolated trends broadly across the region for corn (also known as maize) and more than 25% for soybeans in the southern half of the region, with possible increases in yield in the northern half of the region. Increases in growing-season temperature in the Midwest are projected to be the largest contributing factor to declines in the productivity of U.S. agriculture.[2] In particular, heat stress in maize during the reproductive period is projected by crop models to reduce yields in the second half of the 21st century.[67] These losses may be mitigated by enhanced photosynthesis and reduced crop water use, although the magnitude is uncertain.[68,69] Elevated atmospheric $CO_2$ is expected to partially, but not completely, offset yield declines caused by climate extremes, with effects on soybeans less than on maize.[70]

Non-commodity crops produced in the Midwest include tree fruits, sweet corn, and vegetables for farmers markets and canning. While the general impacts of climate change on specialty crops are similar to commodity crops, the more intense heat waves, excessive rain interspersed with drought, and higher humidity of a future climate likely will degrade market quality as well as yield by mid-century.[71] Although data on climate-related losses are sparse, excess moisture is emerging as a major cause of crop loss.[72] Wild rice is an annual plant harvested by tribes and others in shallow wetlands of northern Minnesota, Wisconsin, and Michigan. Stable production depends on a stable climate that maintains ecosystem diversity. Declines in production are expected, related to increases in climate extremes and climate-related disease and pest outbreaks as well as northward shifts of favorable growing regions.[73]

Longer growing seasons and the introduction of hoop buildings (low, translucent, fabric-covered structures that protect plants from extreme weather) have allowed local growers of annual vegetable crops to extend the fresh produce season. However, unsheltered perennial crops such as tree fruits may be subjected increasingly to untimely budbreak followed by cold pulses due to earlier and longer occurrences of warm conditions in late winter.

Most animal agriculture in the region is in confinement, rather than range-based without shelter, and therefore offers an opportunity for mitigating some of the effects of climate change. Without adaptive actions, breeding success and production of milk and eggs will be reduced due to projected temperature extremes by mid-century.[74,75,76]

### Adaptation

Soil-erosion suppression methods in row-crop agriculture subjected to more intense rains include use of cover crops, grassed waterways, water management systems, contour farming, and prairie strips.[6,40] More diversity in planting dates, pollination periods, chemical use, and crop and cultivar selection reduces vulnerability of overall production to specific climate extremes or the changes in pests and pathogens that they cause.

An example of a highly successful program is the Iowa State Science-based Trials of Row-crops Integrated with Prairie Strips (STRIPS) program that demonstrates that replacing 10 percent of cropland with prairie grasses reduced sediment loss 20-fold while total nitrogen concentrations were 3.3 times lower (Figure 21.2).[33] An example of a private–public response is the National Corn Growers Association's Soil Health Partnership (SHP),[77] a network of working farms across the Midwest

**Conservation Practices Reduce Impact of Heavy Rains**

**Figure 21.2:** Integrating strips of native prairie vegetation into row crops has been shown to reduce sediment and nutrient loss from fields, as well as improve biodiversity and the delivery of ecosystem services.[33] Iowa State University's STRIPS program is actively conducting research into this agricultural conservation practice.[34] The inset shows a close-up example of a prairie vegetation strip. Photo credits: (main photo) Lynn Betts, (inset) Farnaz Kordbacheh.

engaged in refining techniques for growing cover crops, implementing conservation tillage, and using science-based nutrient management to reduce erosion and nutrient loss while increasing organic matter.

Acreage under irrigation has expanded modestly since 2002,[78] mostly in the northern part of the Midwest where coarse soils of lower water-holding capacity are more vulnerable to drying under increased temperature. No strategies currently are available for maintaining historical trends in commodity agriculture production to cope with increases in spring rainfall and summer heat waves projected for mid-century.[2,65]

## Key Message 2

### Forestry

**Midwest forests provide numerous economic and ecological benefits, yet threats from a changing climate are interacting with existing stressors such as invasive species and pests to increase tree mortality and reduce forest productivity. Without adaptive actions, these interactions will result in the loss of economically and culturally important tree species such as paper birch and black ash and are expected to lead to the conversion of some forests to other forest types or even to non-forested ecosystems by the end of the century. Land managers are beginning to manage risk in forests by increasing diversity and selecting for tree species adapted to a range of projected conditions.**

Forests are a defining characteristic of many landscapes within the Midwest, covering more than 91 million acres. From the oak–hickory forests of the Missouri Ozarks to the northern hardwood forests of the Upper Midwest, forest ecosystems sustain the people and communities within the region by providing numerous ecological, economic, and cultural benefits. The economic output of the Midwest forestry sector totals around $122 billion per year.[79,80,81,82,83,84,85,86] Forest-related recreation such as hunting, fishing, hiking, skiing, camping, wildlife watching, off-highway vehicles, and many other pursuits add to the region's economy. For example, forest-based recreationists spend approximately $2.5 billion (in 1996 dollars) within Wisconsin communities.[87] Forests are fundamental to cultural and spiritual practices within tribal communities, supporting plants and animals of central cultural importance and providing food and resources for making items such as baskets, canoes, and shelters.[88]

Climate change is anticipated to have a pervasive influence on forests within this region over the coming decades.[36,89,90,91,92,93,94] Tree growth rates and forest productivity have benefited from longer growing seasons and higher atmospheric carbon dioxide concentrations, but continued benefits are expected only if adequate moisture and nutrients are available to support enhanced growth rates.[95] As growing-season temperatures rise, reduced tree growth[96,97] or widespread tree mortality[98] is expected as the frequency of drought stress increases from drier air (as a result of increases in vapor pressure deficit [VPD]; Figure 21.3) and changing patterns of precipitation. Greater tree mortality from increased VPD likely will be particularly evident where competition for water is high in dense stands of trees[99,100] or where forests naturally transition to grasslands due to limited soil moisture.[101] Late-growing-season heat- and drought-related vegetation stress is projected to shift the composition and structure of forests in the region[102] by increasing mortality of younger trees, which are sensitive to drought.[19] Warming winters will reduce snowpack that acts to insulate soil from freezing temperatures, increasing frost damage to shallow tree roots[103] and reducing tree regeneration.[104] Additionally, increases in existing biological stressors of forests are expected as temperatures rise. Effects of insect pests and tree pathogens are anticipated to intensify as winters warm, increasing winter survival of pests and allowing expansion into new regions.[105,106] Changing climate conditions and atmospheric carbon dioxide concentrations will likely favor invasive plant species over native species, potentially decreasing tree regeneration.[107,108] Overall, the increasing stress on trees from rising temperatures, drought, and frost damage raises the susceptibility of individual trees to the negative impacts from invasive plants, insect pests, and disease agents (Ch. 6: Forests, Figure 6.1).[109,110,111]

Impacts from human activities such as logging, fire suppression, and agricultural expansion have lowered the diversity of the Midwest's forests from the pre-Euro-American settlement period. The forest types that occur within the region have been altered significantly relative to presettlement forests, with greater homogeneity in tree species composition across existing forest types.[112] Changes in modern forest types also include reduced structural complexity and less diverse mixes of tree species and tree ages.[113] Forests with reduced diversity are at an increased risk of negative effects from climate change, because the potential for tree species or age classes that are resistant to impacts from biological stressors and climate change is reduced.[93] Forests composed of trees of similar size and age or with lower tree diversity are at increased risk of widespread mortality[114,115] or declines in productivity.[116] In many midwestern forests, fire suppression has decreased the prevalence of

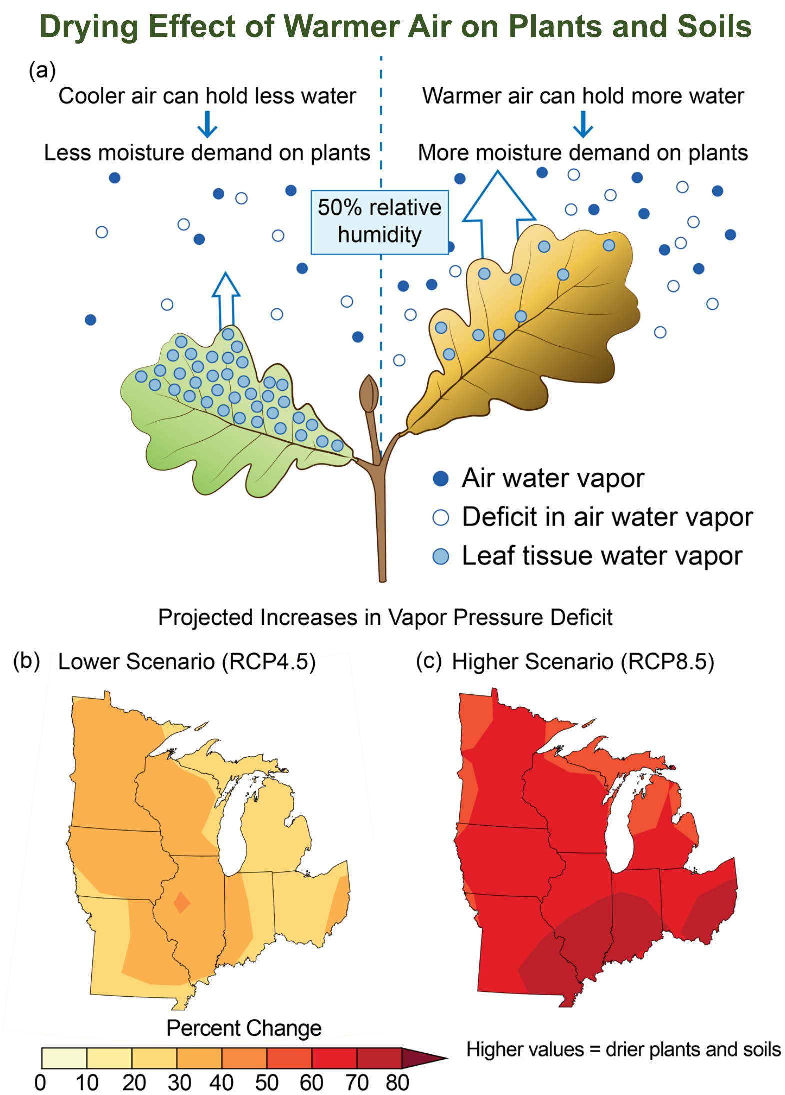



**Figure 21.3:** As air temperature increases in a warming climate, vapor pressure deficit (VPD) is projected to increase. VPD is the difference between how much moisture is in the air and the amount of moisture in the air at saturation (at 100% relative humidity). Increased VPD has a drying effect on plants and soils, as moisture transpires (from plants) and evaporates (from soil) into the air. (a) Cooler air can maintain less water as vapor, putting less demand for moisture on plants, while warmer air can maintain more water as vapor, putting more demand for moisture on plants. (b, c) The maps show the percent change in the moisture deficit of the air based on the projected maximum 5-day VPD by the late 21st century (2070–2099) compared to 1976–2005 for (b) lower and (c) higher scenarios (RCP4.5 and RCP8.5). Sources: U.S. Forest Service, NOAA NCEI, and CICS-NC.

the drought-tolerant tree species, such as oak, hickory, and pine, while increasing the abundance of species with higher moisture requirements, such as maples.[89,117] This results in greater risk of declines in forest health and productivity as the frequency of drought conditions increases.[118,119]

Changes in climate and other stressors are projected to result in changes in major forest types and changes in forest composition as tree species at the northern limits of their ranges decline and southern species experience increasingly suitable habitat.[120] However, the fragmentation of midwestern forests and the flatness of the terrain raise the possibility that the ranges of particular tree species will not be able to shift to future suitable habitats within the Midwest.[121] For example, to reach areas 1.8°F (1°C) cooler, species in flat terrain must move up to 90 miles (150 km) north to reach cooler habitat, whereas species in mountainous terrain can shift higher in altitude over less latitudinal (north–south) distance.[122] These changes raise the possibility of future losses of economic and cultural benefits of forests due to conversion to different forest types or the change to non-forest ecosystems.[119,123,124] Projected shifts in forest composition in the central hardwood region (southern Missouri, Illinois, Indiana, and Ohio) by the end of the century under a higher scenario (RCP8.5) would result in substantial declines in wildlife habitat and reduce economic value of timber in the region by up to $788 billion (in 2015 dollars).[125]

Changing climate conditions increasingly cause both cultural and economic impacts within the Midwest, and it is very likely these impacts will worsen in the future. For example, many tree species on which tribes depend for their culture and livelihoods—such as paper birch, northern white cedar, and quaking aspen—are highly vulnerable due to temperature increases.[90,91,92,126] Populations of the emerald ash borer, a destructive invasive insect pest that attacks native ash trees, will increase due to warming winters in the region. Mortality of black ash trees, which are important for traditional basket-making for many tribes, is highly likely as winter temperatures continue to rise.[127]

Warming winters already have economic impacts on the forest industry, as well. Forest operations (for example, site access, tree harvesting, and product transport) in many northern regions are conducted on snowpack or frozen ground to protect the site from negative impacts such as soil disturbance and compaction,[128] but the timing of suitable conditions has become shorter and more variable. In the Upper Midwest, the duration of frozen ground conditions suitable for winter harvest has been shortened by 2 to 3 weeks in the past 70 years.[129] The contraction of winter snow cover and frozen ground conditions has increased seasonal restrictions on forest operations in these areas,[130] with resulting economic impacts to both forestry industry and woodland landowners through reduced timber values.[131]

Forestry professionals in the Midwest increasingly are considering the risks to forests from climate change[132] and are responding by incorporating climate adaptation into land management.[8] There are a growing number of examples of climate adaptation in forest management developed by more than 150 organizations that have participated in the Climate Change Response Framework, an approach to climate change adaptation led by the U.S. Forest Service.[133,134,135] Management actions intended to maintain healthy and productive forests in a changing climate include a diverse suite of actions[135] but largely focus on activities that enhance species and structural diversity of existing forest communities and on management approaches that aim to increase the prevalence of species that are better suited to future climatic conditions.[8] Forest management on tribal lands and ceded territory within the region increasingly integrates Scientific Ecological Knowledge of natural resource management with Traditional Ecological Knowledge, a highly localized, place-based system of knowledge learned and observed over many generations.[136] This integration can inform the co-creation of approaches to climate adaptation important for maintaining healthy, functioning forests that continue to provide cultural and spiritual benefits (see Case Study “Adaptation in Forestry”).

## Case Study: Adaptation in Forestry

The Menominee Forest is well known as an exemplary forest; for generations, the Menominee Tribe has pioneered practices that have preserved nearly 220,000 acres with numerous species and varied habitats while maximizing the sustainable production of forest products. However, climate change—along with invasive species and insect pests and diseases—is creating new challenges for maintaining these diverse habitats and the sustainable supply of timber.

In response to tree mortality caused by oak wilt disease, an introduced exotic disease first identified in 1944 in Wisconsin, foresters at Menominee Tribal Enterprises (MTE) have integrated climate change adaptation into reforestation activities on severely disturbed areas created by the disease.[134] Using science guided by Traditional Ecological Knowledge of forest communities, forest openings created by oak wilt disease were replanted with a diverse array of tree and understory plant species that are expected to fare better under future climate conditions. Many of these species tolerate late-growing-season heat- and drought-related stress, while also providing important cultural benefits to the tribe such as food and medicine. The selection of locally collected plants and seeds used for restoring the oak wilt-affected openings combined scientific information on the future habitat of tree species with Indigenous knowledge of the forest communities necessary for guiding the development of diverse and healthy forests.

**Figure 21.4:** The photo shows Menominee Tribal Enterprises staff creating opportunity from adversity by replanting a forest opening caused by oak wilt disease with a diverse array of tree and understory plant species that are expected to fare better under future climate conditions. Photo credit: Kristen Schmitt.

> The grass, plant, and shrub species are put together to strengthen the immune system of the deep-rooted trees. We tried to emphasize the underground biotic community within these openings. A healthy underground community ensures a healthy aboveground community. The shrubs hold the key to a healthy change of species within the local plant communities.
>
> —MTE forester and tribal member

## Key Message 3

### Biodiversity and Ecosystems

**The ecosystems of the Midwest support a diverse array of native species and provide people with essential services such as water purification, flood control, resource provision, crop pollination, and recreational opportunities. Species and ecosystems, including the important freshwater resources of the Great Lakes, are typically most at risk when climate stressors, like temperature increases, interact with land-use change, habitat loss, pollution, nutrient inputs, and nonnative invasive species. Restoration of natural systems, increases in the use of green infrastructure, and targeted conservation efforts, especially of wetland systems, can help protect people and nature from climate change impacts.**

Species already are responding to environmental changes that have occurred over the last several decades,[17,18,19] and rapid climate change over the next century is expected to cause or further amplify stress in many species and ecological systems in the Midwest.[20,21,22] Land conversion and a wide range of other stressors have already greatly reduced biodiversity in many of the region's prairies, wetlands, forests, and freshwater systems. High rates of change in climate factors like air and water temperature and increasing drought risk likely will accelerate the rate of species declines and extinctions.[18,137] The Midwest region supports the world's largest freshwater ecosystem, the Great Lakes, which are at risk from rising temperatures, changes in seasonal stratification of lake temperatures, and increased summer evaporation rates, combined with stresses from pollution, nutrient inputs that promote harmful algal blooms, and invasive species (Box 21.1).

The loss of species and degradation of ecosystems have the potential to reduce or eliminate essential ecological services such as flood control, water purification, and crop pollination, thus reducing the potential for society to successfully adapt to ongoing changes.

Observations, ecological theory, experimental studies, and predictive models provide insights into how shifts in several climate factors (temperature, precipitation patterns, humidity, and moisture stress) may interact over the next several decades.[120,138,139] Vulnerability assessments for species and ecosystems quickly become complex, as species in the same ecosystem may have different climate sensitivities, and interactions with land-use change and other factors can strongly influence the level of impact (Ch. 5: Land Changes, KM 2; Ch. 17: Complex Systems, KM 1). Local expertise, input from multiple stakeholders, and tools like scenario planning can help improve assessment of vulnerability so that risks can be connected to management actions.[132,140] Changes observed in the Midwest include species range shifts (avoiding exposure to new climatic conditions by shifting location), changes in population size (indicating a change in viability in a given place), shifts in body size and growth rates, and changes in the timing of seasonal events (phenology). Since the Third National Climate Assessment,[27] the number of studies documenting these types of changes has continued to grow. For example, climate change appears to have contributed to the apparent local extinction of populations of the Federally Endangered Karner blue butterfly at sites in the southern end of its range in northern Indiana, despite active management and extensive habitat restoration efforts. While climate change cannot be singled out as the only cause, the populations disappeared following multiple years of warming conditions and a very early onset of spring in 2012.[139] New evidence of shifting ranges comes from

Wisconsin forests, where a set of 78 understory plant species sampled in the 1950s and again in the 2000s have demonstrated shifts in their abundance centroids (a measure of the distribution and local abundance of populations) of about 30 miles (49 km ± 29 km) over this 50-year period (Figure 21.5).[141] The dominant direction of this shift was to the northwest, which matches the direction of change in important climatic conditions associated with the distributions of these species. While this shift suggests the potential for successful adaptation to changing conditions, the rate of change for most species was much less than the amount of change in the climate metrics over the same time period, raising the concern that the climate is changing too fast for these species to keep up.[141] Similarly, a study of shifts in the timing of spring green-up, an indicator of when plant-feeding insects emerge, and the timing of migratory bird arrivals found that while both are shifting earlier in the Midwest, the arrival of birds is not advancing as quickly as the plants.[142] Risks to birds from this mismatch in phenology include the potential for birds to arrive after food availability has peaked or for later arrivals to be less able to compete for territories or mates. Land protection and management strategies that help maintain or increase phenological variation of plants within key migratory and breeding habitats like the Great Lakes coastlines may help increase the odds that birds can find the resources they need.[143]

The drivers of changes in species ranges or abundance can be complex and difficult to detect until key thresholds are crossed. For example, in the Midwest region, cool- and coldwater fishes in inland lakes are particularly susceptible to changes in climate because habitat with appropriate temperatures and oxygen concentrations is often limited during summer months. In lakes at the southern (warmer) end of their ranges, these fish experience a squeezing of available habitat during summer months as the water near the lake surface becomes too warm and the dissolved oxygen levels in deeper waters drop (Figure 21.6).[144,145,146] This "invisible" loss of habitat is driven by increases in water temperatures, longer duration of the stratified period (which delays the mixing of oxygen-rich water into the deeper waters), and declines in ice cover.[147,148,149,150] Recent research has identified fish kill events tied to temperature and oxygen stress from increased air temperatures, and modeling results forecast increased numbers of these events, likely leading to local extinction of cool- and coldwater fish species in some lakes and reduced geographic distribution across the Midwest.[151,152,153,154]

## Climate Change Outpaces Plants' Ability to Shift Habitat Range

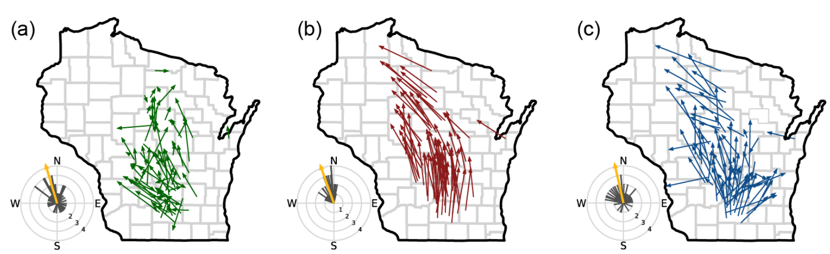



**Figure 21.5:** While midwestern species, such as understory plants in Wisconsin, are showing changes in range, they may not be shifting quickly enough to keep up with changes in climate. The panels here represent 78 plant species, showing (a) observed changes in the center of plant species abundances (centroids) from the 1950s to 2000s, (b) the direction and magnitude of changes in climate factors associated with those species, and (c) the lag, or difference, between where the species centroid is now located and where the change in climate factors suggests it should be located in order to keep pace with a changing climate. Source: adapted from Ash et al. 2017.[141] ©John Wiley & Sons, Ltd.

## Coldwater Fish at Risk

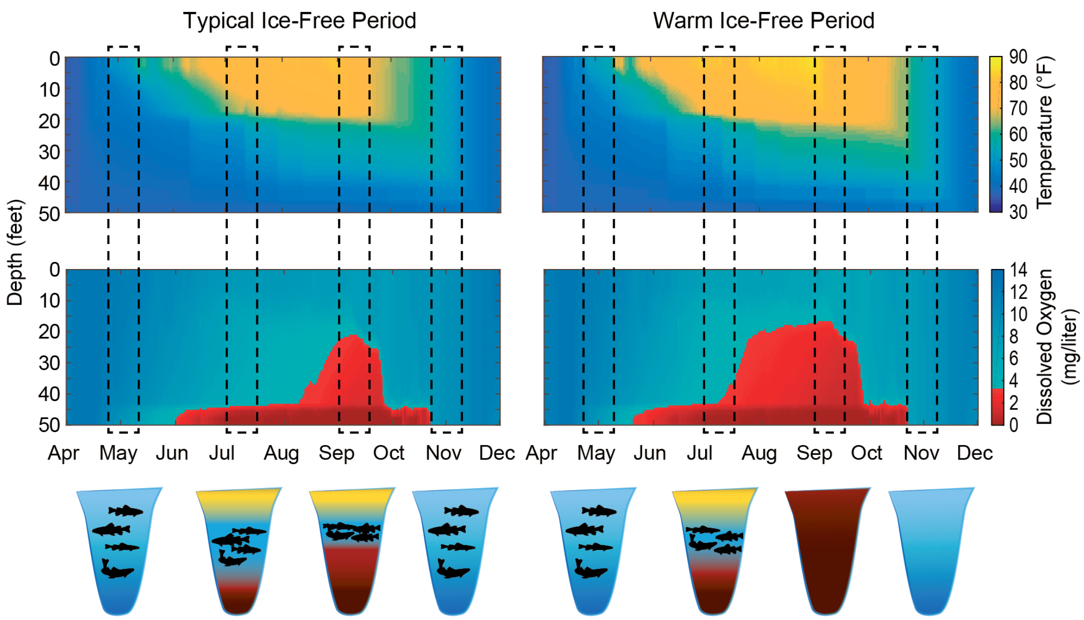



**Figure 21.6:** The graphic shows the oxythermal (oxygen and temperature) habitat of coldwater fish in midwestern inland lakes, illustrated by water depth under (left) a typical ice-free period and (right) a warm ice-free period (right). The top plots show water temperatures during the ice-free period, and the bottom plots show the dissolved oxygen concentrations. The schematics at the bottom illustrate the area of the lake that is ideal habitat for coldwater fish (in blue) and areas that represent water outside of the temperature or dissolved oxygen limit (in yellow and red, respectively). The left plots show how available habitat "squeezes" during a typical year, while the right plots illustrate a complete loss of suitable habitat during very warm years. Source: Madeline Magee, University of Wisconsin.

Taken individually, responses like range shifts, changes in local abundance, or changes in phenology may indicate that a species is successfully adapting to new conditions, or conversely may indicate a species is under stress. The extent to which responses indicate risk and the challenge of attributing changes to climate drivers when systems are exposed to many additional stressors are important sources of uncertainty that likely slow progress on climate change adaptation within the resource management sector.[155,156] Further, while evidence of species- and ecosystem-level responses to direct climate change impacts is increasing, many of the most immediate risks are even more challenging to track, because they relate to climate-driven enhancement of existing stressors, such as habitat loss and degradation, pollution, the spread of invasive species, and drainage and irrigation practices in agricultural landscapes.[138,157] As species are lost from midwestern ecosystems, there likely will be a net loss of biodiversity, as numerous additional stressors, especially widespread land conversion across the southern Midwest, limit opportunities for these gaps to be filled by species moving in from other regions (Ch. 7: Ecosystems, KM 1 and 2).[158,159]

While movement of species from the south-central United States could help sustain species-diverse ecosystems as some of the Midwest's current species move north, these range expansions can further stress current species. Many species and ecosystems in the Midwest, especially the Upper Midwest, are best suited to survive and compete for resources when winter conditions are harsh and growing seasons are short. As winter warms and the growing season extends, species from the south-central United States, as well as species from outside the country that are more traditionally viewed as invasive species, are expected to be able to grow faster and take advantage of these changes, increasing the rate of loss of the region's native species.[160,161] For invasive insect pests, these impacts may be compounded as extended growing seasons allow time for additional generations to be produced in a single season;[162] the same mechanism can promote higher impacts from native insect pests, as well. Given that some native species will decline in the region, to maintain or increase species diversity, some managers are beginning to plan for and even promote some native plant species that are present in a region, but more common to the south, as conditions change. While these can be important strategies for maintaining diversity and ecosystem functions, especially in isolated habitats where inward migration is not likely, careful consideration of the source of plant stocks is important when seeking to avoid introducing new or more competitive genotypes.[163] Further, as some native species decline, managers will benefit from increased vigilance in keeping potential invasive species from outside of North America from gaining a foothold.

Declines in native pollinator species are another important concern in the Midwest, as both native and managed pollinator species (typically nonnative bee species) play vital roles in supporting food production and farmer livelihoods and are critical for supporting wild plant reproduction and the diversity of ecosystems.[164,165] Key threats to this diverse group of insects, mammals, and birds include habitat loss and degradation, pathogens, pesticide use, and invasive species.[164,165,166] Most native and agricultural crops that require a pollinator are pollinated by insects, and where information is available, declines in populations of pollinator insects in the Midwest have primarily been linked to the expansion of intensive agriculture.[167,168,169,170] In addition to habitat loss, climate change is likely to act as an added stressor for many species, through many different mechanisms.[164] Many insects may be limited by their ability to shift to new habitats as conditions change; for example, many bumble bee species are showing population declines at southern range edges but not expanding as quickly at northern range edges.[171] It is likely that pollinators that specialize on one or a few species for some aspect of their life history will be particularly vulnerable.[172] Within the Midwest, observed high rates of decline in the monarch butterfly,[167] which relies on milkweed species as a host plant, are the focus of a network of outreach and ambitious multi-partner conservation efforts that are helping raise awareness of pollinator declines and links between pollinators and habitat availability.[173] These efforts, boosted by research demonstrating that habitat restoration can help sustain pollinator populations,[174,175] provide examples of how to help support the adaptation of this critical group of species.

Perhaps more than in any other region of the United States, human land use has influenced the structure and function of natural systems of the Midwest. Widespread conversion of natural systems to agriculture has changed much of the region's water and energy balance (Ch. 5: Land Changes, KM 1). When vegetation has been removed or undergoes a major change, runoff and flooding both tend to increase.[24,176,177] As land has been cleared for agriculture and cities, it simultaneously has lost the capacity to store water due to the resulting conversion to pavement, compaction of soils, and widespread loss of wetlands. More than half of the region's wetlands have been drained (Ch. 22: N. Great Plains, Case Study "Wetlands and the Birds of the Prairie Pothole Region"); in states at the southern end of the region, fewer than

10%–15% of presettlement wetlands remained in the 1980s.[178] The growth of agriculture and loss of wetlands in the Midwest mean that changes to the timing, type (snow or rain), and amount of precipitation are acting on a system that is already highly altered in ways that tend to promote flooding.[24] Climate change modeling suggests that the southern half of the Midwest likely will see increases in saturated soils, which also indicates risks to agriculture and property from inundation and flooding;[179] recent work incorporating land-use change and population changes also suggests the number of people at risk from flooding will increase across much of the Midwest.[180] However, understanding these relationships also highlights important climate adaptation strategies. For example, restoring systems like wetlands and forested floodplains and implementing agricultural best management strategies that increase vegetative cover (such as cover crops and riparian buffers) can help reduce flooding risks and protect water quality (Figure 21.7).[23,24,25]

### Wetland Restoration Projects Can Help Reduce Impacts

**Figure 21.7:** The Blausey Tract restoration project on the U.S. Fish and Wildlife Service's Ottawa National Wildlife Refuge (Ohio) restored 100 acres of former Lake Erie coastal wetlands that were previously in row crop production. In addition to providing habitat for wildlife and fish, these wetlands help reduce climate change impacts by storing water from high-water events and by filtering nutrients and sediments out of water pumped from an adjacent farm ditch. This work was carried out by two conservation groups, The Nature Conservancy and Ducks Unlimited, in partnership with the U.S. Fish and Wildlife Service, and was funded by The Great Lakes Restoration Initiative.[186,187] (top) Shown here is the Blausey Tract restoration site in early spring of 2011, prior to the restoration activities. (bottom) In the spring of 2013, just two years after the start of restoration, the site already was providing important habitat for wildlife and fish. Photo credits: (top) ©The Nature Conservancy, (bottom) Bill Stanley, ©The Nature Conservancy.

As the flooding risk example above illustrates, understanding both the history of change and how future climate patterns can drive additional changes is useful for identifying meaningful strategies for reducing risks to both people and biodiversity through strategically protecting and restoring ecosystems. Since the Third National Climate Assessment,[27] the recognition, promotion, and implementation of green or ecosystem-based climate change adaptation solutions have expanded. While the idea of using natural systems to reduce risks and provide benefits to society is not new, efforts to document and quantify benefits, costs, and costs savings (relative to hard, or "gray," infrastructure) of these types of approaches are increasing.[181] These approaches often help replace systems that have been lost, such as Great Lakes coastal wetlands, prairies, and vegetated floodplains along rivers and streams that slow water flows and act as sponges that keep floodwaters from people, property, and infrastructure (Figure 21.7),[182,183] or tree cover that increases shade and improves urban air quality.[181,184] The important role of nature-based solutions like reforestation for mitigating climate change is also increasingly being recognized and quantified.[185] From the perspective of protecting the biodiversity of the Midwest, adaptation and mitigation strategies that incorporate protection or restoration of natural systems can be a great win-win approach, because they often add habitat and restore ecological and hydrological functions that were reduced as a result of land conversion.

### Box 21.1: Focus on the Great Lakes

The Great Lakes contain 20% of the world's surface freshwater, provide drinking water and livelihood to more than 35 million people,[188] and allow for important economic and cultural services such as shipping and recreation. The Great Lakes influence regional weather and climate conditions and impact climate variability and change across the region. The lakes influence daily weather by 1) moderating maximum and minimum temperatures of the region in all seasons, 2) increasing cloud cover and precipitation over and just downwind of the lakes during winter, and 3) decreasing summertime convective clouds and rainfall over the lakes.[189,190] In recent decades, the Great Lakes have exhibited notable changes that are impacting and will continue to impact people and the environment within the region.[191] In particular, lake surface temperatures are increasing,[11,12] lake ice cover is declining,[12,13,14] the seasonal stratification of temperatures in the lakes is occurring earlier in the year,[15] and summer evaporation rates are increasing.[13,16]

Along the Great Lakes, lake-effect snowfall has increased overall since the early 20th century. However, studies have shown that the increase has not been steady, and it generally peaked in the 1970s and early 1980s before decreasing.[193] As the warming in the Midwest continues, reductions in lake ice may increase the frequency of lake-effect snows until winters become so warm that snowfall events shift to rain.[194,195]

Lake-surface temperatures increased during the period 1985–2009 in most lakes worldwide, including the Great Lakes.[196] The most rapid increases in lake-surface temperature occur during the summer and can greatly exceed temperature trends of air at locations surrounding the lakes.[197] From 1973 to 2010, ice cover on the Great Lakes declined an average of 71%;[14] although ice cover was again high in the winters of 2014 and 2015,[192] a continued decrease in ice cover is expected in the future.[198,199]

Water levels in the Great Lakes fluctuate naturally, though levels more likely than not will decline with the changing climate.[200] A period of low water levels persisted from 1998 to early 2013. A single warm winter in

### Box 21.1: Focus on the Great Lakes, *continued*

## The Changing Great Lakes

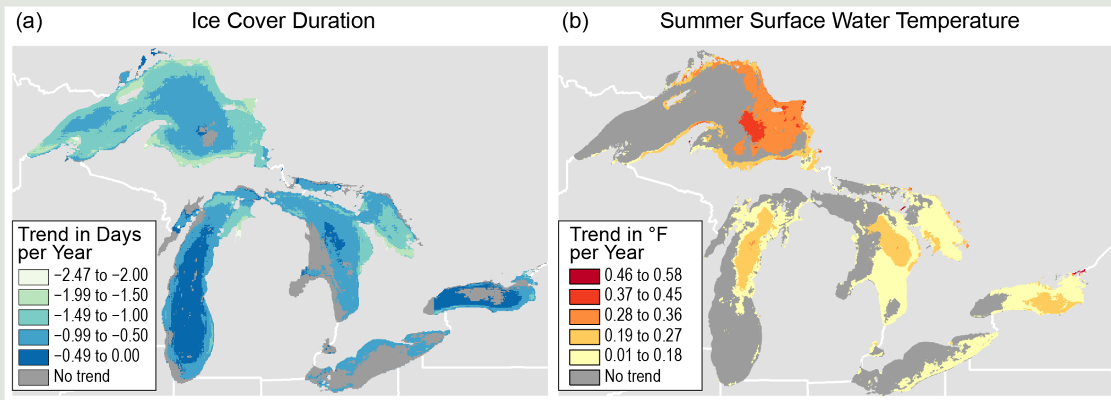



**Figure 21.8:** The duration of seasonal ice cover decreased in most areas of the Great Lakes between 1973 and 2013, while summer surface water temperature (SWT) increased in most areas between 1994 and 2013. (a) The map shows the rate of change in ice cover duration. The greatest rate of decrease in seasonal ice cover duration is seen near shorelines, with smaller rates occurring in the deeper central parts of Lakes Michigan and Ontario, which rarely have ice cover. (b) The map shows the rate of change in summer SWT. The greatest rates of increase in summer SWT occurred in deeper water, with smaller increases occurring near shorelines. Source: adapted from Mason et al. 2016.[192] Used with permission from Springer.

1997–1998 (corresponding to a major El Niño event) and ongoing increases in sunlight reaching the lake surface (due to reduced cloud cover) were likely strong contributors to these low water levels.[11] Following this period, water levels rose rapidly. Between January 2013 and December 2014, Lake Superior's water rose by about 2 feet (0.6 meters) and Lakes Michigan and Huron's by about 3.3 feet (1.0 meter).[201] Recent projections with updated methods of lake levels for the next several decades under 64 global model-based climate change simulations (from the Coupled Model Intercomparison Project Phase 5, or CMIP5 database, using the RCP4.5, RCP6.0, and RCP8.5 scenarios) on average show small drops in water levels over the 21st century (approximately 6 inches for Lakes Michigan and Huron and less for the other lakes), with a wide range of uncertainty.[200]

An important seasonal event for biological activity in the Great Lakes is the turnover of water, or destratification, which historically has occurred twice per year. Destratification occurs during the fall as the water temperature drops below a threshold of 39°F, the point at which freshwater attains its maximum density, and again during the spring when the water temperature rises above that threshold. The resultant mixing carries oxygen down from the lake surface and nutrients up from the lake bottom and into the water column. In a pattern that is similar to changes in duration of the growing season on land, the climate projections suggest that the overturn in spring that triggers the start of the aquatic "growing season" will happen earlier, and the fall overturn will happen later.[198,202] This trend toward a longer stratified season has been documented at locations in Lake Superior.[197,203] As the duration of the stratified period increases, the risk of impacts from low oxygen levels at depth and a lack of nutrient inputs at the surface increases, potentially leading to population declines of species in both zones. As warming trends continue, it is possible that a full overturning may not occur each year.[204] For example, lake surface temperatures failed to drop below the 39°F threshold during the winters of 2012 and 2017 in parts of southern Lake Michigan and Lake Ontario (see https://coastwatch.glerl.noaa.gov/glsea/glsea.html). When this lack of water mixing contributes to persistently low oxygen levels, the result may be reductions in the growth of phytoplankton (algae) and zooplankton (microscopic animals) that form the basis of aquatic food webs, potentially leading to cascading effects on the health and abundance of species across all levels of Great Lakes food webs.[202,205,206]

### Box 21.1: Focus on the Great Lakes, *continued*

Ecological impacts of climate change in the Great Lakes occur in the context of multiple stressors, as these important ecosystems are under stress from pollution, nutrient and sediment inputs from agricultural systems, and invasive species (Ch. 17: Complex Systems, KM 1).[9,10] Human influence on habitats is another stressor. Examples include coastal wetland damage[207] and disturbance by human structures that change habitat conditions and water flow patterns.[208] Fish harvest and other management activities also have influences on populations.[209] Especially in Lake Erie, runoff from agricultural watersheds can carry large volumes of nutrients and sediments that can reduce water quality, potentially leading to hypoxia (inadequate oxygen supply),[210,211] an occurrence that is predicted to be more likely as the climate continues to change.[10] Increased water temperatures and nutrient inputs also contribute to algal blooms, including harmful cyanobacterial algae that are toxic to people, pets, and many native species.[212,213]

As with the inland lake fish described above (see Figure 21.6), climate change is expected to impact the species and fisheries of the Great Lakes.[214] However, the vast size and low temperatures in these lakes suggest that mortality events from temperature are a much lower risk. One key aspect of the influence of warming lakes on fish growth is the availability of suitable thermal habitat, as ectotherms, or cold-blooded species, can grow faster in warmer water due to temperature impacts on metabolic rates. Fish can behaviorally thermoregulate, meaning they can migrate to the portion of the water column that contains water of the particular species' preferred temperature.[215] Bottom-water temperatures in the deep parts of the lakes are expected to remain close to 39°F, while temperatures above the seasonal thermocline (the distinct temperature transition zone separating warmer surface waters from colder waters below) are expected to warm considerably.[202] This means that fish will be able to find habitats that favor higher growth rates for a longer period of time during the year. This same growth rate increase may occur for some species in smaller lakes, but the potential for exceeding critical thresholds is likely higher (Figure 21.6). If sufficient food is available, this will enhance the growth rates for economically important species like yellow perch and lake whitefish even though they are classed as cool-water and coldwater fishes, respectively.[216] It remains unclear, however, if a sufficient food supply will be available to sustain this increase in growth rates.

While some native fish may show enhanced growth, these same changes can influence the survival and growth of invasive species. Nonnative species such as alewife[217] and zebra and quagga mussels[218] have had dramatic impacts on the Great Lakes. Warmer conditions may lead to increases in invasion success and may increase the impact of invasive species that are already present. For example, sea lamprey are parasitic fish that are native to the Atlantic Ocean, and in the Great Lakes, they are the focus of several forms of control efforts.[219] Climate change has potential to reduce the effectiveness of these efforts. In the Lake Superior watershed, in years with longer growing seasons (defined as the number of days with water temperatures above 50°F), lamprey reach larger weights before spawning.[161] Larger body sizes suggest a greater impact on other fish species, because larger lamprey produce more eggs and require more food to survive.[161]

Coastal communities and several economic sectors, including shipping, transportation, and tourism, are vulnerable to the aforementioned climate impacts (Ch. 8: Coastal, KM 1). While the most recent research[200] underscores the great uncertainty in future lake levels, earlier research showed that scenarios of decreasing lake levels will increase shipping costs even if the shipping season is longer,[220] or that lower ice cover could increase the damage to coastal infrastructure caused by winter storms.[221,222] While several coastal communities have expressed willingness to integrate climate action into planning efforts, access to useful climate information and limited human and financial resources constrain municipal action. Producers and users of climate

**Box 21.1: Focus on the Great Lakes, *continued***

information are working together to create customized climate information and resources, which increases trust and legitimacy, addressing this challenge (see Case Study "Great Lakes Climate Adaptation Network"). This has been demonstrated in projects, for instance, with marinas and harbors in Michigan, with ravine management in Illinois and Wisconsin, and with the Chicago Climate Action Plan in Illinois.[223,224,225,226] Although many communities in the region are taking steps to incorporate climate change and related impacts into policy and planning decisions, many more may benefit from using their existing stakeholder networks to engage with producers of climate information and build upon lessons learned from leaders in the region.[227]

## Key Message 4

### Human Health

**Climate change is expected to worsen existing health conditions and introduce new health threats by increasing the frequency and intensity of poor air quality days, extreme high temperature events, and heavy rainfalls; extending pollen seasons; and modifying the distribution of disease-carrying pests and insects. By mid-century, the region is projected to experience substantial, yet avoidable, loss of life, worsened health conditions, and economic impacts estimated in the billions of dollars as a result of these changes. Improved basic health services and increased public health measures—including surveillance and monitoring—can prevent or reduce these impacts.**

Climate change directly and indirectly impacts human health (Ch. 14: Human Health, KM 1). Midwestern populations are already experiencing adverse health impacts from climate change, and these impacts are expected to worsen in the future.[26,27] The risks are especially high for people who are less able to cope because characteristics like age, income, or social connectivity make them more vulnerable.[228]

### Air Quality

Degraded air quality impacts people living in the Midwest. Increases in ground-level ozone and particulate matter are associated with the prevalence of various lung and cardiovascular diseases, which can lead to missed school days, hospitalization, and premature death (Ch. 13: Air Quality, KM 1).[26,28] Despite successful efforts to reduce particulate matter and ozone pollution, climate change could increase the frequency of meteorological conditions that lead to poor air quality.[26,229] In the absence of mitigation, ground-level ozone concentrations are projected to increase across most of the Midwest, resulting in an additional 200 to 550 premature deaths in the region per year by 2050.[28] These account for almost half of the total projected deaths due to the climate-related increase in ground-level ozone nationwide and may cost an estimated $4.7 billion (in 2015 dollars).[28]

Pollen production has been on the rise in the Midwest in recent years, with pollen seasons starting earlier and lasting longer (Ch. 13: Air Quality, KM 3).[28,230] People, particularly children, with asthma and other respiratory diseases are especially vulnerable to aeroallergens.[231] Aeroallergens can cause allergic rhinitis and exacerbate asthma and sinusitis.[231] Oak pollen may be responsible for an increase of 88 to 350 asthma-related emergency room visits by 2050 under the higher scenario (RCP8.5), with an estimated average annual cost ranging between $43,000 and $170,000 (in 2015 dollars).[28]

## Projected Changes in Ozone-Related Premature Deaths

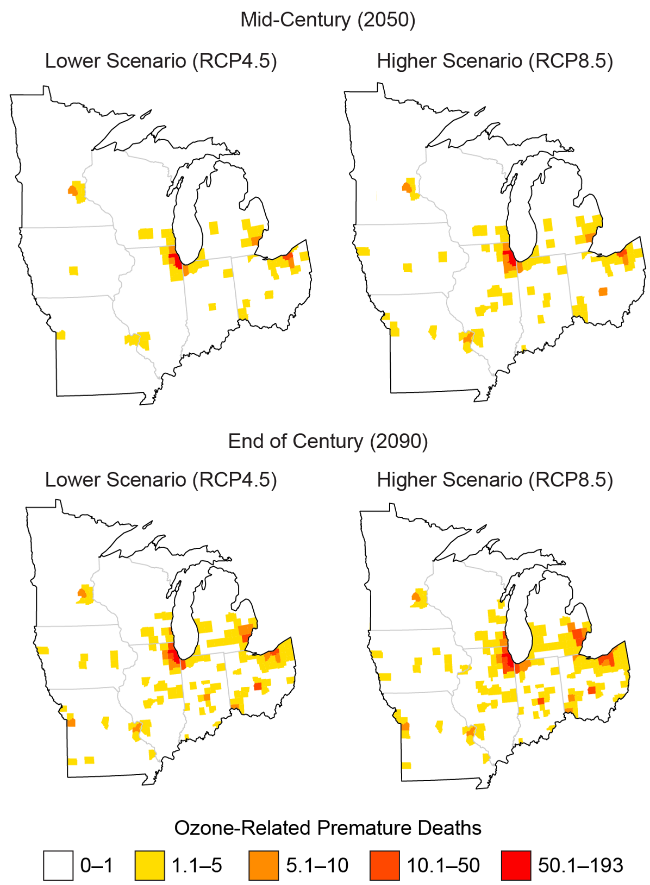



**Figure 21.9:** Maps show county-level estimates for the change in average annual ozone-related premature deaths over the summer months in 2050 (2045–2055) and 2090 (2085–2095) compared to 2000 (1995–2005) under the lower and higher scenarios (RCP4.5 and RCP8.5) in the Midwest. The results represent the average of five global climate models. Source: adapted from EPA 2017.[28]

### Temperature

Increased daytime and nighttime temperatures are associated with heat-related diseases (for example, dehydration and heatstroke) and death in the Midwest.[26,232] Extreme heat in urban centers like Chicago, St. Louis, Cincinnati, Minneapolis/St. Paul, Milwaukee, and Detroit can cause dangerous living conditions.[26,232,233,234,235,236] High rates of heat-related illness also have been observed in rural populations,[235] where occupational exposure to heat and access to care is a concern. Exposure to high temperatures impacts workers' health, safety, and productivity.[29]

Future risk of heat-related disease could be significantly higher. As an example, Figure 21.10 shows the projected number of days over 100°F in Chicago over the 21st century using 32 models and two scenarios. Currently, days over 100°F in Chicago are rare. However, they could become increasingly more common in both the lower and higher scenarios (RCP4.5 and RCP8.5). The higher scenario (RCP8.5) yields a wider range and a higher number of days over 100°F than the lower scenario (RCP4.5), especially by 2070–2090. Near the upper end of the model results (95th percentile) at late-century, with the potential for almost 60 days per year over 100°F, conditions could be more typical of present-day Las Vegas than Chicago. While the degree of uncertainty becomes larger further into the future, all model results show an increase in heat in the last two periods of the 21st century—changes that would pose a significant challenge to Chicago and other midwestern cities.

Compared to other regions where worsening heat is also expected to occur, the Midwest is projected to have the largest increase in extreme temperature-related premature deaths under the higher scenario (RCP8.5): by 2090, 2,000 additional premature deaths per year, compared to the base period of 1989–2000, are projected due to heat alone without adaptation efforts.[28] Northern midwestern communities and vulnerable populations (see Key Message 6) that historically have not experienced high temperatures may be at risk for heat-related disease and death. Risk of death from extremely cold temperatures will decrease under most climate projection scenarios.[28]

Unabated climate change will translate into costs among the workforce and in utility bills, potentially exacerbating existing health disparities among those most at risk. By 2050, increased temperatures under the higher scenario (RCP8.5) are estimated to cost around $10 billion (in 2015 dollars) due to premature deaths and lost work hours.[28] Increased electricity demand is estimated to amount to $1.2 billion by 2090 (in 2015 dollars).[28] For those who are chronically ill or reliant on electronic medical devices, the increased cost of electricity, which contributes to energy insecurity,[28] may introduce financial and health burdens.

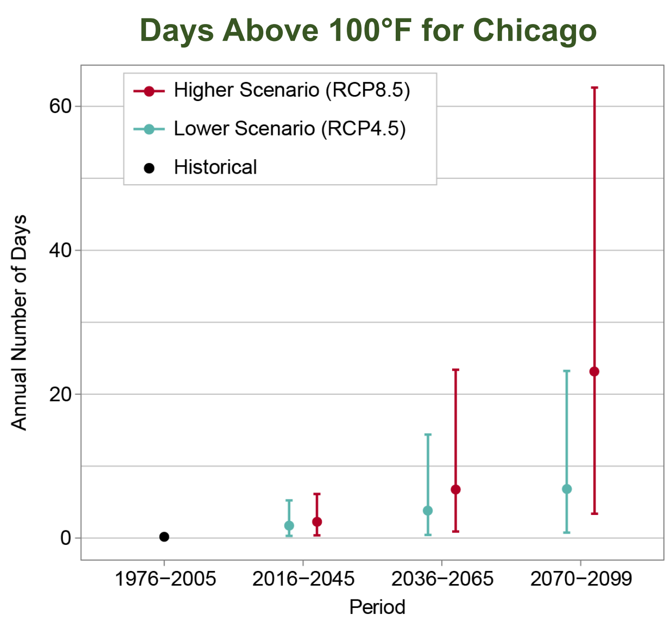



**Figure 21.10:** This graph shows the annual number of days above 100°F in Chicago for the historical period of 1976–2005 (black dot) and projected throughout the 21st century under lower (RCP4.5, teal) and higher (RCP8.5, red) scenarios. Increases at the higher end of these ranges would pose major heat-related health problems for people in Chicago. As shown by the black dot, the average number of days per year above 100°F for 1976–2005 was essentially zero. By the end of the century (2070–2099), the projected number of these very hot days ranges from 1 to 23 per year under the lower scenario and 3 to 63 per year under the higher scenario. For the three future periods, the teal and red dots represent the model-weighted average for each scenario, while the vertical lines represent the range of values (5th to 95th percentile). Both scenarios show an increasing number of days over 100°F with time but increasing at a faster rate under the higher scenario. Sources: NOAA NCEI and CICS-NC.

### Precipitation

An increase in localized extreme precipitation and storm events can lead to an increase in flooding.[27] River flooding in large rivers like the Mississippi, Ohio, and Missouri Rivers and their tributaries can flood surface streets and low-lying areas, resulting in drinking water contamination, evacuations, damage to buildings, injury, and death.[26] Flooded buildings can experience mold growth that can trigger asthma attacks and allergies during cleanup efforts.[237] Mental stress following flooding events can cause substantial health impacts, including sleeplessness, anxiety, depression, and post-traumatic stress disorder.[238] Similarly, drought has been identified as a slow-moving stressor that contributes to acute and chronic mental health impacts such as anxiety and depression.[239]

Precipitation events can transport pathogens that cause gastrointestinal illnesses, putting populations who rely on untreated groundwater (such as wells) at an increased risk of disease,[240] particularly following large rainfall events.[241] Many midwestern communities use wells as their drinking water sources. Adaptive measures, such as water treatment installations, may substantially reduce the risk of gastrointestinal illness, in spite of climate change.[240]

### Habitat Conditions

Climate-related changes in habitats (see Key Message 3) for disease-carrying insects like the mosquito found in the Midwest (*Culex pipiens* and *Culex tarsalis*) that transmits West Nile virus (WNV) and the blacklegged, or deer, tick (*Ixodes scapularis*) that transmits Lyme disease have been associated with higher rates of infection.[242,243] Northern expansion of the *Culex* species in the Midwest is expected to result in upwards of 450 additional WNV cases above the 1995 baseline by 2090 absent greenhouse gas mitigation.[28]

Harmful algal blooms (Box 21.1), such as one that occurred in August 2014 in Lake Erie, can introduce cyanobacteria into drinking and recreational water sources, resulting in restrictions on access and use.[28] Contact with and consumption of water contaminated with cyanobacteria have been associated with skin and eye irritation, respiratory illness, gastrointestinal illness, and liver and kidney damage.[26] The occurrence of conditions that encourage cyanobacteria growth, such as higher water temperatures, increased runoff, and nutrient-rich habitats, are projected to increase in the Midwest.[28]

### Challenges and Opportunities

Climate-sensitive health impacts are complex and dynamic. Coordination across public health, emergency preparedness, planning, and communication agencies can maximize outreach to the most at-risk populations while directing activities to reduce health disparities and impacts.[244] Public health agencies in the Midwest have developed interdisciplinary communities of practice around climate and health adaptation efforts, effectively enhancing the resilience of the region's public health systems.[244,245,246,247,248] Activities around increased surveillance of climate-sensitive exposures and disease are gaining momentum and interest among practitioners and researchers.[249,250]

Actions tied to reducing contributions to global climate change can result in direct co-benefits related to health and other outcomes (such as economic development).[251] Reducing emissions related to energy production and transportation may involve changes to fuel sources, vehicle technology, land use, and infrastructure.[251] Active transportation, such as biking and walking, has been found to significantly decrease disease burden.[252,253,254] A study of the 11 largest midwestern metropolitan areas estimated a health benefit of nearly 700 fewer deaths per year by swapping half of short trips from car to bike.[255] As Midwest Rust Belt metropolitan areas revitalize and reinvest, there are opportunities to prioritize active living to maximally reduce climate change drivers and improve health.

## Key Message 5

### Transportation and Infrastructure

**Storm water management systems, transportation networks, and other critical infrastructure are already experiencing impacts from changing precipitation patterns and elevated flood risks. Green infrastructure is reducing some of the negative impacts by using plants and open space to absorb storm water. The annual cost of adapting urban storm water systems to more frequent and severe storms is projected to exceed $500 million for the Midwest by the end of the century.**

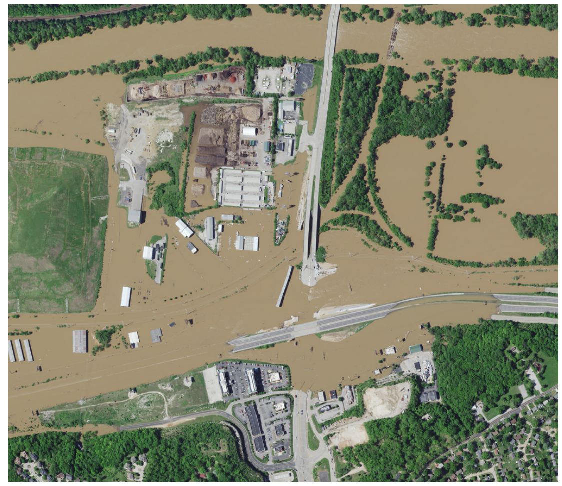
Climate change poses several challenges to transportation and storm water systems in the Midwest. Annual precipitation in the Midwest has increased by 5% to 15% from the first half of the last century (1901–1960) compared to present day (1986–2015).[193] Winter and spring precipitation are important to flood risk in the Midwest and are projected to increase by up to 30% by the end of this century. Heavy precipitation events in the Midwest have increased in frequency and intensity since 1901 and are projected to increase through this century.[193]

There has been an increase in extreme precipitation events that overwhelm storm water sewage systems, disrupt transportation networks, and cause damage to infrastructure and property. Runoff from extreme precipitation events can exceed the capacity of storm water systems, resulting in property damage, including basement backups (Ch. 11: Urban, KM 2).[37,256] In addition, in metropolitan areas with older sewer systems that combine sanitary sewage with storm water, extreme rain can result in the release of raw sewage into rivers and streams, posing both health and ecological risks.[257] These releases, known as combined sewer overflows (CSO), pose challenges to major sources of drinking water including the Mississippi River[258] and the Great Lakes.[259,260] On the Great Lakes, increases in CSO frequency and volume are projected under mid-high and higher scenarios (RCP6.0 and RCP8.5).[261] The U.S. Environmental Protection Agency (EPA) estimates that the cost of adapting urban storm water systems to handle more intense and frequent storms in the Midwest could exceed $480 million per year (in 2015 dollars) by the end of the century under either the lower or higher scenario (RCP4.5 or RCP8.5).[28] Extreme precipitation events also affect transportation systems (Ch. 12: Transportation, KM 1). Heavy rainstorms can result in the temporary closure of roadways. In addition, faster streamflow caused by extreme precipitation can erode the bases of bridges, a condition known as scour. A study of six Iowa bridges deemed to be critical infrastructure found that under all emissions scenarios (in the Coupled Model Intercomparison Project Phase 3), each location was projected to have increased vulnerability from more frequent episodes of overtopping and potential scour.[55] The EPA estimates that the annual cost of maintaining current levels of service on midwestern bridges in the face of increased scour damage from climate change could reach approximately $400 million in the year 2050 under either the lower or higher scenario (RCP4.5 or RCP8.5).[28]

In addition to its impacts on infrastructure, heavy precipitation also affects the operation of roadways by reducing safety and capacity while increasing travel times (Ch. 12: Transportation, KM 1). Projected increases in the number of extreme precipitation events have been linked to an increased risk of traffic crashes.[262] Intelligent Transportation Systems (ITS) use sensors and cameras to monitor road conditions. This allows for rapid deployment of emergency response vehicles and use of electronic signage to reroute traffic. Such systems allow transportation agencies to minimize the adverse impacts associated with extreme weather.[263]

Flooding on major rivers also poses a challenge to Midwest communities. Major river floods differ from flash floods on smaller streams in that they affect a larger area and require longer periods of heavy precipitation to create flood conditions. The Nation's two largest rivers, the Mississippi and the Missouri, flow through the Midwest. River floods can cause loss of life, as well as significant property damage. River floods have caused the closure of interstate highways in the Midwest and temporary inundation of secondary roads. During floods in May 2017, more than 400 state roads in Missouri were closed due to flooding, including several stretches of Interstate 44 (Figure 21.11).[264] High water also disrupts barge traffic on the Mississippi River.[265,266,267,268,269,270] Billion-dollar floods in the Midwest have occurred three times in the last quarter-century.[271] Climate projections suggest an increased risk of inland flooding under either the lower or higher scenario (RCP4.5 or RCP8.5). Average annual damages from heightened flooding risk in the Midwest are projected to be in excess of $500 million (in 2015 dollars) by 2050.[28]

Changes in temperature also can pose challenges to infrastructure. Extreme heat creates material stress on road pavements, bridge expansion joints, and railroad tracks. Milder winter temperatures, however, may be expected to partially offset these damages by reducing the amount of rutting caused by the freeze–thaw cycle. Even taking into account



**River Flooding in the Midwest**

**Figure 21.11:** This composite image shows portions of Interstate 44 near St. Louis that were closed by Meramec River flooding in both 2015 and 2017. The flooding shown here occurred in May 2017. Image credit: Surdex Corporation.

the benefits of milder winters for paved surfaces, the EPA estimates that higher temperatures associated with unmitigated climate change would result in approximately $6 billion annually in added road maintenance costs and over $1 billion in impacts to rail transportation by 2090 (in 2015 dollars).[28]

Green infrastructure—the use of plants and open space to manage storm water—is helping communities in the Midwest become more resilient to challenges associated with heavy precipitation. At the site or neighborhood level, rain gardens and other planted landscape elements collect and filter rainwater in the soil, slowing runoff into sewer systems. Permeable pavements on parking lots allow water to be stored in the soil. Trees planted next to streets also provide important storm water management benefits. Larger-scale projects include preservation of wetlands. In addition to their storm water management benefits, some types of green infrastructure, such as urban trees and green roofs, contribute to climate change mitigation by acting as carbon sinks.[272,273,274]

There are many examples of green infrastructure projects in the Midwest, though not all explicitly identify climate change as a rationale. The examples below enhance resilience to the heavy rains that are projected to become more frequent.

- The Cermak/Blue Island Sustainable Streetscape Project in the Pilsen neighborhood of Chicago uses bioswales, rain gardens, and permeable pavements to reduce up to 80% of storm water runoff. It also uses street trees and other vegetation to reduce the urban heat island effect while also providing an attractive public space.[275]

- The Metropolitan Sewer District in St. Louis has embarked upon a $100 million rainscaping project designed to divert storm water runoff in the northern portion of the City of St. Louis and adjacent north St. Louis County.[276]

- The City of Minneapolis uses street trees to reduce storm water runoff through enhanced evaporation and infiltration of water into the soil.[277] The City of Cleveland also prioritizes tree planting as an adaptation strategy, with an emphasis on increasing the tree canopy in low-income neighborhoods. In addition to its storm water management benefits, urban forestry also reduces the urban heat island effect and acts as a carbon sink.[278]

At the scale of a metropolitan region, preservation and restoration of streams, floodplains, and watersheds are enhancing biodiversity while also reducing storm water runoff.

- *Open Space Preservation*: Many communities in the Midwest are recognizing that preservation of open space, particularly in floodplains, is a cost-effective method for managing storm water. Ducks Unlimited, a non-profit organization, has purchased conservation easements that restrict future development on nearly 10,000 acres of floodplain around the confluence of the Mississippi and Missouri Rivers. In the Milwaukee area, the Ozaukee Washington Land Trust has preserved more than 6,000 acres of forests, wetlands, and open space through acquisitions and the purchase of conservation easements, preserving lands important for absorbing rainwater and filtering toxins from sediment.[279,280]

- *Stream Restoration*: Several midwestern communities are turning to dechannelization (the removal of concrete linings placed in waterways) and daylighting (bringing back to the surface streams that had been previously buried in pipes) as methods of storm water management. The Milwaukee Metropolitan Sewerage District is currently undertaking a dechannelization of the Kinnickinnic River. According to the District, the concrete lining of the waterway actually makes the waterway more dangerous during heavy rain. Flooding motivated the City of Kalamazoo to daylight a 1,500-foot section of Arcadia Creek in the downtown district.[281,282]

- *Ravine Restoration*: Lake Michigan's western shore in Wisconsin and northern Illinois holds more than 50 small watersheds, known locally as ravines. Storm water runoff subjects these ravines to serious erosion, which threatens property and infrastructure. The Great Lakes Alliance has produced guides to reduce erosion through best management practices, including stream buffers, use of native plants for stabilization, and reducing the steepness or gradient of the stream bank.[223]

## Key Message 6

### Community Vulnerability and Adaptation

**At-risk communities in the Midwest are becoming more vulnerable to climate change impacts such as flooding, drought, and increases in urban heat islands. Tribal nations are especially vulnerable because of their reliance on threatened natural resources for their cultural, subsistence, and economic needs. Integrating climate adaptation into planning processes offers an opportunity to better manage climate risks now. Developing knowledge for decision-making in cooperation with vulnerable communities and tribal nations will help to build adaptive capacity and increase resilience.**

### Vulnerability and Adaptation

In the Midwest, negative impacts related to climate change are projected to affect human systems, including cities, rural and coastal communities, and tribes.[28,283,284] Higher temperatures, increasing variation in precipitation patterns, and changes in lake levels are likely to increase the vulnerability of these systems to extreme events (including flooding, drought, heat waves, and more intense urban heat island effects), compounding already existing stressors such as economic downturns, shrinking cities, and deteriorating infrastructure.[285] Extreme heat such as that experienced in July 2011 (with temperatures reaching over 100°F in the majority of the Midwest) is expected to intensify,[286] and urban heat islands may cause hardships to those most vulnerable, such as the old and infirm and those without resources to control their microclimate (for example, through the use of air conditioning).[287] Under the higher scenario (RCP8.5), extreme heat is projected to result in losses in labor and associated losses in economic revenue up to $9.8 billion per year in 2050 and rising to $33 billion per year in 2090 (in 2015 dollars).[28] Expanding the use of green infrastructure and locating it properly may mitigate the negative impact of heat islands in urban settings (see Key Messages 4 and 5) (see also Ch. 11: Urban, KM 4).

To mitigate or better respond to these impacts, scholars and practitioners highlight the need to engage in risk-based approaches that not only focus on assessing vulnerabilities but also include effective planning and implementation of adaptation options (Ch. 28: Adaptation, KM 3).[32] These place-based approaches actively rely on participatory methodologies to evaluate and manage risk and to monitor and evaluate adaptation actions.[32] However, documented implementation of climate change planning and action in Midwest cities and rural communities remains low. For example, in 2015, only four counties and cities in the region—Marquette and Grand Rapids in Michigan and Dane County and Milwaukee in Wisconsin—had created formal climate adaptation plans, none of which have been implemented.[288] Moreover, a recent study of 371 cities in the Great Lakes region found that only 36 of them could identify a climate entrepreneur, that is, a public official clearly associated with pushing for climate action.[285] Attempts to assess vulnerabilities, especially for poor urban communities, face persisting environmental and social justice barriers, such as lack of participation and historical disenfranchisement,[289] despite evidence that these communities are going to be disproportionately affected by climate impacts.[290] Additionally, in-depth interviews with local decision-makers on water management across scales have suggested that a lack of political and financial support at the state and federal levels is a barrier to adaptation action in cities and counties.[291] While initiatives are underway in the Midwest to mainstream adaptation action—that is, embed and integrate climate adaptation action in what cities already do (see Case Study "Great Lakes Climate Adaptation Network") (see also Ch. 28: Adaptation, KM 5)—there are few examples in the published literature that document failure or success (but see Kalafatis et al. 2015, Vogel et al. 2016[292,293]).

## Case Study: Great Lakes Climate Adaptation Network

The Great Lakes Climate Adaptation Network (GLCAN) is a regional, member-driven peer network of local government staff who work together to identify and act on the unique climate adaptation challenges of the Great Lakes region. GLCAN formed in 2015 as a regional network of the Urban Sustainability Directors' Network (USDN) to unite Great Lakes cities with universities in the region. It has been cooperating actively with a regional climate organization, the Great Lakes Integrated Sciences and Assessments (GLISA), a NOAA-supported program housed at the University of Michigan and Michigan State University, to create climate information in support of decision-making in member cities. In this example of sustained engagement, GLCAN and GLISA work as a boundary chain that moves climate information from producers at the Universities to users in the cities, as well as across cities. This minimizes transaction costs, in terms of human and financial resources, while building trust and legitimacy.[292,294] In one example of this partnership, with funding from USDN, GLCAN and GLISA worked with the Huron River Watershed Council and five Great Lakes cities (Ann Arbor, Dearborn, Evanston, Indianapolis, and Cleveland) to develop a universal vulnerability assessment template that mainstreams the adaptation planning process and results in the integration of climate-smart and equity-focused information into all types of city planning.[295] The template is publicly available;[296] its purpose is to reduce municipal workloads and save limited resources by mainstreaming existing, disparate planning domains (such as natural hazards, infrastructure, and climate action), regardless of city size or location. Based on this work, USDN funded a follow-up project for GLISA to work with additional Great Lakes and Mid-Atlantic cities and a nonprofit research group (Headwaters Economics) to develop a socioeconomic mapping tool for climate risk planning.

### Linked Boundary Chain Model

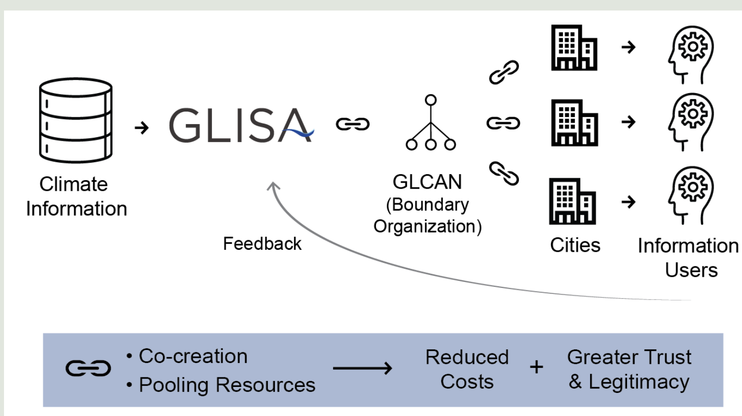



**Figure 21.12:** Shown here is a configuration of the boundary chain employed in the Great Lakes Climate Adaptation Network (GLCAN) Case Study. The information is tailored and moves through different boundary organizations (links in the chain) to connect science to users. By co-creating information and pooling resources throughout the chain, trust and legitimacy are built and cost is decreased. Source: adapted from Lemos et al. 2014.[294] ©American Meteorological Society.

In addition, work on estimating the cost of adaptation nationally and in the Midwest remains limited, though the EPA has estimated that the Midwest is among the regions with the largest expected damages to infrastructure, including the highest estimated damages to roads, rising from $3.3 billion per year in 2050 to $6 billion per year in 2090 (in 2015 dollars) under a higher scenario (RCP8.5), and highest number of vulnerable bridges (Key Message 5).[28] Additionally, economic models that value climate amenities—for example, offering residents the benefits of warmer winters or cooler summers—indicate that while the Midwest is among the regions with the largest predicted amenity loss, certain cities (such as Minneapolis and Minnesota) and subregions (such as upper Michigan) will be among the few places where the value of warmer winters outweighs the cost of hotter summers.[297,298] Limited evidence indicates that household consideration of climate amenities may contribute to reversing long-standing trends in out-migration from the Midwest[298] and that changes in national migration patterns will contribute to population growth in the region.[28] More research is needed to understand how cities in the Midwest might be affected by long-term migration to the region.[31]

### Collaboratively Developing Knowledge and Building Adaptive Capacity

Interactions among producers of climate information (for example, universities and research institutes), end users (such as city planners, watershed managers, and natural resource managers), and intermediaries (for example, information brokers and organizations) play a critical role in increasing the integration and use of climate knowledge for adaptation.[299] In the Midwest, organizations such as the Great Lakes Integrated Sciences and Assessments (GLISA; glisa.umich.edu) and the Wisconsin Initiative on Climate Impacts (wicci.wisc.edu), and research projects such as Useful to Usable (U2U), have created mechanisms and tools, such as climate scenarios, decision support tools, and climate data, that promote the joint development of usable climate information across different types of stakeholders, including city officials, water managers, farmers, and tribal officials.[224,294,300] For example, working closely with corn farmers and climate information intermediaries, including extension agents and crop consultants, in Iowa, Nebraska, Michigan, and Indiana, an interdisciplinary team of climate scientists, agronomists, computer scientists, and social scientists have not only created a suite of decision support tools (see Key Message 1) but also significantly advanced understanding of corn farmers' perceptions of climate change,[301] willingness to adapt,[302] and opportunities for and limitations of the use of climate information in the agricultural sector.[294,303] Strategies being implemented as a result of these collaborations, including the use of green infrastructure and water conservation efforts, are proving effective at reducing sensitivity to the impacts of climate change in the Midwest.[304,305,306] In addition, binational partnerships between the United States and Canada, in support of the Great Lakes Water Quality Agreement, synthesized annual climate trends and impacts for a general audience in a pilot product for 2017 to provide a timely and succinct summary in an easy-to-understand format (Ch. 16: International, KM 4).[307] However, these organizations face challenges including the high costs in interacting with users, contextualizing and customizing climate information, and building trust.[308] The development of new forms of sustained engagement likely would increase the use of climate information in the region.

### Tribal Adaptation

Tribes and Indigenous communities in the Midwest have been among the first to feel the effects of climate change as it impacts their culture, sovereignty, health, economies, and ways of life.[39] The Midwest contains ceded territory—large swaths of land in Minnesota, Wisconsin, and Michigan in which Ojibwe tribes reserved hunting, fishing, and gathering rights in treaties with the United States government.[88] Climate change presents challenges to the Ojibwe tribes in co-managing these resources with other land managers; as the climate changes, various species utilized by tribes are declining and may shift entirely outside of treaty boundaries and reserved lands.[127,309,310] In certain tribal cultures, all beings (species) are important; climate adaptation efforts that favor certain beings at the detriment of others can be problematic. Adaptation to climate change might also mean giving up on something deeply embedded in tribal culture for which no substitute exists.[31] A family sugarbush (a forest stand used for maple syrup), for example, cannot be replaced culturally, spiritually, or economically if the sugar maple range were to shift outside of treaty or reservation boundaries. As the effects of climate change become more pronounced, further research can shed light on how tribal nations are being affected.

Projected changes in climate, particularly increases in extreme precipitation events, will have pronounced impacts on tribal culture and tribal people in the Midwest.[283] Reservations often are located in isolated rural communities, meaning emergency response to flooding presents challenges in getting help to tribal citizens. Additionally, in areas of the Midwest, infestations of the invasive emerald ash borer already are devastating ash tree populations and corresponding Indigenous cultural and economic traditions.[127]

Across the United States, a number of tribal nations are developing adaptation plans, including in the Midwest (Ch. 15: Tribes, KM 3).[283] These plans bring together climate data and projections with Traditional Ecological Knowledge [311,312] of tribal members. Within Indigenous oral history lies a complex and rich documentation of local ecosystems—not found in books—that can be used to understand and document the changes that are occurring.[313] Climate change effects are not typically immediate or dramatic because they occur over a relatively long period of time, but tribal elders and harvesters have been noticing changes, such as declining numbers of waabooz (snowshoe hare), many of which Scientific Ecological Knowledge has been slower to document. The Traditional Ecological Knowledge of elders and harvesters who have lived and subsisted in a particular ecosystem can provide a valuable and nuanced understanding of ecological conditions on a smaller, more localized scale. Integrating this Traditional Ecological Knowledge with Scientific Ecological Knowledge in climate change initiatives provides a more complete understanding of climate change impacts.[136] Community input to tribal adaptation plans ensures that Traditional Ecological Knowledge can be used to produce adaptation strategies trusted by community members.[314]

## Acknowledgments

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### Opening Image Credit

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# Traceable Accounts

### Process Description

The chapter lead authors were identified in October 2016, and the author team was recruited in October and November 2016. Authors were selected for their interest and expertise in areas critical to the Midwest with an eye on diversity in expertise, level of experience, and gender. The writing team engaged in conference calls starting in December 2016, and calls continued on a regular basis to discuss technical and logistical issues related to the chapter. The Midwest chapter hosted an engagement workshop on March 1, 2017, with the hub in Chicago and satellite meetings in Iowa, Indiana, Michigan, and Wisconsin. The authors also considered other outreach with stakeholders, inputs provided in the public call for technical material, and incorporated the available recent scientific literature to write the chapter. Additional technical authors were added as needed to fill in the gaps in knowledge.

Discussion amongst the team members, along with reference to the Third National Climate Assessment and conversations with stakeholders, led to the development of six Key Messages based on key economic activities, ecology, human health, and the vulnerability of communities. In addition, care was taken to consider the concerns of tribal nations in the northern states of the Midwest. The Great Lakes were singled out as a special case study based on the feedback of the engagement workshop and the interests of other regional and sector chapters.

### Note on regional modeling uncertainties

Interaction between the lakes and the atmosphere in the Great Lakes region (e.g., through ice cover, evaporation rates, moisture transport, and modified pressure gradients) is crucial to simulating the region's future climate (i.e., changes in lake levels or regional precipitation patterns).[315,316] Globally recognized modeling efforts (i.e., the Coupled Model Intercomparison Project, or CMIP) do not include a realistic representation of the Great Lakes, simulating the influence of the lakes poorly or not at all.[192,198,317,318,319] Ongoing work to provide evaluation, analysis, and guidance for the Great Lakes region includes comparing this regional model data to commonly used global climate model data (CMIP) that are the basis of many products practitioners currently use (i.e., NCA, IPCC, NOAA State Climate Summaries). To address these challenges, a community of regional modeling experts are working to configure and utilize more sophisticated climate models that more accurately represent the Great Lakes' lake–land–atmosphere system to enhance the understanding of uncertainty to inform better regional decision-making capacity (see http://glisa.umich.edu/projects/great-lakes-ensemble for more information).

## Key Message 1

**Agriculture**

The Midwest is a major producer of a wide range of food and animal feed for national consumption and international trade. Increases in warm-season absolute humidity and precipitation have eroded soils, created favorable conditions for pests and pathogens, and degraded the quality of stored grain (*very likely, very high confidence*). Projected changes in precipitation, coupled with rising extreme temperatures before mid-century, will reduce Midwest agricultural productivity to levels of the 1980s without major technological advances (*likely, medium confidence*).

### Description of evidence base

Humidity is increasing. Feng et al. (2016)[3] show plots of trends in surface and 850 hPa specific humidity of 0.4 and 0.2 g/kg/decade, respectively, from 1979–2014 for the April–May–June period across the Midwest. These represent increases of approximately 5% and 3% per decade, respectively. Automated Surface Observing Stations in Iowa[320] having dew point records of this length and season show dew point temperature increases of about 1°F per decade. Brown and DeGaetano (2013)[49] show increasing dew points in all seasons throughout the Midwest. Observed changes in annual average maximum temperature for the Midwest over the 20th century (Vose et al. 2017,[54] Table 6.1) have been less than 1°F. However, future projected changes in annual average temperature (Vose et al. 2017,[54] Table 6.4), as well as in both warmest day of the year and warmest 5-day 1-in-10 year events (Vose et al. 2017,[54] Table 6.5), are higher for the Midwest than in any other region of the United States.

Garbrecht et al. (2007)[321] state that precipitation changes are sufficient to require U.S. policy changes for agricultural lands. The Soil Erosion Site (http://soilerosion.net/water_erosion.html) describes the soil erosion process and provides links to soil erosion models.[322] Nearing et al. (2004)[44] report that global climate models project increases in erosivity (the ability or power of rain to cause soil loss) across the northern states of the United States over the 21st century.

Spoilage in stored grain is caused by mold growth and insect activity, which are related to the moisture content and temperature of the stored grain.[323] The ability of fungi to produce mycotoxins, including aflatoxin and fumonisins, is largely influenced by temperature, relative humidity, insect attack, and stress conditions of the plants.[57,324] Humidity has a determining influence on the growth rate of these degradation agents.[325]

Germination of wheat declined in storage facilities where moisture level increased with time.[326] Freshly harvested, high-moisture content grain must be dried to minimize (or prevent) excessive respiration and mold growth on grains.[327] The storage life of grain is shortened significantly when stored at warm temperatures. One day of holding warm, wet corn before drying can decrease storage life by 50%.[45]

Feng et al. (2016)[3] show humidity is rising in the Midwest in the warm season. Cook et al. (2008)[4] show that the factors leading to these humidity increases (warming Gulf of Mexico and strengthening of the Great Plains Low-Level Jet) will increase in a warming climate.

The ability of fungi to produce mycotoxins is largely influenced by temperature, relative humidity, insect attack, and stress conditions of the plants.[324] More extreme rainfall events would favor formation of Deoxynivalenol, also known as vomitoxin.[57]

Hatfield et al. (2011,[50] Table 1) give the relationships between temperature and vegetative function as well as reproductive capacity. This work was expanded and updated in Walthall et al. (2012).[328]

Mader et al. (2010)[74] report a comprehensive climate index for describing the effect of ambient temperature, relative humidity, radiation, and wind speed on environmental stress in animals. St-Pierre et al. (2003)[329] provide tables estimating economic losses in dairy due to reduced reproduction. The data show a strong gradient across the Midwest (with losses in Iowa, Illinois, and Indiana being three times the losses in Minnesota, Wisconsin, and Michigan under the current climate). Temperature and humidity increases projected for the Midwest will increase economic losses across the entire region. Lewis and Bunter (2010)[330] document heat stress effects of temperature on pig production and reproduction.

St-Pierre et al. (2003)[329] provide tables estimating economic losses in dairy, beef, swine, and poultry, resulting in declines from both meat/milk/egg production. The data show a strong gradient across the Midwest (with losses in Iowa, Illinois, and Indiana being twice the losses in Minnesota, Wisconsin, and Michigan under the current climate). Temperature and humidity increases projected for the Midwest will increase losses across the entire region. Babinszky et al. (2011)[75] identified temperature thresholds for meat/egg/milk production, beyond which performance declines. The adverse effects of heat stress include high mortality, decreased feed consumption, poor body weight gain and meat quality in broiler chickens, and poor laying rate, egg weight, and shell quality in laying hens.[76]

Takle et al. (2013)[65] found that by mid-century, yields of corn and soybean are projected to fall well below projections based on extrapolation of trends since 1970 even under an optimistic economic scenario, with larger interannual variability in yield and total production. Liang et al. (2017)[2] report that the ratio of measured agricultural output to measured inputs would drop by an average 3% to 4% per year under medium to high emissions scenarios and could fall to pre-1980 levels by 2050 even when accounting for present rates of innovation. Schauberger et al. (2017)[66] found that the impact of exposure to temperatures from 30°C to 36°C projected for the end of the century under RCP8.5 creates yield losses of 49% for maize and 40% for soybean.

According to Easterling et al. (2017),[193] evidence suggests that droughts have become less frequent in the Midwest as the region has become wetter. However, they note that "future higher temperatures will likely lead to greater frequencies and magnitudes of agricultural droughts throughout the continental United States as the resulting increases in evapotranspiration outpace projected precipitation increases."

### Major uncertainties

Global and regional climate models do not simulate well the dynamical structure of mesoscale convective systems in the Midwest, which are the critical "end processes" that create intense precipitation from increasing amounts of moisture evaporated over the Gulf of Mexico and transported by low-level jets (LLJs) into the Midwest. Secondly, the strengthening of future LLJs depends on strengthening of both the Bermuda surface high pressure and the lee surface low over the eastern Rocky Mountains. Confirming simulations of this in future climates are needed. Global and regional climate models do simulate future scenarios having increasing temperatures for the region with high confidence (a necessary ingredient for increased humidity). There is uncertainty of the temperature thresholds for crops because, as pointed out by Schauberger et al. (2017),[66] some negative impacts of higher temperatures can be overcome through increased water availability. Agricultural yield models, productivity models, and integrated assessment models each provide different ways of looking at agricultural futures, and each of these three types of models has high levels of uncertainty. However, all point to agriculture futures that fail to maintain upward historical trends.

**Description of confidence and likelihood**

There is *very high confidence* that increases in warm-season absolute humidity and precipitation *very likely* have eroded soils, created favorable conditions for pests and pathogens, and degraded quality of stored grain. There is *medium confidence* that projected increases in moisture, coupled with rising mid-summer temperatures, *likely* will be detrimental to crop and livestock production and put future gains in commodity grain production at risk by mid-century. Projected changes in precipitation, coupled with rising extreme temperatures, provide *medium confidence* that by mid-century Midwest agricultural productivity *likely* will decline to levels of the 1980s without major technological advances.

## Key Message 2

### Forestry

Midwest forests provide numerous economic and ecological benefits, yet threats from a changing climate are interacting with existing stressors such as invasive species and pests to increase tree mortality and reduce forest productivity (*likely, high confidence*). Without adaptive actions, these interactions will result in the loss of economically and culturally important tree species such as paper birch and black ash (*very likely, very high confidence*) and are expected to lead to the conversion of some forests to other forest types (*likely, high confidence*) or even to non-forested ecosystems by the end of the century (*as likely as not, medium confidence*). Land managers are beginning to manage risk in forests by increasing diversity and selecting for tree species adapted to a range of projected conditions.

**Description of evidence base**

Multiple ecosystem vulnerability assessments that have been conducted for major forested ecoregions within the Midwest[89,90,91,92,93] suggest that climate change is expected to have significant direct impacts to forests through effects of warming and changes in the timing and amounts of precipitation.[96,98,103,104]

Significant indirect impacts to forests are expected as warming increases the negative effects of invasive plants, insect pests, and tree pathogens of forests.[105,106] Increasing stress on individual trees from climate changes (warming temperatures, drought, and frost damage) increases the susceptibility of trees to the impacts from invasive plants, insect pests, and disease agents.[109,111]

Direct and indirect impacts of climate change may lead to the decline of culturally[88,127] and economically important tree species,[125] as well as leading to shifts in major forest types and altered forest composition as tree species at the northern limits of their ranges decline and southern species experience increasing suitable habitat.[120] These shifts raise the possibility of future losses of economic and cultural benefits of forests due to conversion to different forest types or the change to non-forest ecosystems.[119,123,124]

Many examples of land managers implementing climate adaptation in forest management exist, suggesting significant willingness to address the impacts of a changing climate across diverse land ownerships in managed forests[134] and urban forests.[133] Forest management strategies to adapt to a changing climate highlight the importance of increasing forest diversity and managing for tree species adapted to a range of climate conditions.[8] The importance of Traditional Ecological Knowledge for informing approaches for climate adaptation on tribal lands and within ceded territory is recognized.[331]

### Major uncertainties

There is significant uncertainty surrounding the ability of tree species migration rates to keep pace with changes in climate (based on temperature and precipitation) due to existing forest fragmentation and loss of habitat. Uncertainty in forest management responses, including active and widespread adaptation efforts that alter forest composition, add to the uncertainty of tree species movements. This leads to considerable uncertainty in the extent to which shifts in tree species ranges may lead to altered forest composition or loss of forest ecosystems in the future.

Due to the complex interactions among species, there is uncertainty in the extent that longer growing seasons, warming temperatures, and increased $CO_2$ concentrations will benefit tree species, due to both limitations in available water and nutrients, as well as limited benefits for trees relative to the positive influences of these changes on stressors (invasives, insect pests, pathogens).

### Description of confidence and likelihood

There is *high confidence* that the interactions of warming temperatures, precipitation changes, and drought with insect pests, invasive plants, and tree pathogens will *likely* lead to increased tree mortality of some species, reducing productivity of some forests. There is *very high confidence* that these interactions will *very likely* result in the decline of some economically or culturally important tree species. Additionally, there is *high confidence* that suitable habitat conditions for tree species will change as temperatures increase and precipitation patterns change, making it *likely* that forest composition will be altered and forest ecosystems may shift to new forest types. Due to uncertainties on species migration rates and forest management responses to climate changes, there is *medium confidence* that by the end of the century, some forest ecosystems are *as likely as not* to convert to non-forest ecosystems.

## Key Message 3

### Biodiversity and Ecosystems

The ecosystems of the Midwest support a diverse array of native species and provide people with essential services such as water purification, flood control, resource provision, crop pollination, and recreational opportunities. Species and ecosystems, including the important freshwater resources of the Great Lakes, are typically most at risk when climate stressors, like temperature increases, interact with land-use change, habitat loss, pollution, nutrient inputs, and nonnative invasive species (*very likely, very high confidence*). Restoration of natural systems, increases in the use of green infrastructure, and targeted conservation efforts, especially of wetland systems, can help protect people and nature from climate change impacts (*likely, high confidence*).

### Description of evidence base

Changes in climate will very likely stress many species and ecological systems in the Midwest. As a result of increases in climate stressors, which typically interact with multiple other stressors, especially in the southern half of the Midwest region, both the ecological systems and the ecological services (water purification, pollination of crops and wild species, recreational opportunities, etc.) they provide to people are at risk. We draw from a wide range of national and global scale assessments of risks to biodiversity (e.g., Maclean and Wilson 2011, Pearson et al. 2014, and the review by Staudinger et al. 2013 that covered literature included in the Third National Climate Assessment[20, 18,22]), which all agree that on the whole, we are highly likely to see increases in species declines and extinctions as a result of climate change. It is very challenging to say specifically what combination of factors will drive these responses, but the weight of evidence suggests very high confidence in the overall trends. The link to interactions with other stressors is also very strong and is described in Brook et al. (2008)[157] and Cahill et al. (2013),[17] among others. Terrestrial ecosystem connectivity, thought to be important for the adaptive capacity of many species, is very low in the southern half of the Midwest region.[158,159] This may limit the movement of species to more suitable habitats or for species from the southern United States to migrate into the Midwest. These connectivity/movement potential studies also support the idea that land-use change will constrain the potential for retaining function and overall diversity levels. The last section refers to the benefits of restoration as a mechanism for protecting people and nature from climate change impacts. While it is not possible to fully demonstrate that protection of people and nature is indeed occurring now from climate change impacts (we would need attribution of current floods, etc.), there is strong evidence that actions like restoring wetlands can reduce flooding impacts[182] and that protecting forests protects water quality and supply.

### Major uncertainties

There is significant uncertainty surrounding the ability of species and ecosystems to persist and thrive under climate change, and we expect to see many different types of responses (population increases, declines, local and regional extinctions).[17] In some cases, climate change does have the potential to benefit species; for example, fish in the coldest regions of the Great Lakes (i.e., Lake Superior) are likely to show increases in productivity, at least in the short run.[332] However, as a whole, given the environmental context upon which climate change is operating, and the presence of many cold-adapted species that are close to the southern edge of their distributional range, we expect more declines than increases.

The last section of the Key Message focuses on land protection and restoration—conservation strategies intended to reduce the impacts of land-use change. Many modeling studies have called out loss of habitat in the Midwest as a key barrier to both local survival and species movement in response to climate change (Schloss et al. 2012 and Carroll et al. 2015 are two of the most recent[158,159]). Restoring habitat can restore connectivity and protect key ecological functions like pollination services and water purification. Restoring wetlands also can help protect ecosystems and people from flooding, which is the rationale for the last line in the Key Message.

### Description of confidence and likelihood

In the Midwest, we already have seen very high levels of habitat loss and conversion, especially in grasslands, wetlands, and freshwater systems. This habitat degradation, in addition to the pervasive impacts of invasive species, pollution, water extraction, and lack of connectivity, all suggest that the adaptive capacity of species and systems is compromised relative to systems that are more intact and under less stress. Over time, this pervasive habitat loss and degradation has contributed to population declines, especially for wetland, prairie, and stream species. A reliance on cold surface-water systems, which often have compromised connectivity (due to dams, road-stream crossings with structures that impede stream flow, and other barriers) suggests that freshwater species, especially less mobile species like mussels, which are already rare, are at particular risk of declines and extinction. Due to the variety of life histories and climate sensitivities of species within the region, it is very challenging to specify what mechanisms will be most important in terms of driving change. However, knowing that drivers like invasive species, habitat loss, pollution, and hydrologic modifications promote species declines, it is *very likely* that the effects of climate change will interact, and we have *very high confidence* that these interactions will tend to increase, rather than decrease, stresses on species that are associated with these threats. While there is strong evidence that investments in restoring habitat can benefit species, we currently do not have strong observational evidence of the use of these new habitats, or benefits of restored wetlands, in response to isolated climate drivers. Thus, the confidence level for this statement is lower than for the first half of the message.

## Key Message 4

### Human Health

Climate change is expected to worsen existing conditions and introduce new health threats by increasing the frequency and intensity of poor air quality days, extreme high temperature events, and heavy rainfalls; extending pollen seasons; and modifying the distribution of disease-carrying pests and insects (*very likely, very high confidence*). By mid-century, the region is projected to experience substantial, yet avoidable, loss of life, worsened health conditions, and economic impacts estimated in the billions of dollars as a result of these changes (*likely, high confidence*). Improved basic health services and increased public health measures—including surveillance and monitoring—can prevent or reduce these impacts (*likely, high confidence*).

### Description of evidence base

There is strong evidence that increasing temperatures and precipitation in the Midwest will occur by the middle and end of the 21st century.[27] The impacts of these changes on human health are broadly captured in the 2016 U.S. Global Change Research Program's Climate and Health Assessment.[26] Air quality, including particulate matter and ground-level ozone, is positively associated with increased temperatures and has been well-documented to show deleterious impacts on morbidity and mortality.[231] Likewise, increased temperatures have been shown in communities in the Midwest, as well as across the United States, to have substantial impacts on health and well-being.[232,233,235,236,333,334] The frequency of extreme rainfall events in the Midwest has increased in recent decades, and this trend is projected to continue.[193] Studies have shown that extreme rainfall events lead to disease, injury, and death.[237] Increases in seasonal temperatures and shifting precipitation patterns have been well documented to be correlated with increased pollen production, allergenicity, and pollen season length.[230,231] Similarly, there is agreement that shifting temperature and precipitation patterns are making habitats more suitable for disease-carrying vectors to move northward toward the Midwest region.[242,243,250,335,336,337] The disease burden and economic projections primarily are based on EPA estimates.[28]

Access to basic preventive care measures quantifiably reduces disease burden for climate-sensitive exposures.[238,240] Gray literature indicates that public health practitioners are dedicated to increasing capacity for adapting to climate change through classic public health activities such as conducting vulnerability assessments, employing communication and outreach campaigns, and investing in surveillance efforts.[26,244,245,246,247,248]

### Major uncertainties

While the modeling performed by the EPA was completed using the best available information, there is uncertainty around the extent to which biophysical adaptations will protect midwestern populations from heat-, air pollution-, aeroallergen-, and vector-related illness and death. Likewise, while there is a general consensus regarding habitat suitability for disease-carrying vectors in the eastern and western United States, the degree to which the disease burden may increase or decrease is largely uncertain.

### Description of confidence and likelihood

Based on the evidence, there is *very high confidence* that climate change is *very likely* to impact midwesterners' health.

## Key Message 5

### Transportation and Infrastructure

Storm water management systems, transportation networks, and other critical infrastructure are already experiencing impacts from changing precipitation patterns and elevated flood risks (*medium confidence*). Green infrastructure is reducing some of the negative impacts by using plants and open space to absorb storm water (*medium confidence*). The annual cost of adapting urban storm water systems to more frequent and severe storms is projected to exceed $500 million for the Midwest by the end of the century (*medium confidence*).

### Description of evidence base

The patterns of increased annual precipitation, and the size and frequency of heavy precipitation events in the Midwest, are shown in numerous studies and highlighted in Melillo et al. (2014)[27] and Easterling et al. (2017).[193] Increases in annual precipitation of 5% to 15% are reported across the Midwest region.[193] In addition, both the frequency and the intensity of heavy precipitation events in the Midwest have increased since 1901.[193]

For the early 21st century (2016–2045), both lower and higher scenarios (RCP4.5 and RCP8.5) indicate that average annual precipitation could increase by 1% to 5% across the Midwest, suggesting that the observed increases are likely to continue. By mid-century (2036–2065), both scenarios (RCP4.5 and RCP8.5) indicate precipitation increases of 1% to 5% in Missouri and Iowa and 5% to 10% increases in states to the north and east. By late century (2070–2089), precipitation is expected to increase by 5% to 15% over present day, with slightly larger increases in the higher scenario (RCP8.5). Model simulations suggest that most of these increases will occur in winter and spring over the 21st century. Similar to annual precipitation, the amounts from the annual maximum one-day precipitation events (a measure of heavy precipitation events) are projected to increase over time in the Midwest. The size of the events could increase by 5% to 15% by late century.[193]

Gray literature documents that heavy rains in the Midwest are overwhelming storm water management systems, leading to property damage. Kenward et al. (2016)[256] provide examples of rain-related sewage overflows in the Midwest. These include an overflow of 681 million gallons during heavy rains in April 2015 in Milwaukee and an overflow of over 100 million gallons from December 26–28, 2015, in St. Louis. Winters et al. (2015)[37] document that failure of storm water management systems in heavy rain leads to property damage, including basement backups.

The disruption of transportation networks by heavy precipitation in the Midwest has been documented by collecting contemporary news reports and by compiling state government reports. Posey (2016)[338] relates that four storms between April 2013 and April 2014 forced evacuations or damaged cars in St. Louis, Missouri. In the same period, there were 18 flood-related closures on Missouri roads, a figure that excludes closures on small local roads. Flooding in May 2017 led to the closure of more than 400 roads across Missouri, a figure that again excludes local roads. Closed roadways included multiple stretches of Interstate 44, as well as sections of I-55, affecting interstate traffic between St. Louis and Memphis.[339] News reports document that the same stretch of I-44 was shut down during the floods of December 2015–January 2016.[340]

Flood-related disruptions to Midwest barge and rail traffic in 2013 were documented by several articles in *Journal of Commerce*, a shipping trade magazine.[265,266] *WorkBoat*, a trade journal of the inland shipping industry, documents that Mississippi River navigation has been halted by flooding in 2013, 2015, 2016, and 2017. It also documents low river conditions affecting navigation in 2012 and 2015.[267,268,269,270,341] Disruptions to rail service caused by the floods of 2017 were documented in news media accounts.[342] Changon (2009)[343] documents that flooding in 2008 resulted in extensive damage to railroads in Illinois and adjacent states, with costs exceeding $150 million due to direct damage and lost revenue.

Although there is ample documentation of transportation systems in the Midwest being disrupted by floods in recent years, there is a lack of long-term time series data on disruptions with which to determine whether these incidents are becoming more frequent. Development of long-term data on transportation disruptions in the Midwest is a research need. It is clear that flood frequency and severity on major rivers in the Midwest have increased in recent decades, although additional research is needed on the relative contributions of climate change and land-use change to increases in flood risk.[344,345,346]

The EPA estimated economic costs related to infrastructure and transportation in the Midwest, including costs associated with bridge scour and pavement degradation.[28] The use of green infrastructure to reduce impacts associated with heavy precipitation is also documented in gray literature, including municipal planning documents. Using planted areas to absorb rainfall and reduce runoff has become a common approach to storm water management.[223,275,276,347,348,349,350] Dechannelization and restoration of streams as a technique for improving storm water management is described in Trice (2013)[282] and Milwaukee Metropolitan Sewer District (2017).[281] Preservation of open space is described in Ducks Unlimited (2017)[279] and the Ozaukee Washington

Land Trust (2016).[280] The use of urban forestry as an adaptation method is documented in the Minneapolis Marq2 Project (2017)[277] and the Cleveland Tree Plan (2015).[278] Projected costs to storm water systems are based on EPA projections.[28]

### Major uncertainties

Although there is *very high confidence* that flood risk is increasing in the Midwest, there remains uncertainty about the relative contributions of climate change and land-use change. There is, however, sufficient evidence that changing precipitation patterns are leading to changes in hydrology in the Midwest,[351,352,353,354,355] and that heavier precipitation patterns are consistent with projections from climate models, to justify a rating of *medium confidence* to the assertion that climate change is contributing to changes in flooding risk. There is *high confidence* that local governments and nongovernmental organizations are turning to green infrastructure solutions as a response to increased flooding risk. Additional research is needed to quantify the aggregate benefits of these approaches.

While it is clear that flood frequency and severity on major rivers in the Midwest have increased in recent decades, it must be emphasized that the change in precipitation levels is not the only factor contributing to the increase in flood risk. Land-use change, particularly the destruction of floodplains by levee systems, has also been documented as a key contributor to increasing flood risk in the Midwest.[344,345,346] On smaller streams, tile drainage systems have been shown to exacerbate flood risk.[24] Determining the relative contribution of land-use change and climate change to increases in riverine flood risk is an important research need.

### Description of confidence and likelihood

There is *medium confidence* that climate change is contributing to increased flood risk in the Midwest; there is *medium confidence* that green infrastructure is reducing flood risk. There is much uncertainty associated with specific numerical projections. This leads to *medium confidence* that costs will exceed $500 million. However, the EPA projections are sufficient to provide *high confidence* that increasing the capacity of existing storm water systems in order to maintain current levels of service would require significant expenditures on the part of urban sewer districts.

## Key Message 6

### Community Vulnerability and Adaptation

At-risk communities in the Midwest are becoming more vulnerable to climate change impacts such as flooding, drought, and increases in urban heat islands (*as likely as not, high confidence*). Tribal nations are especially vulnerable because of their reliance on threatened natural resources for their cultural, subsistence, and economic needs (*likely, medium confidence*). Integrating climate adaptation into planning processes offers an opportunity to better manage climate risks now (*medium confidence*). Developing knowledge for decision-making in cooperation with vulnerable communities and tribal nations will help to build adaptive capacity and increase resilience (*high confidence*).

### Description of evidence base

Limited evidence in the scientific literature indicates that at-risk communities in the Midwest will be increasingly vulnerable to the impacts of climate change, including increased flooding resulting from increased variation in precipitation patterns and changing lake levels,[285] urban heat islands,[287] and an intensification of heat and drought (see also the impacts and associated references in the previous sections).[286]

Several recent survey reports[28,283,284] project negative climate impacts for tribal nations and Indigenous communities, especially as a result of an increased frequency of extreme precipitation events.[283] Tribal nations are especially vulnerable to climate impacts because of their reliance on natural resources,[127] the isolation of rural communities, and potential shifts of species out of sovereign land.[309,310] Climate change thus poses a threat to tribal culture, sovereignty, health, and way of life.[39]

Gray literature,[293] survey reports,[32] and scientific literature[292] point to a few initiatives to integrate adaptation into municipal planning processes and utilize participatory methodologies to evaluate and manage climate risk.

A growing body of research indicates that interaction between producers of climate information, intermediaries, and end users plays a critical role in increasing climate knowledge integration and use for adaptation in the Midwest.[224,294,300,308] Limited evidence links the implementation of adaptation actions identified as a result of these collaborations to reduced sensitivity.[304,305,306]

### Major uncertainties

Limited research specific to the Midwest region contributes to uncertainty around the specific vulnerabilities of at-risk communities, including urban and rural communities and tribal nations. Though climate change planning and action in both Midwest cities and rural areas are underway, documentation remains low, few examples exist in the public literature of the failure or success of efforts to mainstream climate action into municipal governance, and attempts to assess vulnerabilities, especially in poor urban communities, frequently encounter climate justice barriers. Likewise, the number, scope, and nature of tribal adaptation plans remain undocumented, as does the degree of implementation of these plans and the manner in which Traditional Ecological Knowledge is incorporated.

### Description of confidence and likelihood

There is *high confidence* that communities in the Midwest will *as likely as not* be increasingly vulnerable to climate change impacts such as flooding, urban heat islands, and drought. Similarly, there is *medium confidence* that tribal nations in the Midwest are *likely* to be especially vulnerable because of their reliance on threatened natural resources for their cultural, subsistence, and economic needs. Due to limited documentation in the literature, there is *medium confidence* that integrating adaptation into planning processes will offer an opportunity to manage climate risk better. Finally, there is *high confidence* that developing knowledge for decision-making in cooperation with vulnerable communities and tribal nations will help to decrease sensitivity and build adaptive capacity.

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# EVALUATING THE EFFECTS OF FOSSIL FUEL SUPPLY PROJECTS ON GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE UNDER NEPA

MICHAEL BURGER* & JESSICA WENTZ**

ABSTRACT

Despite the high certainty of our looming climate catastrophe, fossil fuel production and consumption, and the greenhouse gas emissions that result, are increasing. In the United States, fossil fuel production reached record levels in 2018, and oil and gas pipelines are being constructed at an unprecedented pace. The National Environmental Policy Act ("NEPA") provides the legal framework for the federal government to evaluate the climate impacts of these supply projects, such as leasing public lands and approving pipelines and export terminals. Yet, while federal agencies have begun to analyze how such projects impact climate change there are major inconsistencies in agency practice as well as questions about the accuracy and integrity of these assessments. Some agencies are seeking to avoid any meaningful analysis of GHG emissions, others are downplaying the significance of GHG impacts, others are claiming that the impacts are too uncertain to inform the agency's decision. There is no programmatic analysis that evaluates the cumulative effects of U.S. fossil fuel policies. The result is a patchwork of project-level analyses that provides fragments of useful information.

*Evaluating the Effects of Fossil Fuel Supply Projects on Greenhouse Gas Emissions and Climate Change under NEPA* argues that agencies are too often short-changing the public by seeking to limit the scope of their environmental assessments and to elide the central question of the significance of fossil fuel supply projects, and that more comprehensive

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analyses are necessary in order to draw meaningful conclusions about the effect of government decision-making on fossil fuel use and climate change. After a brief introduction, Part I provides a statutory and factual context. Parts II and III examine recent trends in environmental review and NEPA litigation; analyze nuanced questions of the scope and significance of fossil fuel supply projects' climate change impacts, the assumptions and analytical techniques that have factored and should factor into NEPA analysis, as well as the core question of whether and to what extent NEPA requires agencies to look at the cumulative effects of multiple fossil fuel leasing and transportation approvals; and propose best practices for agencies seeking to inform themselves and the public about the climate impacts of our nation's fossil fuel decisions. This Article concludes in the last few paragraphs.

## INTRODUCTION

The world is at a critical juncture in the fight against climate change. When the Paris Agreement was adopted in 2015, the nations of the world agreed that we must limit global warming to "well below" 2°C or preferably 1.5°C above pre-industrial temperatures, recognizing that this would significantly reduce the risks and impacts of climate change.[1] But the window of opportunity for meeting these targets is quickly closing.

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[1] U.N. Framework Convention on Climate Change, *Adoption of the Paris Agreement*, U.N. Doc. FCCC/CP/2015/L.9/Rev.1, annex I, art. 2 (Dec. 12, 2015).

In 2018, the Intergovernmental Panel on Climate Change ("IPCC") published a report in which it found that global greenhouse gas ("GHG") emissions must be reduced by nearly 50 percent by 2030 and reach net zero levels by 2050 to have a reasonable chance of meeting the 1.5°C target.[2] Reducing emissions at this speed and scale would require massive and unprecedented changes in energy infrastructure and most critically a rapid phase out of fossil fuels. Indeed, the vast majority of known fossil fuel reserves must be left unused to have a chance of meeting the Paris Agreement targets.[3]

Despite widespread agreement on the need for immediate and far-reaching action, global GHG emissions and fossil fuel consumption continue to increase and the world remains on track to significantly exceed 2°C of warming.[4] While many jurisdictions have enacted demand-side policies aimed at regulating the end-use of fossil fuels,[5] far less attention has been given to supply-side policies aimed at limiting the production of fossil fuels and the expansion of infrastructure intended to transport those fuels to markets. To the contrary, governments continue to authorize and even subsidize the development of new fossil fuel reserves as well as the expansion of fossil fuel transport infrastructure.[6] This is the

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[2] IPCC, *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 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 (V. Masson-Delmotte et al. eds., 2018).

[3] GREG MUTTITT ET AL., THE SKY'S LIMIT: WHY THE PARIS CLIMATE GOALS REQUIRE A MANAGED DECLINE OF FOSSIL FUEL PRODUCTION 20 (Collin Rees ed., 2016); Richard Heede & Naomi Oreskes, *Potential Emissions of $CO_2$ and Methane from Proved Reserves of Fossil Fuels: An Alternative Analysis,* 36 GLOBAL ENVTL. CHANGE 12, 17 (2016); Christophe McGlade & Paul Ekins, *The Geographical Distribution of Fossil Fuels Unused When Limiting Global Warming to 2 °C*, 517 NATURE 187, 187 (2015).

[4] Nina Chestney, *Climate policies put world on track for 3.3C warming: study*, REUTERS (Dec. 11, 2018), https://www.reuters.com/article/us-climate-change-accord-warming/climate-policies-put-world-on-track-for-3-3c-warming-study-idUSKBN1OA0Z2 [https://perma.cc/V5ZU-F5ZY]; Kyla Mandel, *World 'not on track' to stop 1.5 degrees of global warming warns UN Secretary General*, THINKPROGRESS (May 12, 2019), https://thinkprogress.org/world-not-on-track-to-stop-dangerous-climate-change-warns-un-secretary-general-58797036970f/ [https://perma.cc/276H-QLBX]; *2011 Warming Projections*, CLIMATE ACTION TRACKER, https://climateactiontracker.org/global/temperatures [https://perma.cc/2E7C-86TQ].

[5] EPA, CUTTING POWER SECTOR CARBON POLLUTION : STATE POLICIES AND PROGRAMS 8, 25, 32 (2016); David Roberts, *It's time to think seriously about cutting off the supply of fossil fuels*, VOX (May 31, 2018), https://www.vox.com/energy-and-environment/2018/4/3/17187606/fossil-fuel-supply [https://perma.cc/9NKP-SF53].

[6] The United States and other governments also continue to subsidize fossil fuels through

case in the United States, where fossil fuel production reached record levels in 2018,[7] and where oil and gas pipelines have been constructed at an unprecedented pace.[8] There is a pressing need for the United States and other governments to re-evaluate their position on fossil fuel supply infrastructure in light of the growing threat of climate change.

In the United States, the National Environmental Policy Act ("NEPA") provides the legal framework whereby the federal government must evaluate the climate impacts of fossil fuel leasing and transport proposals to make informed decisions about whether and how to proceed with these proposals.[9] Driven by litigation and public pressure, federal agencies have analyzed how fossil fuel supply projects affect fossil fuel use and GHG emissions in some of their NEPA reviews, but there are major inconsistencies in agency practice as well as questions about the accuracy and integrity of these assessments. In some instances, agencies have sought to avoid any meaningful analysis of GHG emissions, downplaying the significance of GHG impacts, or claiming that the impacts are too uncertain to inform the agency's decision about whether and how to proceed with individual fossil fuel leasing or transportation proposals. At the same time, the federal government has never conducted a programmatic analysis to evaluate the cumulative effects of its leasing decisions or transport approvals on fossil fuel use and GHG emissions. The result is a patchwork of project-level NEPA documentation that provides only pieces of insight on how federal decisions about fossil fuel supply infrastructure affect fossil fuel use and GHG emissions.

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policies such as tax breaks for fossil fuel exploration and low royalty rates for fossil fuels produced on public lands. *See* David Coady et al., *Global Fossil Fuel Subsidies Remain Large: An Update Based on Country-Level Estimates* 23, 35 (IMF, Working Paper No. 19/89, 2019).

[7] EIA, APRIL 2019 MONTHLY ENERGY REVIEW 3 (2019), https://www.eia.gov/totalenergy/data/monthly/archive/00351904.pdf [https://perma.cc/H2K8-7YJF]; EIA, ANNUAL ENERGY OUTLOOK 2019, 12, 16 (2019), https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf [https://perma.cc/X6AK-2CSL].

[8] The United States is outpacing any other country in terms of pipeline development: over 50 percent of all oil and gas pipelines in preconstruction or construction stages are located in the United States. *See* TED NACE ET AL., GLOBAL ENERGY MONITOR, PIPELINE BUBBLE: NORTH AMERICA IS BETTING OVER $1 TRILLION ON A RISKY FOSSIL INFRASTRUCTURE BOOM 3–5 (2019), https://globalenergymonitor.org/wp-content/uploads/2019/04/GFITPipelineBubble_2019_v6.pdf [https://perma.cc/KZ85-J2QA]; *Global Fossil Project Tracker*, GREEN INFO. NETWORK, https://greeninfo-network.github.io/fossil_tracker/ [https://perma.cc/47MS-D5XM] (last visited Dec. 3, 2019).

[9] National Environmental Policy Act, 42 U.S.C. § 4321 (2012); *Summary of the National Environmental Policy Act*, EPA, https://www.epa.gov/laws-regulations/summary-national-environmental-policy-act/ [https://perma.cc/8RCE-SJXB] (last updated Aug. 15, 2019).

Litigation has played a major role in prompting more thorough analysis of GHG emission impacts.[10] Our 2017 article, *Downstream and Upstream Greenhouse Gas Emissions: The Proper Scope of NEPA Review*, analyzed whether NEPA required agencies to account for emissions from activities that occur "upstream" or "downstream" on the fossil fuel supply chain as indirect effects of proposed projects, and concluded that it does.[11] Here, we focus on recent trends in environmental review and NEPA litigation and examine some of the more nuanced questions of scope and significance, related to agencies' assumptions and analytical techniques, as well as the core question of whether and to what extent NEPA requires agencies to look at the cumulative effects of multiple fossil fuel leasing and transportation approvals. We argue that agencies too often short-change the public by seeking to limit the scope of their environmental assessments and to elide the question of significance, and that more comprehensive analyses are necessary in order to draw meaningful conclusions about the effect of government decision-making on fossil fuel use and climate change.

In our view, full compliance with NEPA's requirements matters. Critics may contend that NEPA is merely a "paper tiger" in that it imposes significant procedural obligations without any substantive requirement to mitigate or avoid adverse environmental impacts.[12] But the NEPA review process can lead to improved environmental decision-making, particularly when the statute's procedural mandates are fully implemented and enforced.[13] The disclosure of environmental impacts makes an agency

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[10] There is a growing body of research on what NEPA requires in this context. *See, e.g.*, Michael Burger, *A Carbon Fee as Mitigation for Fossil Fuel Extraction On Federal Lands*, 42 COLUM. J. ENVTL. L. 295, 313, 326 (2017); Arnold W. Reitze, Jr., *The Role of NEPA in Fossil Fuel Resource Development and Use in the Western United States*, 39 B.C. ENVTL. AFF. L. REV. 283, 285 (2012); Jessica Wentz, *Assessing the Impacts of Climate Change on the Built Environment: A Framework for Environmental Reviews*, 45 ENVTL. L. REV. 11,015, 11,017, 11,019 (2015). *See also* James W. Coleman, *Beyond the Pipeline Wars: Reforming Environmental Assessment of Energy Transport Infrastructure*, 2018 UTAH L. REV. 119, 121–22, 126–27 (2018); James W. Coleman, *Pipelines & Power-Lines: Building the Energy Transport Future*, 80 OHIO ST. L.J. 263, 266, 304 (2019).

[11] Michael Burger & Jessica Wentz, *Downstream and Upstream Emissions: The Proper Scope of NEPA Review*, 41 HARV. ENVTL. L. REV. 109, 181 (2017).

[12] *See, e.g.*, Michael C. Blumm & Keith Mosman, *The Overlooked Role of the National Environmental Policy Act in Protecting the Western Environment: NEPA in the Ninth Circuit*, 2 WASH. J. ENVTL. L. & POL'Y 193, 198 (2012).

[13] *See id.* at 195–99; Paul Stanton Kibel, *The Paper Tiger Awakens: North American Environmental Law After the Cozumel Reef Case*, 39 COLUM. J. TRANSNAT'L L. 395, 409, 425 (2001); Raymond Laws, *NEPA and the Northern Integrated Supply Project: Wielding the*

accountable for those impacts, thus placing pressure on the agency to mitigate or avoid adverse impacts which cannot be justified by the project's benefits or are otherwise unacceptable to the public. This appears to be true for the fossil fuel supply proposals discussed in this Article: the fact that agencies have tried to limit their GHG disclosures and downplay the significance of GHG emissions suggests that they are concerned about the potential consequences of such disclosure. But this practice cannot continue. The federal government needs to assess and disclose the emissions impact of the fossil fuel production and transportation infrastructure that it authorizes, not only to support informed decision-making, but also to ensure that the public has access to this information and can meaningfully engage with policymakers on appropriate supply-side policies for fossil fuels.

Part I provides a factual and legal background. It discusses the rationale for critically evaluating fossil fuel supply projects in the context of climate change goals and policies, explains the scope of U.S. federal authority over fossil fuel extraction and transport proposals, summarizes NEPA requirements that are relevant to the U.S. government's review of such proposals, and reviews the evolution of federal practice and policy on fossil fuel development and NEPA reviews. Part II summarizes and synthesizes recent case law on the scope of GHG emissions that must be disclosed as effects of fossil fuel supply projects under NEPA, focusing on emissions which qualify as indirect effects, cumulative effects, and effects of related actions. Part III examines new and emerging legal questions that pertain to GHG emissions analysis under NEPA, particularly the reasonableness of agency assumptions and findings related to (i) the effect of fossil fuel supply projects on energy markets and fossil fuel end-use, and the net emissions impact of the proposal in light of those market impacts; (ii) the significance of GHG emissions impacts; and (iii) the evaluation of alternatives and mitigation measures that would reduce GHG emissions. The Conclusion includes a summary of key points and recommendations on how agencies can best satisfy their NEPA obligations in this context.

## I. BACKGROUND

The Intergovernmental Panel on Climate Change's ("IPCC") special report on *Global Warming of 1.5°C* and the U.S. Global Change Research

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*'Paper Tiger' in the Tenth Circuit*, 27 COLO. NAT. RESOURCES, ENERGY & ENVTL. L. REV. 101, 102, 108, 111 (2016).

Program's ("USGCRP") *Fourth National Climate Assessment* recognize that rapid reductions in greenhouse gas emissions will be needed to limit global warming to 1.5°C or "well below" 2°C.[14] Even if we attain this ambitious goal, the world will still experience a wide range of significant and adverse impacts from climate change, but the potential impacts of 2°C or 3°C of warming would be dramatically worse.[15] But despite broad scientific consensus on this imperative and national commitments to address climate change, GHG emissions and atmospheric concentrations continue to increase, breaking records in both 2018 and 2019.[16]

Globally, fossil fuel combustion remains the dominant source of anthropogenic GHG emissions as well as the primary driver of recent emission increases.[17] The growth in fossil fuel emissions actually accelerated in 2017 and 2018 notwithstanding the adoption of the Paris Agreement.[18] In the United States, fossil fuel emissions increased by 2.7 percent in 2018, the second-largest margin in twenty years, after three years of decline.[19] This increase occurred despite a steep drop in coal use because the reductions in coal-related emissions were more than offset by significant increases in oil and gas consumption.[20]

There is still a very narrow window of time in which action could be taken to meet the Paris Agreement. One study found that it may still be possible to limit global warming to 1.5°C if all fossil fuel-powered infrastructure (power plants, factories, vehicles, ships, and planes) are replaced by zero-carbon alternatives at the end of their useful lives and no new fossil fuel–powered infrastructure is constructed, but the world

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[14] 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 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 v–vi (V. Masson-Delmotte et al. eds., 2018); USGCRP, FOURTH NATIONAL CLIMATE ASSESSMENT VOL. II: IMPACTS, RISKS, AND ADAPTATION IN THE UNITED STATES 1351 (D.R. Reidmiller et al. eds., 2018).

[15] IPCC, *supra* note 14.

[16] INT'L ENERGY AGENCY, GLOBAL ENERGY & $CO_2$ STATUS REPORT 2018 3 (2018); *Global Carbon Budget 2018*, GLOBAL CARBON PROJECT (Dec. 5, 2018), https://www.globalcarbonproject.org/carbonbudget [https://perma.cc/996P-F43T]; *Global Monthly Mean $CO_2$*, NAT'L OCEANIC & ATMOSPHERIC ADMIN., https://www.esrl.noaa.gov/gmd/ccgg/trends/global.html [https://perma.cc/2CW2-56XN] (last visited Dec. 3, 2019).

[17] *See* sources cited *supra* note 16.

[18] Travis Houser et al., *Final US Emissions Estimates for 2018*, RHODIUM GRP. (May 31, 2019), https://rhg.com/research/final-us-emissions-estimates-for-2018/ [https://perma.cc/QG94-TGN8].

[19] *Id.*

[20] *Id.*

would likely exceed that target if this phase-out is delayed until 2030.[21] This is in line with the IPCC's findings that limiting global warming to 1.5°C would require "rapid and far-reaching" changes across all sectors, particularly the energy and transport sectors.[22]

### A. *Thinking Critically About Fossil Fuel Supply and Climate Policy*

To accelerate the fossil fuel phase-out, many advocate for supply-side policies aimed at limiting fossil fuel extraction and the expansion of infrastructure to transport fuels to end-users—the central message to governments being to "keep it in the ground."[23] These advocacy efforts are grounded in scientific research on fossil fuels and the global carbon budget, most notably a 2015 study which found that the world would need to leave at least 80 percent of the remaining known fossil fuel reserves unused in order to have a 50 percent chance of limiting global warming to 2°C.[24] It is not just undeveloped reserves that need to be left in the ground: another study on developed reserves found that 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 if those reserves are fully exploited, and that developed reserves of oil and gas alone are enough to push the world beyond 1.5°C of warming even if coal is phased out immediately.[25]

Governments have been slow to enact supply-side restrictions, in part because fossil fuel extraction and trade are viewed as central to economic development and energy security, and in part because supply-side actions are sometimes viewed as ineffective in a global marketplace.[26] One critical question is whether government approvals of new fossil fuel supply projects are fundamentally at odds with the imperative to phase out fossil fuel use. The answer to this question may seem obvious, but different projects may warrant different conclusions: a proposal

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[21] Christopher J. Smith et al., *Current Fossil Fuel Infrastructure Does Not Yet Commit Us to 1.5 °C Warming,* 10 NATURE COMM. 101 (2019).
[22] IPCC, *supra* note 14.
[23] *See generally* Kate Schimel, *How the Keep it in the Ground movement came to be*, HIGH COUNTRY NEWS (July 19, 2016), http://www.hcn.org/articles/how-the-keep-it-in-the-ground-movement-gained-momentum [https://perma.cc/G4M2-ZXWT].
[24] McGlade & Ekins, *supra* note 3, at 187.
[25] MUTTITT ET AL., *supra* note 3.
[26] For a more in-depth analysis of why supply-side policies have not been widely used to date, see Michael Lazarus & Harro van Asselt, *Fossil Fuel Supply and Climate Policy: Exploring the Road Less Taken*, 150 CLIMATIC CHANGE 1, 1–2 (2018); Michael Lazarus et al., *Supply-Side Climate Policy: The Road Less Taken* 14 (Stockholm Environmental Institute, Working Paper No. 2015-13, 2015).

to exploit new coal reserves may be totally at odds with climate goals, whereas a natural gas pipeline might be justified if there is sound evidence that it will reduce coal use among end-users—but such a justification would need to be supported by an analysis of whether there are alternatives to coal and gas for meeting energy demand, such as renewables or efficiency improvements, and whether the investment in new natural gas infrastructure will "lock in" reliance on natural gas rather than carbon-free energy substitutes. Upon careful assessment, decision makers may find that the expansion of any fossil fuel production or transportation infrastructure is irrational and imprudent in light of the need to immediately and rapidly phase out fossil fuel use and the prospect that such investments may result in stranded assets within the next several decades.[27]

A related question is whether supply-side restrictions are both effective at reducing fossil fuel use and in alignment with other policy goals. Here, again, the analysis is complicated. Critics have argued that such policies may be ineffective, economically suboptimal, and may threaten energy security.[28] But there is a growing body of research suggesting that supply-side policies can and should be integrated into the portfolio of government responses to climate change.[29] For example, one study found that "restrictive supply-side policy instruments (targeting fossil fuels) have numerous characteristic economic and political advantages over otherwise similar restrictive demand-side instruments (targeting greenhouse gases)" including: (i) low administrative and transaction costs, (ii) higher abatement certainty, (iii) comprehensive within-sector coverage, (iv) advantageous price/efficiency effects, (v) the mitigation of infrastructure "lock-in" risks, and (vi) mitigation of the "green paradox"—that is, the risk that policies reducing the value of fossil fuel resources will cause an increase in consumption of those resources.[30] Other studies have found that constraining fossil fuel production and supply can significantly increase fuel prices

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[27] For more information on stranded assets, see BEN CALDECOTT ET AL., STRANDED ASSETS: A CLIMATE RISK CHALLENGE (Ana R. Rios ed., 2016); J.F. Mercure et al., *Macroeconomic Impact of Stranded Fossil Fuel Assetts,* 8 NATURE CLIMATE CHANGE 588 (2019); NACE ET AL., *supra* note 8.

[28] *See, e.g.*, Michael A. Levi, *The Environmental and Climate Stakes in Arctic Oil Drilling,* COUNCIL ON FOREIGN REL. BLOG (May 13, 2015), https://www.cfr.org/blog/environmental-and-climate-stakes-arctic-oil-drilling [https://perma.cc/W97S-Q2U2] (arguing that supply-side restrictions on fossil fuel supply in one jurisdiction are ineffective due to global trade in fossil fuels).

[29] Fergus Green & Richard Denniss, *Cutting With Both Arms of the Scissors: The Economic and Political Case for Restrictive Supply-Side Climate Policies,* 150 CLIMATIC CHANGE 73, 78 (2018).

[30] *Id.* at 73.

thereby reducing consumption vis-à-vis lower carbon energy sources.[31] In particular, a 2018 study found that ceasing the issuance of new leases for fossil fuel extraction on federal lands and waters in the United States would reduce global $CO_2$ emissions by an estimated 280 million tons annually by 2030, which would be comparable to the effects of other major climate policies adopted or considered by the Obama administration.[32]

### B. *Federal Authority Over Fossil Fuel Extraction and Transport*

The U.S. federal government oversees the leasing of coal, oil, and gas reserves on public lands, which contain more than one quarter of the country's known fossil fuel reserves.[33] The Department of Interior ("DOI"), Bureau of Land Management ("BLM"), U.S. Forest Service ("USFS"),

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[31] Peter Erickson & Michael Lazarus, *Would Constraining US Fossil Fuel Production Affect Global $CO_2$ Emissions? A Case Study of US Leasing Policy,* 150 CLIMATIC CHANGE 29, 34 (2018) [hereinafter Erickson & Lazarus]; Taran Fæhn et al., *Climate Policies in a Fossil Fuel Producing Country—Demand Versus Supply Side Policies*, 38 ENERGY J. 77, 83 (2017); Filip Johnson et al., *The Threat to Climate Change Mitigation Posed by the Abundance of Fossil Fuels*, 19 CLIMATE POL'Y 258, 266 (2018); Lazarus & van Asselt, *supra* note 26, at 5; Philippe Le Billon & Berit Kristoffersen, *Just Cuts for Fossil Fuels? Supply-Side Carbon Constraints and Energy Transition,* 0 ENV'T & PLAN. 1, 4 (2019); Georgia Piggot et al., *Swimming Upstream: Addressing Fossil Fuel Supply Under the UNFCCC,* 18 CLIMATE POL'Y 1189, 1190 (2018); Jianliang Wang et al., *The Implications of Fossil Fuel Supply Constraints on Climate Change Projections: A Supply-Side Analysis*, 86 FUTURES 58, 66–67 (2017); Peter Erickson, *Confronting Carbon Lock-In: Canada's Oil Sands,* STOCKHOLM ENV'T INST. 7 (2018); Peter Erickson & Michael Lazarus, *How Limiting Oil Production Could Help California Meet its Climate Goals*, STOCKHOLM ENV'T INST. 2 (2018); *see* Cleo Verkuijl et al., *Aligning Fossil Fuel Production with the Paris Agreement*, STOCKHOLM ENV'T INST. 3 (Mar. 2018); Lazarus et al., *supra* note 26, at 6. Much of this research focuses on the effects of constraining fossil fuel production, but imposing such constraints on fossil fuel transportation infrastructure is also a supply-side approach which would affect fuel prices, demand, and consumption. *See* U.S. DEP'T OF ENERGY, NATURAL GAS INFRASTRUCTURE IMPLICATIONS OF INCREASED DEMAND FROM THE ELECTRIC POWER SECTOR v–vi (Feb. 2015), https://www.energy.gov/sites/prod/files/2015/02/f19/DOE%20Report%20Natural%20Gas%20Infrastructure%20V_02-02.pdf [https://perma.cc/4QVS-CRJS] (discussing how natural gas transmission constraints can increase prices); LESSLEY GOUDARZI & FRANCES WOOD, ONLOCATION.INC, THE IMPACTS OF RESTRICTING FOSSIL FUEL ENERGY PRODUCTION i (Apr. 2017) (finding that a U.S. policy consisting of restrictions on both extraction and transport projects would result in economy-wide emission reductions approximately 10 percent greater than a reference case without that policy).

[32] Erickson & Lazarus, *supra* note 31, at 36–37.

[33] Approximately one-third of known coal reserves, one quarter of crude oil reserves, and one quarter of natural gas reserves are located on public lands and managed by the federal government. MARC HUMPHRIES, U.S. CRUDE OIL AND NATURAL GAS PRODUCTION IN FEDERAL AND NONFEDERAL AREAS 2 (June 22, 2016), https://fas.org/sgp/crs/misc/R42432.pdf [https://perma.cc/DZ72-UG6J]; ROBERT H. NELSON, THE USE AND MANAGEMENT OF FEDERAL COAL 9 (2017).

Bureau of Ocean and Energy Management ("BOEM"), and Office of Surface Mining Reclamation and Enforcement ("OSM") all share authority over fossil fuel leasing on public lands and act as lead agencies in NEPA reviews for these activities.[34] The Mineral Leasing Act and other statutes grant broad discretion to these agencies to decide how and whether to lease federal lands for fossil fuel development, and the agencies can and must account for environmental effects when making decisions about the location and amount of lands made available for leasing.[35]

The federal government also has considerable authority over the construction of infrastructure that is used to transport fossil fuels to domestic and international markets. The Federal Energy Regulatory Commission ("FERC") has authority over the siting, construction, and operation of interstate natural gas pipelines, liquified natural gas ("LNG") export terminals, and associated infrastructure such as liquefaction facilities.[36] In addition, Department of Energy ("DOE") authorization is required for LNG exports.[37] The Surface Transportation Board ("STB") has exclusive licensing authority over the construction and operation of rail lines, which are the primary mode of transport for coal.[38] The federal government does not have equivalent authority over the construction of oil pipelines—however, such pipelines frequently require federal approvals that trigger NEPA requirements.[39] The statutes authorizing these agencies to approve this infrastructure also require consideration of environmental impacts and the responsible agencies have broad discretion to deny approvals based on environmental impacts or other issues pertaining to the public interest.[40]

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[34] Which agency oversees fossil fuel leasing depends on where the leasing occurs. For a more detailed discussion, see ADAM VANN, CONG. RESEARCH SERV., R40806, ENERGY PROJECTS ON FEDERAL LANDS: LEASING AND AUTHORIZATION 4–12 (2012); Burger & Wentz, *supra* note 11, at 116–26.

[35] *See* VANN, *supra* note 34, at 4–12; Burger & Wentz, *supra* note 11, at 116–26.

[36] LAWRENCE R. GREENFIELD, AN OVERVIEW OF THE FEDERAL ENERGY REGULATORY COMMISSION AND FEDERAL REGULATION OF PUBLIC UTILITIES 10 (June 2018), https://www.ferc.gov/about/ferc-does/ferc101.pdf [https://perma.cc/G62N-8U76].

[37] *Liquified Natural Gas (LGE)*, DEP'T ENERGY, https://www.energy.gov/fe/science-innovation/oil-gas/liquefied-natural-gas [https://perma.cc/R2G3-RVWA] (last visited Dec. 3, 2019).

[38] 49 U.S.C. § 10901 (2012) (establishing that a person may construct or add to railroad lines only if authorized by the Board).

[39] *See, e.g.*, 33 U.S.C. § 1344(a) (2012) (requiring a permit under Clean Water Act section 404 for any project that involves the discharge of dredged and/or fill materials into navigable waters, tributaries, and adjacent wetlands); *see also* 33 U.S.C. § 403 (2012) (requiring a Rivers and Harbors Act section 10 permit for projects that involve construction and/or dredge and fill activities in the navigable waters of the United States).

[40] *See* Burger & Wentz, *supra* note 11, at 119–21.

### *C. NEPA Requirements for Assessing Impacts of Fossil Fuel Supply Projects*

NEPA establishes a procedural framework for assessing the environmental impacts of federal proposals and using those assessments to make better-informed decisions about whether and how to proceed with those proposals.[41] The statute recognizes that it is "the continuing responsibility of the Federal Government to use all practicable means" to "improve and coordinate" federal activities such that the nation may "fulfill the responsibilities of each generation as trustee of the environment for succeeding generations."[42] To effectuate this policy, it requires federal agencies to prepare a detailed environmental impact statement ("EIS") for proposals that significantly affect the quality of the human environment, in which the agency must evaluate the environmental effects of the proposal and reasonable alternatives.[43] The statute also establishes a Council on Environmental Quality ("CEQ"), which is responsible for issuing regulations and guidance on the implementation of NEPA.[44] The CEQ regulations and guidance are supplemented by agency-specific rules and procedures for NEPA reviews.[45]

The Supreme Court has interpreted NEPA's mandates as "essentially procedural" because NEPA does not require agencies to adopt any particular course of action based on the outcome of the review,[46] but has

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[41] Much has already been written on NEPA's sweeping environmental policies and review requirements. *See, e.g.*, Ted Boling, *Making the Connection: NEPA Processes for National Environmental Policy*, 32 WASH. U. J.L. & POL'Y 313, 314–20 (2010); Bradley Karkkainen, *Toward a Smarter NEPA: Monitoring and Managing Government's Environmental Performance*, 102 COLUM. L. REV. 903, 909–16 (2002).
[42] 42 U.S.C. § 4331(b) (2006).
[43] 42 U.S.C. § 4332(C).
[44] NEPA does not expressly state that CEQ shall develop implementing regulations for NEPA. Rather, CEQ's authority to issue regulations under NEPA is based on the duties and functions outlined in Title II of NEPA, as well as two Executive Orders. *See* 42 U.S.C. § 4344(3) (directing CEQ to "review and appraise" federal programs and activities to determine the extent to which they fulfill the statute's stated policy, and to make recommendations to the President with respect thereto); Exec. Order No. 11,514, 35 Fed. Reg. 4248 (Mar. 7, 1970); Exec. Order No. 11,991, 42 Fed. Reg. 26,967 (May 24, 1977). Courts have consistently deferred to CEQ's interpretation of NEPA. *See, e.g.*, Robertson v. Methow Valley Citizens Council, 490 U.S. 332, 355 (1989) (CEQ regulations are entitled to "substantial deference"); *see also* Andrus v. Sierra Club, 442 U.S. 347, 358 (1979).
[45] *Agency NEPA Implementing Procedures*, CEQ, https://ceq.doe.gov/laws-regulations/agency_implementing_procedures.html [https://perma.cc/7AHP-7X7C] (last visited Dec. 3, 2019).
[46] Strycker's Bay Neighborhood Council, Inc. v. Karlen, 444 U.S. 223, 227–28 (1980); Vermont Yankee Nuclear Power Corp. v. NRDC, 435 U.S. 519, 588 (1978).

also recognized that NEPA serves an "action-forcing" function and its procedural mandates must be interpreted in light of its twin aims of preventing uninformed agency decisions and providing adequate disclosure to allow public participation in those decisions.[47] Thus, when assessing the adequacy of NEPA documentation, courts must consider whether an agency has overlooked or underestimated an important environmental impact that is of consequence to the public's understanding of the proposal and the agency's decision about whether and how to proceed with the proposal.[48]

Below, we summarize NEPA procedures and some of the core requirements pertaining to the scope and adequacy of environmental reviews, highlighting areas that are of particular relevance to the analysis of fossil fuel supply projects and their contribution to climate change. We focus on the requirements outlined in CEQ regulations, as these apply to all federal projects. We also briefly touch on some aspects of CEQ's 2016 guidance on climate change and NEPA reviews,[49] which was rescinded by President Trump,[50] as well as the new draft guidance that CEQ issued in June 2019 to take its place.[51] Although the 2016 guidance is no longer in effect,[52] it provides some useful insights into how CEQ interpreted NEPA requirements in the past and contains relatively specific instructions to agencies on how to meaningfully account for and assess the significance of GHG emissions. The 2019 draft guidance, in comparison, contains a number of provisions which appear aimed at limiting NEPA disclosures of GHG emissions and climate change impacts, but in many cases these provisions are too vague to provide meaningful direction, and in many cases merely restate existing law.[53]

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[47] *Methow Valley Citizens*, 490 U.S. at 349. *See also* Marsh v. Or. Nat. Res. Council, 490 U.S. 360, 371 (1989) (referring to "the Act's manifest concern with preventing uninformed action").
[48] *Methow Valley Citizens*, 490 U.S. at 349.
[49] Memorandum from the Council of Environmental Quality on Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews (Aug. 1, 2016), https://ceq.doe.gov/docs/ceq-regulations-and-guidance/nepa_final_ghg_guidance.pdf [https://perma.cc/Y9Z7-FE46] [hereinafter CEQ, Final Guidance Memo].
[50] Exec. Order No. 13,783, 82 Fed. Reg. 16,093 (Mar. 31, 2017).
[51] CEQ, Draft National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emission, 84 Fed. Reg. 30,097 (June 26, 2019) [hereinafter CEQ, 2019 Draft GHG Guidance].
[52] Exec. Order No. 13,783, *supra* note 50.
[53] For example, the draft guidance directs agencies to quantify emissions where they are "substantial enough to warrant quantification" (presumably seeking to curtail quantification)

### 1. NEPA Procedures and Documentation Types

There are three types of documentation that can be used to demonstrate compliance with NEPA. The EIS is the most comprehensive form of documentation and, as provided in the statute, it is required for any major federal action that has significant environmental impacts.[54] If an agency is unsure about whether an action will have significant environmental impacts, it may prepare an environmental assessment ("EA")—a shorter document used to identify potentially significant impacts.[55] Based on the EA, the agency must either proceed with the preparation of a full EIS or issue a finding of no significant impact ("FONSI").[56] The regulations also permit agencies to designate categorical exclusions ("CEs") for categories of actions which the agency has determined "do not individually or cumulatively have a significant effect on the human environment" and thus do not require preparation of an EIS or EA.[57]

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without providing any guidance on what is meant by "substantial enough" in this context. CEQ, 2019 Draft GHG Guidance, *supra* note 51. It also tells agencies that impacts should be "discussed in proportion to their significance" and tells agencies that they "need not give greater consideration to potential effects from GHG emissions than to other potential effects on the human environment." *Id.* This is simply a restatement of NEPA requirements: agencies need not give greater consideration to any particular type of effect as a general matter, but they must conduct a more in-depth analysis of potentially significant impacts. For more on this topic, see Jessica Wentz, *New Draft Guidance on Climate Change and NEPA Reviews Unlikely to Significantly Affect Agency Practice or Judicial Interpretation of NEPA Obligations*, CLIMATE LAW BLOG (June 24, 2019), http://blogs.law.columbia.edu/climatechange/2019/06/24/new-draft-guidance-on-climate-change-and-nepa-reviews-unlikely-to-significantly-affect-agency-practice-or-judicial-interpretation-of-nepa-obligations/ [https://perma.cc/Y92G-ACPU].

[54] 40 C.F.R. §§ 1501.7, 1502.9, 1505.2 (2019) (preparing an EIS involves three steps: a scoping phase, where public input on the scope of the review is solicited; a draft EIS which is made available for public comment; and a final EIS which is published along with a record of decision (ROD) indicating the course of action that the agency intends to take); 40 C.F.R. §§ 1501.4(b), 1501.4(e)(1) (The regulations are less explicit about the process for preparing an EA—they state that the agency "shall involve environmental agencies, applicants, and the public, to the extent practicable" when preparing EAs, and that FONSIs must be made available to the affected public); 40 C.F.R. § 1506.6 (The regulations also contain some general provisions pertaining to public involvement, such as a requirement to "[m]ake diligent efforts to involve the public in preparing and implementing their NEPA procedures.").

[55] *See* 40 C.F.R. § 1508.9; *see also National Environmental Policy Act Review Process*, EPA, https://www.epa.gov/nepa/national-environmental-policy-act-review-process [https://perma.cc/4MU3-YGNN] (last updated Jan. 24, 2017).

[56] 40 C.F.R. §§ 1501.4(e), 1508.13.

[57] 40 C.F.R. § 1508.4.

2. Scope of Analysis: Actions, Impacts, and Alternatives

The CEQ regulations outline the proper scope of analysis for NEPA reviews—that is, the "range of actions, alternatives, and impacts to be considered" in a single impact statement.[58]

a. Scope of Impacts

First, regarding the scope of impacts, agencies must consider three types of impacts: (i) direct effects, which are "caused by the action and occur at the same time and place"; (ii) indirect effects, which are "caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable"; and (iii) cumulative effects, which result from "the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or nonfederal) or person undertakes such other actions."[59]

For proposals that involve fossil fuel supply infrastructure, direct emissions would include emissions from vehicles and equipment used to construct the infrastructure as well as emissions generated from the operation of the infrastructure (e.g., methane emissions from coal mining).[60] Indirect emissions from fossil fuel extraction proposals would include downstream emissions from the eventual transport, processing, and combustion of the produced fossil fuels, and indirect emissions from fossil fuel transport proposals would include not only downstream emissions but also upstream emissions from the production of the transported fuel.[61]

As for the requirement to evaluate cumulative effects—there are two ways that this could be interpreted in the context of a GHG assessment for fossil fuel supply projects. One interpretation is that the impacts of climate change (e.g., sea level rise) qualify as cumulative effects of the proposal, since these impacts will occur when the proposal's GHG emissions are added to all other past, present, and reasonably foreseeable GHG emissions. Certainly, a general description of climate change impacts could be useful to decision makers and the public, but this type of analysis does

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[58] 40 C.F.R. § 1508.25.
[59] 40 C.F.R. §§ 1508.7, 1508.8.
[60] CEQ, Final Guidance Memo, *supra* note 49.
[61] *See* Burger & Wentz, *supra* note 11, at 142–43, 149; *infra* Part II; *see also* CEQ, Final Guidance Memo, *supra* note 49, at 13–14, 16. There are other emissions which may qualify as indirect effects of fossil fuel supply projects, such as the emissions from induced vehicle trips that occur offsite (e.g., worker commutes), but for the purposes of this Article we focus on upstream and downstream emissions.

not provide much insight on the specific action under review.[62] Another interpretation, which would likely generate more useful data for decision-making on fossil fuel supply proposals, is that NEPA requires consideration of the cumulative emissions from other reasonably foreseeable actions affecting fossil fuel supply—for example, the cumulative effects analysis for a coal leasing proposal should encompass cumulative emissions from all federal coal leasing in the state, region, and/or nation. This second interpretation is consistent with the CEQ's guidance on cumulative effects analysis which directs agencies to consider activities that are of a similar nature or that have similar environmental effects when setting boundaries for this analysis.[63]

b. Scope of Actions

Agencies must consider three types of "related actions" when determining the scope of an EIS: connected actions, cumulative actions, and similar actions. Actions are considered "connected" if they: (i) automatically trigger other actions which may require EISs, (ii) cannot or will not proceed unless other actions are taken previously or simultaneously, or (iii) are independent parts of a larger action and depend on the larger action for their justification.[64] Such connected actions are "closely related and therefore *should* be discussed in the same impact statement."[65] Cumulative actions are those that "when viewed with other proposed actions have cumulatively significant impacts" and like connected actions, they should be discussed in the same impact statement.[66] Similar actions are

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[62] CEQ, 2019 Draft GHG Guidance, *supra* note 51. CEQ's 2019 revised draft guidance endorses this approach, stating that agencies may satisfy the requirement to evaluate cumulative effects by: (i) comparing the project's GHG emissions to local, regional, national, or sector-wide emissions, and (ii) providing a qualitative summary of the effects of GHG emissions. This may be sufficient for some types of proposals. However, as discussed in Section II.B, more may be required in the context of fossil fuel supply projects. There are at least two recent decisions in which courts have required quantification of cumulative emissions from federal fossil fuel-related approvals in this context. *See* WildEarth Guardians v. Zinke, 368 F. Supp. 3d 41, 53 (D.D.C. 2019); Indigenous Envtl. Network v. U.S. Dep't of State, 347 F. Supp. 3d 561, 590 (D. Mont. 2018) (requiring the Department of State to disclose emissions from the Alberta Clipper pipeline as part of its cumulative effects analysis for the Keystone XL pipeline).

[63] CEQ, CONSIDERATION OF CUMULATIVE EFFECTS UNDER THE NATIONAL ENVIRONMENTAL POLICY ACT 13 tbl. 2-1 (1997).

[64] 40 C.F.R. § 1508.25(a)(1).

[65] *Id.* (emphasis added).

[66] *Id.* § 1508.25(a)(2).

those which "have similarities that provide a basis for evaluating their environmental consequences together, such as common timing or geography."[67] The regulations state that "[a]n agency may wish to analyze these actions in the same impact statement" but that an agency "*should* do so when the best way to assess adequately the combined impacts of similar actions or reasonable alternatives to such actions is to treat them in a single impact statement."[68]

The regulations also prohibit improper segmentation of proposals. One provision specifies that "[p]roposals or parts of proposals which are related to each other closely enough to be, in effect, a single course of action *shall* be evaluated in a single impact statement."[69] Reinforcing this point the section of the regulations which deals with significance determinations states that an agency cannot break down an action into "small component parts"—or improperly segment an action—in order to avoid a determination that the action will have a significant effect on the environment.[70]

There is overlap between the requirement to review "indirect impacts" and impacts from "connected actions." Consider a situation where the federal government is simultaneously reviewing a coal lease application and a proposal to construct a railway to transport the coal from the mine to end-users (or an existing rail system). The emissions from the railway would qualify as "indirect effects" of the coal mine and vice versa, and both actions would also qualify as "connected actions" that lack independent utility and should thus be reviewed in a single NEPA document (even if two different agencies are responsible for the approvals). However, if there is no pending federal action for a connected activity, the proper approach would be to analyze the emissions from the nonfederal activity as indirect effects of the federal action.

There is also overlap between the requirement to review "cumulative effects" and the requirement to review impacts from cumulative and similar actions. For example, an agency could treat emissions from multiple fossil fuel leasing decisions as cumulative effects in the EIS for an individual leasing proposal, or it could prepare a single EIS to evaluate those leasing decisions as cumulative and/or similar actions. Again,

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[67] *Id.* 1508.25(a)(3).
[68] *Id.* (emphasis added).
[69] 40 C.F.R. § 1502.4 (emphasis added).
[70] 40 C.F.R. § 1508.27(7). The regulations are not explicit about the relationship between the prohibition on improper segmentation and the requirement to consider "related actions" under section 1508.25. One plausible interpretation is that actions which qualify as "connected actions" under section 1508.25 are "related . . . closely enough to be, in effect, a single course of action."

the best approach depends on whether there are multiple federal proposals simultaneously under review by an agency.

c. Scope of Alternatives

Finally, regarding the scope of alternatives, agencies must consider alternatives which include a no action alternative, other reasonable courses of action, and mitigation measures (not in the proposed action).[71] The regulations further provide that the analysis of alternatives is the "heart of the environmental impact statement" and that this analysis "should present the environmental impacts of the proposal and the alternatives in comparative form, thus sharply defining the issues and providing a clear basis for choice among options by the decisionmaker and the public."[72] In addition, agencies must "rigorously explore and objectively evaluate all reasonable alternatives, and for alternatives which were eliminated from detailed study, briefly discuss the reasons for their having been eliminated."[73]

In NEPA reviews for fossil fuel supply projects, the alternatives analysis can and in many cases should be used to evaluate the merits of different fossil fuel development and transportation scenarios. For example, when preparing an EIS for a resource management plan ("RMP") under which federal lands may be opened for fossil fuel development, an agency must consider different leasing scenarios (with different acreage and levels of production) as well as different land uses and approaches to meeting energy demand (e.g., renewable energy development) in addition to the "no action" alternative.[74] This is precisely the sort of analysis that would facilitate an informed decision about the best uses of public lands.

Agencies may also compare fossil fuel production and consumption scenarios under the proposal and the no action alternative to estimate the net impact of the proposal on fossil fuel use and corresponding emissions. The underlying assumption is that energy demand will be met through other sources (energy substitutes) if the proposal is not approved, and these energy substitutes will also generate emissions when they are produced, transported, and consumed. Thus, the emissions from energy substitutes under the no action alternative can be subtracted from the proposal's gross emissions in order to reach an estimate of net emissions.

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[71] 40 C.F.R. § 1508.25(b).
[72] 40 C.F.R. § 1502.14.
[73] *Id.*
[74] 40 C.F.R. § 1508.25.

Alternatively, if an agency finds that there is too much uncertainty to model the effects on energy markets, it could rely on estimates of gross indirect emissions to measure the proposal's contribution to climate change.[75]

3. Significance and Mitigation

The regulations also contain additional instructions on how agencies should go about analyzing environmental impacts and their significance. EISs should be "analytic rather than encyclopedic" and impacts should "be discussed in proportion to their significance."[76] Agencies must discuss the significance of both direct and indirect effects, taking into account the context and intensity of the impact as well as other more specific considerations, such as whether the impact is highly uncertain or controversial and whether the action is related to other individually insignificant but cumulatively significant actions.[77] The regulations also address how agencies should handle missing or incomplete information about potentially significant environmental impacts, including indirect impacts. In these circumstances, agencies are required to obtain any missing information that is essential to a reasoned choice among alternatives, unless the costs of obtaining the information are exorbitant or the information is simply unavailable.[78]

Finally, the regulations call for consideration of mitigation approaches for impacts that are found to be significant. "Mitigation" is defined as:

> (a) Avoiding the impact altogether by not taking a certain action or parts of an action. (b) Minimizing impacts by limiting the degree or magnitude of the action and its implementation. (c) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment. (d) Reducing or eliminating the impact over time by preservation and

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[75] *See infra* Section III.A.
[76] 40 C.F.R. § 1502.2.
[77] 40 C.F.R. §§ 1502.16, 1508.27.
[78] 40 C.F.R. § 1502.22(b). If an agency cannot obtain the missing information due to exorbitant costs or infeasibility, it must provide: (i) a statement that such information is incomplete or unviable, (ii) a statement of the relevance of the information, (iii) a summary of existing credible scientific evidence which is relevant to evaluating environmental impacts in the absence of such information, and (iv) the agency's evaluation of such impacts based on theoretical approaches or research methods generally accepted in the scientific community. *Id.*

> maintenance operations during the life of the action. (e) Compensating for the impact by replacing or providing substitute resources or environments.[79]

Notably, while the regulations require *consideration* of such measures, NEPA and its implementing regulations do not contain a substantive requirement to actually implement mitigation measures for significant impacts.[80] Agencies, however, do have the authority to require mitigation of impacts as a condition of agency approvals; agencies also may require mitigation to avoid a determination of significant impacts and thereby avoid preparation of an EIS.[81]

No federal agency has yet established a threshold for what constitutes a "significant" GHG contribution, and the CEQ intentionally omitted such a threshold from the rescinded guidance.[82] That guidance did, however, contain a recommendation against using comparisons to overall GHG emissions as a basis for evaluating significance:

> [A] statement that emissions from a proposed Federal action represent only a small fraction of global emissions is essentially a statement about the nature of the climate change challenge, and is not an appropriate basis for deciding whether or to what extent to consider climate change impacts under NEPA. Moreover, these comparisons are also not an appropriate method for characterizing the potential impacts associated with a proposed action and its alternatives and mitigations because this approach does not reveal anything beyond the nature of the climate change challenge itself: the fact that diverse individual sources of emissions each make a relatively small addition to global atmospheric GHG concentrations that collectively have a large impact. When considering GHG emissions and their significance, agencies should use appropriate tools and

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[79] 40 C.F.R. § 1508.20.

[80] *See* 40 C.F.R. §§ 1508.20, 1508.25, 1508.27.

[81] CEQ, Final Guidance for Federal Departments and Agencies on the Appropriate Use of Mitigation and Monitoring and Clarifying the Appropriate use of Mitigated Findings of No Significant Impact, 76 Fed. Reg. 3843 (Jan. 21, 2011).

[82] CEQ, Revised Draft Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in NEPA Reviews, 79 Fed. Reg. 77,802, 77,807, 77,809–11 (Dec. 24, 2014) [hereinafter CEQ, 2014 Revised Draft Guidance].

> methodologies for quantifying GHG emissions and comparing GHG quantities across alternative scenarios. Agencies should not limit themselves to calculating a proposed action's emissions as a percentage of sector, nationwide, or global emissions in deciding whether or to what extent to consider climate change impacts under NEPA.[83]

There is no reason that the lack of a significance threshold should prevent agencies from reaching significance determinations for GHG emissions. Agencies frequently assess the significance of other impacts in the absence of predetermined significance thresholds.[84] And even if the exact threshold of significance for GHG emissions is unknown, there are circumstances in which an action's emissions obviously surpass any reasonable metric of significance when viewed in terms of social costs.[85]

### D. *Evolving Federal Policy and Practice on Fossil Fuels and NEPA Reviews*

Federal agencies have made important progress towards meaningful evaluation and disclosure of GHG effects in NEPA reviews for fossil fuel supply projects. Litigation has played an important role in driving such disclosures, but executive policies and guidance have also helped to shape agency practice. Here, we summarize some key policy developments that occurred under the Obama and Trump administrations and discuss how federal practice in this area has evolved over the past decade.

#### 1. Policy Developments Pertaining to Fossil Fuel Approvals and NEPA Reviews

The federal government has long supported fossil fuel production on federal lands and the expansion of fossil fuel transportation infrastructure.

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[83] CEQ, Final Guidance Memo, *supra* note 49, at 11. In contrast, CEQ's 2019 guidance recommends that agencies compare the proposal's emissions to local, regional, national, or sector-wide emissions as part of the cumulative effects analysis. *See supra* note 62. While such comparisons can provide useful information to decision makers and the public, agencies should not rely on these exclusively for the reasons articulated in the 2016 guidance.

[84] CEQ, 2014 Revised Draft Guidance, *supra* note 82 (examples of impacts for which agencies lack quantitative significance thresholds include impacts on public health, species and ecosystems, cultural resources, recreational values, and aesthetic values).

[85] *The true cost of carbon pollution: How the social cost of carbon improves policies to address climate change*, ENVTL. DEF. FUND, https://www.edf.org/true-cost-carbon-pollution [https://perma.cc/NHM6-HUFJ] (last visited Dec. 3, 2019).

During the Obama administration, federal agencies approved new coal, oil, and gas leases, as well as numerous oil and gas pipelines and LNG export terminals.[86] During Obama's second term the administration adopted several policies that signaled decreasing support for fossil fuels. First, the administration offered fewer new leases and less acreage for coal, oil, and gas development on federal lands and waters between 2012 and 2016.[87] Second, DOI Secretarial Order 3338 established a moratorium on federal coal leasing in 2016 accompanied by a commitment to prepare a programmatic EIS ("PEIS") for the federal coal leasing program.[88] One of the key issues to be addressed in the PEIS was the effect of the program on GHG emissions (including downstream emissions) and climate change.[89]

In addition to these leasing actions, the administration adopted the CEQ guidance on consideration of climate change in 2016 which, as noted above, directed agencies to account for upstream and downstream emissions in NEPA reviews for fossil fuel supply projects and to quantify those emissions where tools and data were available to do so.[90] The administration also adopted a number of other relevant policies and guidance, including federal metrics for estimating the social cost of GHG emissions,[91] department- and agency-specific guidance on accounting for

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[86] *See, e.g.*, *Oil and Gas Statistics*, U.S. BUREAU LAND MGMT., tbl. 3, https://www.blm.gov/programs/energy-and-minerals/oil-and-gas/oil-and-gas-statistics [https://perma.cc/62LE-A6FZ] (last visited Dec. 3, 2019) (BLM issued 7,297 oil and gas leases during President Obama's first term, and 3,997 oil and gas leases during his second term.).

[87] *Id. See also Coal Data: National Coal Statistics Table,* U.S. BUREAU LAND MGMT., https://www.blm.gov/programs/energy-and-minerals/coal/coal-data [https://perma.cc/74Q5-AXF7] (last visited Dec. 3, 2019).

[88] DEP'T OF THE INTERIOR, ORDER NO. 3338, DISCRETIONARY PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT TO MODERNIZE THE FEDERAL COAL PROGRAM 1, 8–9 (Jan. 15, 2016).

[89] U.S. BUREAU OF LAND MGMT., FEDERAL COAL PROGRAM PEIS—SCOPING REPORT, 17–23 (2017).

[90] CEQ, Final Guidance Memo, *supra* note 49. Other agencies, such as USFS and BLM, had also published or were developing their own guidance on accounting for climate change in NEPA reviews. *See, e.g.*, *Climate Change Considerations in Project Level NEPA Analysis*, U.S. FOREST SERV. (2009), https://www.fs.fed.us/emc/nepa/climate_change/includes/cc_nepa_guidance.pdf [https://perma.cc/M8A9-9G4X].

[91] *See* INTERAGENCY WORKING GRP. ON THE SOCIAL COST OF GREENHOUSE GASES, TECHNICAL SUPPORT DOCUMENT: TECHNICAL UPDATE OF THE SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866 (May 2013, revised Aug. 2016); *see also* INTERAGENCY WORKING GRP. ON THE SOCIAL COST OF GREENHOUSE GASES, ADDENDUM TO TECHNICAL SUPPORT DOCUMENT ON SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866: APPLICATION OF THE METHODOLOGY TO ESTIMATE THE SOCIAL COST OF METHANE AND THE SOCIAL COST OF NITROUS OXIDE (Aug. 2016) (These metrics were developed for cost-benefit analyses in rule-makings,

climate change in public land management,[92] and guidance on compensatory mitigation for adverse impacts arising from fossil fuel development and other extractive uses of public lands.[93]

The election of President Trump signaled a major shift in executive policy. The Trump administration made it a priority to support fossil fuel development and use under the mantra of "energy dominance."[94] In particular, the administration has taken measures to: (i) scale up fossil fuel production on federal lands and waters by expanding the areas available for leasing and removing regulatory barriers to the issuance of leases[95] and (ii) expedite the review of pipelines and other fossil fuel transportation infrastructure.[96] These supply-side actions are paired with actions

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but can also be utilized in project-level emission assessments and, as noted in Part III, some courts have required their use in the NEPA context.).

[92] *See, e.g.*, *Navigating the Climate Change Performance Scorecard*, U.S. FOREST SERV. (2011), https://www.fs.fed.us/climatechange/advisor/scorecard/scorecard-guidance-08-2011.pdf [https://perma.cc/L4WX-V5JS].

[93] *See generally* U.S. BUREAU OF LAND MGMT. MANUAL SECTION 1794—MITIGATION (Dec. 22, 2016); U.S. BUREAU OF LAND MGMT. MITIGATION HANDBOOK H-1794-1 (Dec. 22, 2016).

[94] *See About: Mission*, U.S. DEP'T INTERIOR, https://www.doi.gov/whoweare [https://perma.cc/GA7H-LLFN] (last visited Dec. 3, 2019) ("promot[ing] energy dominance" is the first major goal outlined for DOI).

[95] *See, e.g.*, Notice of Availability of the 2019–2024 Draft Proposed Outer Continental Shelf Oil and Gas Leasing Program and Notice of Intent to Prepare a Programmatic Environmental Impact Statement, 83 Fed. Reg. 829, 830 (Jan. 2018); *2017–2022 Outer Continental Shelf Oil and Gas Leasing: Proposed Final Program*, BUREAU OCEAN ENERGY MGMT. (Nov. 2016), https://www.boem.gov/2017-2022-OCS-Oil-and-Gas-Leasing-PFP/ [https://perma.cc/DU63-6T2D]; *Coastal Plain Oil and Gas Leasing EIS*, U.S. DEP'T INTERIOR (Sept. 2019), https://eplanning.blm.gov/epl-front-office/eplanning/planAndProjectSite.do?methodName=dispatchToPatternPage&currentPageId=152110 [https://perma.cc/74ZQ-E897] (In January 2018, BOEM issued a proposed National Outer Continental Shelf Oil and Gas Leasing Program for 2019–2024, which would make over 90 percent of the outer continental shelf ("OCS") available for future oil and gas exploration and development. In comparison with the 2019–2024 Draft, the 2017–2022 offshore leasing program (which would be superseded by this new program) put 94 percent of the OCS off-limits to oil and gas development. The Draft Proposed Program ("DPP") includes forty-seven potential lease sales in twenty-five of twenty-six planning areas—which, according to DOI, is the largest number of lease sales ever proposed for the OCS five-year lease schedule. The administration also took measures to expand leasing areas in the Arctic, and in December 2018, BLM issued a proposal for a Coastal Plain Oil and Gas Leasing Program in the Arctic National Wildlife Refuge ("ANWR") which would make up to 1.5 million acres of the ANWR open for oil and gas development. In March 2019, BLM lifted restrictions on mineral development on approximately nine million acres of sage grouse habitat, opening these previously protected areas for oil and gas leasing and other extractive uses. Many of these actions were challenged in court, and litigation was, at the time of this writing, still pending.).

[96] *See* JESSICA WENTZ & MICHAEL GERRARD, SABIN CTR. FOR CLIMATE CHANGE LAW,

aimed at lifting "downstream" restrictions on fossil fuel use, such as the emission standards for power plants and motor vehicles originally promulgated under the Obama administration.[97]

Some of the Trump administration's major executive actions affecting NEPA reviews for fossil fuel supply projects include:

- The issuance of multiple executive orders directing agencies to streamline approvals for fossil fuel leasing and energy infrastructure;[98]
- The revocation of the CEQ's 2016 guidance on climate change,[99] and promulgation of new draft guidance;[100]
- The revocation of the federal metrics developed for the social cost of carbon (SC-$CO_2$), methane (SC-$CH_4$) and nitrous oxide (SC-$N_2O$);[101] and
- The termination of the programmatic review of the federal coal leasing and the moratorium that had been put in place pending that review.[102]

Acting pursuant to these directives, DOI and its constituent agencies also adopted more specific policies and guidance aimed at expediting and curtailing reviews of coal, oil, and gas leases. For example, BLM issued an instruction memorandum to its field offices on January 31, 2018, which establishes a BLM policy "to simplify and streamline the leasing process [for oil and gas] to alleviate unnecessary impediments and burdens, to expedite the offering of lands for lease, and to ensure quarterly oil and gas lease sales are consistently held."[103] The instruction

PERSISTENT REGULATIONS: A DETAILED ASSESSMENT OF THE TRUMP ADMINISTRATION'S EFFORTS TO REPEAL FEDERAL CLIMATE PROTECTIONS (2019); *see also* U.S. DEP'T OF THE INTERIOR, ECONOMIC REPORT: FY 2017 5 (Oct. 19, 2018), https://doi.sciencebase.gov/doidv/files/2017/pdf/FY%202017%20Econ%20Report.pdf [https://perma.cc/XJA2-ZKP7].

[97] WENTZ & GERRARD, *supra* note 96, at 39–40.

[98] Exec. Order No. 13,868, 84 Fed. Reg. 15,495 (Apr. 10, 2019); Exec. Order No. 13,867, 84 Fed. Reg. 15,491 (Apr. 10, 2019); Exec. Order No. 13,807, 82 Fed. Reg. 40,463 (Aug. 24, 2017); Exec. Order No. 13,795, 82 Fed. Reg. 20,815 (May 3, 2017).

[99] Exec. Order No. 13,783, *supra* note 50.

[100] CEQ, 2019 Draft GHG Guidance, *supra* note 51.

[101] Exec. Order No. 13,783, *supra* note 50.

[102] DEP'T OF THE INTERIOR, ORDER NO. 3348, CONCERNING THE FEDERAL COAL MORATORIUM 1 (Mar. 29, 2017).

[103] Instruction Memorandum No. 2018-034: Updating Oil and Gas Leasing Reform from the Deputy Director of the Bureau of Land Mgmt. to all field officials 1 (Jan. 31, 2018),

memorandum reduces the amount of time that BLM field offices have to review environmental impacts and receive public feedback. It limits the time frame for parcel review for a specific lease sale to six months and limits the amount of time allotted for public protest of lease sales to ten days after notice is posted.[104] It also seeks to eliminate opportunities for public review and disclosure of environmental impacts from oil and gas development on public lands.[105]

These policy changes have resulted in more fossil fuel production on federal lands. DOI announced that the revenue generated from oil and gas lease sales on public lands in 2018 was nearly triple that of the next highest grossing year on record.[106] Granted, coal production and use continued to decline in 2018, but the emissions reduction benefits of declining coal use were more than offset by increased emissions from oil and gas, and both oil and gas production are projected to increase significantly over the next decade.[107] The administration also approved several major coal mining leases that could affect coal prices and consumption in the years ahead.[108] This situation seems untenable at a time when fossil fuel use needs to be phased out rapidly. The duration of these leasing plans and anticipated lifetime of these transportation projects range from ten years to several decades or more—considerably longer than the time frame in which fossil fuels need to be phased out.[109]

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https://www.blm.gov/policy/im-2018-034 [https://perma.cc/WH4L-RVVL] [hereinafter BLM, Memo No. 2018-034]. The U.S. Forest Service has also signaled its intent to modify its regulations in order to streamline and expedite the issuance of oil and gas permits on National Forest lands. *See* Oil and Gas Resources, 83 Fed. Reg. 46,458 (Sept. 13, 2018).

[104] BLM, Memo No. 2018-034, *supra* note 103.

[105] *Id.*

[106] Press Release, U.S. Dep't of the Interior, Energy Revolution Unleashed: Interior Shatters Previous Records with $1.1 Billion in 2018 Oil and Gas Lease Sales (Feb. 6, 2019), https://www.doi.gov/news/energy-revolution-unleashed-interior-shatters-previous-records-11-billion-2018-oil-and-gas [https://perma.cc/4YN6-TXDH].

[107] Kate Wheeling, *U.S. Oil Production is Set to Rise As Experts Say Fossil Fuels Need to be Phased Out*, PAC. STANDARD (Jan. 16, 2019), https://psmag.com/environment/us-oil-production-is-set-to-rise-as-experts-say-fossil-fuels-need-to-be-phased-out [https://perma.cc/5942-UUZX].

[108] Press Release, U.S. Dep't of the Interior, The War on Coal is Over: Interior Announces Historic Coal Projects in Utah (Feb. 14, 2019), https://www.doi.gov/pressreleases/war-coal-over-interior-announces-historic-coal-projects-utah [https://perma.cc/W4ZF-LWEH].

[109] Press Release, U.S. Dep't of the Interior, Energy Revolution Unleashed: Interior Shatters Previous Records with $1.1 Billion in 2018 Oil and Gas Lease Sales (Feb. 6, 2019), https://www.doi.gov/news/energy-revolution-unleashed-interior-shatters-previous-records-11-billion-2018-oil-and-gas [https://perma.cc/5Y3X-JGPB].

It is within this policy context that federal agencies must now conduct NEPA reviews for fossil fuel supply projects. As discussed below, agency practice on GHG analysis and disclosures has improved in many respects—in particular, agencies are more transparent about the downstream emissions from combustion of fossil fuels in NEPA reviews for fossil fuel leasing proposals—and there has not been significant "backtracking" during the Trump administration. This is a testament to the power of litigation and the importance of court decisions. The Trump administration's 2019 revised draft guidance on climate change and NEPA reviews is unlikely to significantly affect agency practice or judicial review in this context, in part for reasons noted above (the guidance is very vague and primarily a restatement of existing law) and in part because it would only be entitled to Skidmore deference.[110]

2. Trends in NEPA Practice

Between 2009 and 2016, federal agencies began to account for GHG emissions in NEPA reviews for land management plans and leases authorizing fossil fuel extraction from federal lands and waters.[111] However, many of these proposals were approved without a meaningful assessment of indirect emissions from the transport, processing and use of the produced fuels, or cumulative emissions from multiple leasing decisions.[112] Some agencies did recognize that downstream emissions—particularly emissions from the combustion of produced fuels—qualified as "indirect effects" and quantitative disclosures of combustion emissions became increasingly common during this period.[113] But practice varied considerably both across and within agencies, resulting in inconsistencies across NEPA documentation.[114]

In some documents, agencies would argue that authorizing fossil fuel production on federal lands would have no actual effect on fossil fuel

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[110] When a court reviews agency guidance documents, the agency's interpretation is entitled to "respect proportional to its power to persuade" in light of the agency's "thoroughness, logic, and expertness, its fit with prior interpretations, and any other sources of weight." United States v. Mead Corp., 533 U.S. 218, 235 (2001) (citing Skidmore v. Swift & Co., 323 U.S. 134, 140 (1944)).
[111] See Burger & Wentz, *supra* note 11, for a more detailed discussion of how federal agencies were accounting for indirect GHG emissions in their NEPA documentation during this period.
[112] *Id.*
[113] *Id.*
[114] *Id.*

consumption and downstream emissions because other sources of coal, oil, or gas would be extracted and used at the same rates if the federal proposals were not approved (an argument that is often referred to as "perfect substitution").[115] In effect, agencies were claiming that the GHG impact would be identical under both the proposed action and the no action alternative. The problem with this approach was that it ignored potential effects of production projects on fossil fuel prices and demand.

There were similar inconsistencies in NEPA reviews of fossil fuel transportation infrastructure. The State Department, DOE, and U.S. Army Corps of Engineers ("USACE") discussed upstream and downstream emissions as potential indirect effects in some of the NEPA documentation prepared for these projects.[116] However, FERC—which conducted the largest number of reviews due to its authority over natural gas pipelines and export terminals—consistently maintained that upstream and downstream emissions did not qualify as indirect effects of its approvals because: (i) the approvals were not the legally relevant cause of those emissions, and (ii) even if there was a causal relationship, the emissions were too speculative to estimate.[117] Granted, other agencies made similar arguments in some of their NEPA documentation (and when defending those documents in court)[118] but none had as firm a policy on the issue as FERC.

Even with the inconsistencies in agency practice, there was a clear trend towards greater disclosure of indirect emissions during this period.[119] This up-tick in federal disclosures was driven, at least in part, by litigation. By 2017, over a dozen lawsuits had been filed challenging the approval of fossil fuel leasing and pipeline proposals because the lead agency failed to adequately consider upstream and/or downstream greenhouse gas emissions in its NEPA review.[120] The critical question in most of these cases was whether such upstream and downstream emissions qualified as indirect effects of these proposals.[121] In early decisions involving NEPA reviews for fossil fuel leasing, courts made it clear that downstream emissions from the consumption of the fossil fuels that would be extracted under the lease qualified as indirect effects under NEPA, and that agencies should quantify those emissions wherever tools and

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[115] *Id.*
[116] *See, e.g.*, U.S. DEP'T OF STATE, FINAL SUPPLEMENTAL EIS, KEYSTONE XL (2014) § 1.4 ("Market Analysis"); Burger & Wentz, *supra* note 11, at Part II.
[117] *See* Burger & Wentz, *supra* note 11, at 137.
[118] *See id.*
[119] *See id.*
[120] *Id.*
[121] *Id.*

data were available to do so.[122] Courts also rejected perfect substitution arguments as a basis for ignoring downstream emissions from leasing.[123] The issue was not so clearly resolved in early decisions involving fossil fuel transportation projects—some courts required disclosure of upstream and/or downstream emissions; others did not.[124] That issue continues to be litigated.[125]

The litigation has led to a shift in agency practice, at least for proposals involving fossil fuel production. For the most part, agencies overseeing fossil fuel production no longer argue perfect substitution as the grounds for ignoring downstream emissions.[126] Instead, agencies sometimes provide a quantitative estimate of downstream emissions (often limited to combustion emissions) accompanied by a qualitative statement about how the actual (net) emissions from the proposal will be much lower as a result of energy substitution under the no action alternative.[127] In that context, agencies may conclude that it is impossible to measure the actual effect of the proposal on climate change, and thus there is no significance determination or discussion of mitigation measures.[128] Another approach, more common for major leasing proposals, is to use energy market models to compare emissions from fossil fuels produced under the proposal with emissions from energy substitutes under the no action alternative to generate an estimate of net emissions.[129] While this approach seems reasonable in theory, there are potential problems in practice. The model results are dependent on parameters (i.e., assumptions about

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[122] *See id.*
[123] Burger & Wentz, *supra* note 11, at 152.
[124] *Id.*
[125] See *infra* Section II.A. At the time of this writing, there is no case invalidating an EIS for failure to consider upstream emissions, but there are cases upholding EISs because they properly accounted for upstream emissions. Whether quantification is required under NEPA depends on whether tools and data are available to do so.
[126] *See* Burger & Wentz, *supra* note 11, at 152.
[127] *Id.*
[128] *See, e.g.*, U.S. FOREST SERV., SUPPLEMENTAL FINAL ENVIRONMENTAL IMPACT STATEMENT, FEDERAL COAL LEASE MODIFICATIONS COC-1362 & COC-67232 at 128 (2017):

> All that can be gleamed from this analysis is that relative to the alternatives themselves, the no action produces the least amount of incremental GHG increases. This does not however translate directly into climate change impact reductions due to the complexities involved with estimating the coal supply market responses to current demand, current fuel substitution transitions to non-coal fuels (beyond the scope of this analysis), and how other governments and sectors of the global economy implement or fail to implement GHG emissions reduction strategies.

[129] Burger & Wentz, *supra* note 11, at 179.

energy resources, price elasticity, and demand) that are highly uncertain and can be manipulated to achieve an intended result.[130] But these are not necessarily insurmountable problems. Agencies can address uncertainty by using multiple scenarios in their energy market analysis (e.g., with different assumptions about energy prices and elasticity) and they can address concerns about integrity and data manipulation by being transparent about the assumptions underpinning their analysis.

As for transportation infrastructure: starting in 2016, FERC started to include increasing amounts of information on upstream and downstream GHG emissions in its pipeline orders.[131] This appeared to be driven by the Obama administration's policy and guidance on NEPA reviews as well as case law requiring disclosure of downstream emissions in other contexts. But FERC placed caveats on this information and analysis—for example, in one EIS where FERC quantified downstream emissions from a pipeline approval pursuant to a D.C. Circuit Court order, FERC claimed that it could not use the quantified downstream GHG emission estimates to evaluate the proposal "[b]ecause the No Action Alternative could result in lesser, equal, or greater GHG emissions" than the scenario in which the pipeline is approved.[132] FERC has also asserted that natural gas pipelines would likely decrease emissions (due to fuel switching from coal to gas) without conducting any analysis to support this conclusion.[133] In 2018, FERC announced that it would no longer even quantify downstream or upstream emissions for most pipeline orders because the effect of pipeline approvals on upstream and downstream emissions was not reasonably foreseeable and therefore not an indirect or cumulative effect that must be evaluated under NEPA.[134]

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[130] *Id.*

[131] *See* Dominion Transmission, Inc., 163 FERC ¶ 61,128 (LaFleur, dissenting).

[132] FERC, FINAL SUPPLEMENTAL EIS, SOUTHEAST MARKET PIPELINES PROJECT, EIS 0279F at 9 (2018).

[133] *See, e.g.*, Petitioners' Joint Opening Brief at 20, Allegheny Def. Project v. FERC, No. 17-1098 (D.C. Cir. Mar. 9, 2018).

[134] Dominion Transmission, Inc., *supra* note 131; Gavin Bade, *Divided FERC restricts climate impacts in pipeline reviews,* UTILITYDIVE (May 18, 2018), https://www.utilitydive.com/news/divided-ferc-restricts-climate-impacts-in-pipeline-reviews/523892/ [https://perma.cc/7448-HSAX]. FERC came under considerable scrutiny for this policy and many of its pipeline approvals are currently being challenged in court. Moreover, two of the five FERC commissioners—Cheryl LaFleur and Richard Glick—dissented with the order establishing the policy on the grounds that downstream and upstream emissions do qualify as indirect or cumulative impacts of pipeline approvals. Dominion Transmission, Inc., *supra* note 131. Commissioner Glick characterized FERC's position as a "remarkably narrow view of its responsibilities under NEPA" and Commissioner LaFleur

There are also some trends which have become prevalent in NEPA reviews for all types of fossil fuel supply proposals. One example is that federal agencies are refusing to disclose social costs of emissions on the grounds that such a cost disclosure is neither required by NEPA nor helpful to decision makers.[135] Another example relates to significance determinations for GHG emissions.[136] The NEPA documentation for both production and transportation projects often contains no discussion (or only a limited discussion) of the significance criteria outlined in the regulations.[137] Instead, the significance "analysis" may entail a comparison of emissions to state, national, or global totals (contrary to the recommendations in the rescinded CEQ guidance), a statement about uncertainty due to energy market substitution, and/or a statement about how there is no significance threshold for GHG emissions and thus no way of defining significance. Based on this cursory analysis, agencies either conclude that emissions are insignificant or do not reach a conclusion on the matter.[138] We are not aware of *any* EIS in which an agency has concluded that emissions from fossil fuel production or transportation qualify as a "significant" impact, even in the context of proposals that would generate millions of tons of GHGs.[139] It also appears that agencies are heavily relying on EAs and FONSIs for oil and gas lease approvals, and hundreds (possibly thousands) of oil and gas leases have been approved based on FONSIs in the past two years.[140]

As federal policies and agency practice have changed, so too has the focus of litigation on the adequacy of the GHG analysis for fossil fuel

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noted that FERC's position was in direct conflict with the D.C. Circuit's interpretation of what NEPA required. *Id.* Commissioner Cheryl LaFleur announced that she would depart from the commission's policy and consider upstream and downstream emissions in her review and consider the broad climate impacts of new natural gas infrastructure when voting on whether to approve new projects. *Id.*; *see also* ROMANY WEBB, SABIN CTR. FOR CLIMATE CHANGE LAW, CLIMATE CHANGE, FERC, AND NATURAL GAS PIPELINES: THE LEGAL BASIS FOR CONSIDERING GREENHOUSE GAS EMISSIONS UNDER SECTION 7 OF THE NATURAL GAS ACT 4 (2019) (finding that FERC rarely considers climate change effects when deciding whether to approve pipeline projects).

[135] WEBB, *supra* note 134, at 30.

[136] *Id.*

[137] *Id.*

[138] *Id* at 44.

[139] *See* MADELEINE SIEGEL & ALEXANDER LOZNAK, SABIN CTR. FOR CLIMATE CHANGE LAW, SURVEY OF GREENHOUSE GAS CONSIDERATIONS IN FEDERAL ENVIRONMENTAL IMPACT STATEMENTS AND ENVIRONMENTAL ASSESSMENTS FOR FOSSIL FUEL–RELATED PROJECTS, 2017–2018 at 2–3 (2019).

[140] *See id.* at 15–16.

supply projects. There are still many lawsuits involving an agency's failure to disclose certain categories of emissions—particularly indirect emissions, cumulative emissions, and emissions from related actions. We discuss these cases involving the proper scope of analysis in Part II. There are also a number of lawsuits that address questions related to the mode or adequacy of analysis—e.g., whether the analysis itself is technically sound, supported by the record, and consistent with the requirements of NEPA regulations. The critical questions include:

- What are reasonable assumptions about energy market impacts, energy substitutions, the "net" effect of the proposal on fossil fuel production and consumption (and the corresponding emissions)?
- How should an agency go about assessing the significance of emissions? Must agencies use tools such as social cost estimates or a global carbon budget to better understand the severity of the emissions impact?
- What is required in terms of assessing alternatives and mitigation for GHG emissions?

We discuss these questions on the mode of analysis in Part III.

## II. THE REQUIRED SCOPE OF GHG EMISSIONS DISCLOSURE FOR FOSSIL FUEL SUPPLY PROJECTS

In this section we propose answers to various aspects of two key questions: (1) To what extent and under what circumstances must agencies account for upstream and downstream emissions from other activities on the supply chain for the fuels that will be produced or transported as a result of federal approvals? and (2) To what extent must agencies account for cumulative emissions of multiple fossil fuel leasing and/or transportation approvals in their NEPA reviews for fossil fuel supply projects? Most of the case law to date focuses on whether such emissions qualify as indirect or cumulative impacts of federal proposals, but some decisions grapple with other aspects of NEPA, such as whether multiple fossil fuel–related approvals constitute "related actions" that must be reviewed jointly, and whether the required scope of disclosure is different when an agency has prepared an EA and has found no significant impact on GHG emissions.

### A. *Upstream and Downstream Emissions from Fossil Fuel Supply Projects*

There are two regulatory requirements that may provide the basis for evaluating disclosure of upstream and/or downstream emissions in this context: the requirement to evaluate indirect effects and the requirement to evaluate the effects of connected actions. We discuss each approach in turn.[141]

#### 1. Upstream and Downstream Emissions as Indirect Impacts

Indirect effects are "caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable."[142] They include "growth inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems."[143] A sufficient causal connection exists if the proposed action is a cause-in-fact of the impact (i.e., the impact would not occur but for the proposed action) and if there is a "reasonably close causal relationship akin to proximate cause in tort law."[144] An impact is "reasonably foreseeable" if it is "sufficiently likely to occur that a person of ordinary prudence would take it into account in reaching a decision."[145] Examples of factors relevant to this analysis include the likelihood of the impact, the utility of the information to the decision maker, and whether the absence of such information now would foreclose its consideration later.[146]

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[141] There are also some cases in which agencies, parties, and courts have treated these as "cumulative emissions"—but characterizing upstream and downstream emissions as cumulative effects fails to account for the causal relationship between the production of fossil fuels or expansion of transport infrastructure and the eventual use of those fuels. As discussed below, courts have found that this causal relationship is sufficient to characterize these emissions as indirect rather than cumulative effects, and this appears to be the better approach in light of that causal connection.
[142] 40 C.F.R. § 1508.8(b) (2011).
[143] *Id.*
[144] U.S. Dep't of Transp. v. Pub. Citizen, 541 U.S. 752, 754 (2004) (citing Metro. Edison Co. v. People Against Nuclear Energy, 460 U.S. 766, 774 (1983)) (internal citations omitted).
[145] City of Shoreacres v. Waterworth, 420 F.3d 440, 453 (5th Cir. 2005) (quoting Sierra Club v. Marsh, 976 F.2d 763, 767 (1st Cir. 1992)); *see also* Mid States Coal. for Progress v. Surface Transp. Bd., 345 F.3d 520, 549 (8th Cir. 2003).
[146] Sierra Club v. Marsh, 976 F.2d 763, 768 (1st Cir. 1992) (citing Sierra Club v. Marsh 769 F.2d 868, 878 (1st Cir. 1985)); *see also* Massachusetts v. Watt, 716 F.2d 946, 952–53 (1st Cir. 1983).

Although agencies are not required to conduct a "crystal-ball" inquiry to identify potential impacts, they must use "[r]easonable forecasting and speculation" to evaluate impacts even when there is uncertainty about the nature and timing of those impacts.[147] Moreover, the NEPA regulations impose an affirmative obligation on agencies to procure information regarding reasonably foreseeable impacts when possible.[148] The agency must also respond to information when it is provided through public comments.[149] In determining whether an agency has violated NEPA by omitting information from its analysis, a court must consider the "usefulness of any new potential information to the decisionmaking process."[150]

Some courts have used the analogy of "links in a chain" to describe the scope of indirect effects that should be reviewed in NEPA documents.[151] This analogy is helpful for thinking about the scope of NEPA analysis for GHG emissions from fossil fuel supply projects. The various stages of fossil fuel production, transportation, processing, and consumption can also be thought of as "links in a chain" which are inextricably connected and should thus be analyzed together.[152]

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[147] Scientists' Inst. for Pub. Info., Inc. v. U.S. Atomic Energy Comm'n, 481 F.2d 1079, 1092 (D.C. Cir. 1973) (noting that the courts must therefore "reject any attempt by agencies to shirk their responsibilities under NEPA by labeling any and all discussion of future environmental effects as 'crystal ball inquiry'"); *see also* City of Davis v. Coleman, 521 F.2d 661, 675 (9th Cir. 1975) ("The nature and extent of development which the project will induce is still uncertain. Davis' fears may be exaggerated. But currently available information and plain common sense indicate that it was hardly 'reasonable' for CDHW or FHWA to conclude, without further study, that the environmental impact of the proposed interchange will be insignificant.").

[148] 40 C.F.R. § 1502.22 (2012).

[149] *Mid States Coal. for Progress*, 345 F.3d at 537.

[150] U.S. Dep't of Transp. v. Pub. Citizen, 541 U.S. 752, 767 (2004).

[151] Sylvester v. U.S. Army Corps of Eng'rs, 884 F.2d 394, 400 (9th Cir. 1989):

> Environmental impacts are in some respects like ripples following the casting of a stone in a pool. The simile is beguiling but useless as a standard. So employed it suggests that the entire pool must be considered each time a substance heavier than a hair lands upon its surface. This is not a practical guide. A better image is that of scattered bits of a broken chain, some segments of which contain numerous links, while others have only one or two. Each segment stands alone, but each link within each segment does not[.]

*See also* Ocean Mammal Inst. v. Cohen, 164 F.3d 631 (9th Cir. 1998); Fla. Audubon Soc'y v. Bentsen, 94 F.3d 658, 668–70 (D.C. Cir. 1996); Border Power Plant Working Grp. v. U.S. Dep't of Energy, 260 F. Supp. 2d 997, 1013 (S.D. Cal. 2003); Ocean Mammal Inst. v. Cohen, No. 98-cv-160, 1998 WL 2017631, at *8 (D. Haw. Mar. 9, 1998) *aff'd sub nom.*

[152] *See, e.g.*, *Border Power Plant Working Grp.*, 260 F. Supp. 2d at 1013–17 (holding environmental impacts of power plant in Mexico were indirect impacts of decision to construct electric transmission line because neither facility would exist without the other).

a. Fossil Fuel Extraction

In our 2017 article, we explained why downstream GHG emissions from the processing, transportation, and consumption of fossil fuels that are produced as a result of federal management plans and lease sales qualify as "indirect effects" that must be considered in an EA or EIS.[153] These downstream activities and the emissions they generate have a clear causal connection to federal authorizations: but for the authorization, the consumed.[154] These downstream activities are also reasonably foreseeable outcomes of authorizing the extraction of the fuels—indeed, producing fuel for energy supply is the primary purpose of the authorizations.[155] NEPA thus requires agencies to disclose downstream emissions as potential effects of fossil fuel supply projects and to quantify the emissions wherever tools and data are available to do so. In particular, where agencies are able to project the quantity of fuels to be produced, they must also estimate the GHG emissions generated from the combustion of the fuels. This is true whether the lease is for coal, oil, or gas.[156] When quantification is not feasible, this does not mean the emissions can be excluded from the analysis—to the contrary, agencies have a duty to qualitatively disclose and evaluate indirect effects where the nature of the effect is reasonably foreseeable even if the exact magnitude or extent is not.[157]

Arguments that consideration and disclosure of downstream emissions are not required in the NEPA analysis for fossil fuel production have proven unpersuasive. One argument, which we call the "status quo" argument, has arisen in the context of proposals to reauthorize or expand coal mines that were already in operation. In that context, agencies asserted that the continued operation of the mine would not increase the *rate* of coal extraction and thus it would not increase the *rate* of coal consumption.[158] Courts have properly rejected this argument, holding that the continued operation of mines generates additional emissions over

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[153] Burger & Wentz, *supra* note 11, at 112.
[154] For a more in-depth explanation of why upstream and downstream emissions qualify as indirect effects, see generally *id.*
[155] *Id.* at 128.
[156] Whether an agency must quantify processing and transportation emissions may depend on other aspects of the project, such as whether the agency knows the route and mode by which the fuels will be transported to end-users.
[157] 40 C.F.R. § 1502.22 (2012); *see also* Mid States Coal. for Progress v. Surface Transp. Bd., 345 F.3d 520, 549–50 (8th Cir. 2003).
[158] S. Fork Band Council of W. Shoshone of Nev. v. U.S. Dep't of the Interior, 588 F.3d 718, 725 (9th Cir. 2009).

time even if it does not change the rate at which those emissions are generated, and this effect must be considered under NEPA.[159]

Another argument, which we call the "perfect substitute" argument, posits that the extraction of fossil fuels will not actually cause an increase in fossil fuel consumption because the same quantity of fuel would be produced elsewhere and eventually consumed even if the agency does not approve the proposal.[160] In *High Country Conservation Advocates v. United States Forest Service*, the first case that specifically examined an agency's obligation to evaluate downstream greenhouse gas emissions from coal production, a district court rejected this argument as "illogical" because increasing coal supply would affect coal prices and the demand for coal relative to other fuel sources.[161] Other courts have adopted the reasoning from *High Country* in cases involving fossil fuel production.[162]

Finally, a third argument, which we call the "It's Not Our Call" argument, posits that the agency approving fossil fuel production lacks jurisdiction over downstream activities such as fossil fuel consumption and is therefore not required to consider the effects of those activities in its NEPA analysis. The primary basis for this argument was the Supreme Court's decision in *Department of Transportation v. Public Citizen*.[163] There, the Supreme Court held that an agency need not consider environmental effects in its NEPA review when it has "no ability" to adopt a course of action that could prevent or otherwise influence those effects.[164] But agencies' reliance on this case in the context of fossil fuel supply projects is misplaced because agencies do have the power to act on information about downstream emissions from leased fossil fuels (specifically, by restricting and limiting fossil fuel leasing from federal lands and waters).[165] Most of

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159 Diné Citizens Against Ruining Our Env't v. U.S. Off. of Surface Mining, Reclamation & Enf't, 82 F. Supp. 3d 1201 (D. Colo. 2015), *appeal dismissed* (Aug. 18, 2015); *S. Fork Band Council of W. Shoshone of Nev.*, 588 F.3d at 725.

160 *See* Section III.A for an overview of litigation challenging agency assumptions about energy market substitution.

161 High Country Conservation Advocates v. U.S. Forest Serv., 52 F. Supp. 3d 1174, 1198 (D. Colo. 2014).

162 WildEarth Guardians v. U.S. Bureau of Land Mgmt., 870 F.3d 1222, 1228 (10th Cir. 2017); WildEarth Guardians v. Zinke, No. 1:17-cv-00080, 2019 WL 2404860, at *30–31 (D. Mont. Feb. 11, 2019); Mont. Envtl. Info. Ctr. v. U.S. Off. of Surface Mining, Reclamation & Enf't, 274 F. Supp. 3d 1074, 1098 (D. Mont. 2017), *amended in part, adhered to in part sub nom.*; Mont. Envtl. Info. Ctr. v. U.S. Off. of Surface Mining, No. CV 15-106-M-DWM, 2017 WL 5047901 (D. Mont. Nov. 3, 2017).

163 U.S. Dep't of Transp. v. Pub. Citizen, 541 U.S. 752, 770 (2004).

164 *Id.* at 766–70.

165 WildEarth Guardians v. Zinke, 368 F. Supp. 3d 41, 74 (D.D.C. 2019); Diné Citizens

the cases that we reviewed in our 2017 article dealt with whether agencies were required to disclose combustion emissions in the context of federal proposals for coal leasing.[166] At that time, there were five district court decisions on this question, all of which had held that such disclosure was required.[167] Since then, there have been a number of new decisions reinforcing the idea that downstream emissions from fossil fuel processing, transportation, and use qualify as indirect effects of fossil fuel production and clarifying that this basic principle applies regardless of the type of fuel being produced, the type of proposal, the type of NEPA documentation (EIS or EA), or the type of downstream emissions.[168]

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Against Ruining Our Env't v. U.S. Off. of Surface Mining, Reclamation & Enf't, 82 F. Supp. 3d 1201, 1217 (D. Colo. 2015).

[166] Burger & Wentz, *supra* note 11, at 109, 164.

[167] In four of these cases, the courts determined that the responsible agencies failed to take the requisite "hard look" at downstream emissions from the combustion of the coal: *Diné Citizens*, 82 F. Supp. 3d at 1211; WildEarth Guardians v. U.S. Off. of Surface Mining, 104 F. Supp. 3d 1208, 1231 (D. Colo. 2015), *vacated as moot* 652 Fed. Appx. 717 (10th Cir. 2016); WildEarth Guardians v. U.S. Off. of Surface Mining, No. CV-14-13-BLG-SPW-CSO, 2015 WL 6442724, at *7 (D. Mont. 2015); High Country Conservation Advocates v. U.S. Forest Serv., 52 F. Supp. 3d 1174, 1195 (D. Colo. 2014). In the fifth case, the court held that the agency's analysis of downstream emissions was adequate, in part because the agency had already disclosed emissions from the combustion of the leased coal. WildEarth Guardians v. U.S. Forest Serv., 120 F. Supp. 3d 1237, 1276 (D. Wyo. 2015).

[168] Citizens for a Healthy Cmty. v. U.S. Bureau of Land Mgmt., 377 F. Supp. 3d 1223, 1237 (D. Colo. 2019); WildEarth Guardians v. Zinke, 368 F. Supp. 3d 41, 74 (D.D.C. 2019) (BLM must analyze downstream emissions in oil and gas lease EAs); WildEarth Guardians v. Zinke, No. 1:17-cv-00080, 2019 WL 2404860, at *21 (D. Mont. Feb. 11, 2019) (OSM must evaluate indirect and cumulative impacts caused by coal trains beyond the area near the mine, as there was sufficient data to support this analysis); W. Org. of Res. Councils v. U.S. Bureau of Land Mgmt., No. 4:16-cv-00021-BMM, 2018 WL 1475470, at *40 (D. Mont. Mar. 26, 2018) (BLM must quantify emissions from coal, oil, and gas combustion in RMP EISs); Wilderness Workshop v. U.S. Bureau of Land Mgmt., 342 F. Supp. 3d 1145, 1156 (D. Colo. 2018) (BLM must disclose emissions from oil and gas combustion in RMP EIS and also evaluate potential impacts of those emissions in light of revised total GHG projections); San Juan Citizens All. v. U.S. Bureau of Land Mgmt., 326 F. Supp. 3d 1227, 1246 (D.N.M. 2018) (BLM must disclose emissions from oil and gas combustion in lease sale EA and also evaluate potential impacts of those emissions in light of revised total GHG projections); Mont. Envtl. Info. Ctr. v. U.S. Off. of Surface Mining, 274 F. Supp. 3d 1074, 1092, 1094 (D. Mont. 2017), *amended in part, adhered to in part sub nom.* Mont. Envtl. Info. Ctr. v. U.S. Off. of Surface Mining, No. CV 15-106-M-DWM, 2017 WL 5047901 (D. Mont. Nov. 3, 2017) (non-GHG effects of coal transport and combustion must also be considered); WildEarth Guardians v. U.S. Bureau of Land Mgmt., 870 F.3d 1222, 1234–39 (10th Cir. 2017) (in a coal lease EIS, agency cannot dismiss the significance of downstream emissions from coal combustion by claiming perfect substitution).

1) Type of Fuel

Downstream emissions qualify as indirect effects of oil and gas production for the same reasons that they qualify as indirect effects of coal production.[169] Some agencies have argued against disclosure on the grounds that emissions from oil and gas combustion are more speculative than those from coal combustion because oil and gas are used for purposes other than energy production.[170] As noted above, the inability to quantify indirect effects does not mean that agencies can ignore these in their analysis. Moreover, the fact that agencies are already quantifying downstream emissions (primarily combustion emissions) in EISs for proposals to authorize oil and gas production demonstrates that such quantification is feasible where the agency has also estimated the amount of oil and gas to be produced. Recognizing this, courts have explicitly ordered agencies to quantify combustion emissions in four of the five decisions requiring disclosure of downstream emissions from oil and gas production.[171] In the fourth decision, the court explained that it was not ordering quantification because, unlike coal which has a "single downstream use," oil is sometimes used for plastics or other products that will not be burned.[172] But the court did note that BLM must "consider whether quantifying GHG emissions from that use is reasonably possible" and "thoroughly explain" any decision not to quantify emissions, and that "if BLM receives estimates

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[169] *Citizens for a Healthy Cmty.*, 377 F. Supp. 3d at 1237; *WildEarth Guardians*, 368 F. Supp. 3d at 74; *W. Org. of Res. Councils*, 2018 WL 1475470, at *31–32; *Wilderness Workshop*, 342 F. Supp. 3d at 1156; *San Juan Citizens All.*, 326 F. Supp. 3d at 1242, 1244.
[170] Supplemental Brief at 5–6, WildEarth Guardians v. Zinke, 368 F. Supp. 3d 41 (D.D.C. 2019) (No. 1:16-cv-01822).
[171] *Citizens for a Healthy Cmty.*, 377 F. Supp. 3d at 1237; *W. Org. of Res. Councils*, 2018 WL 1475470, at *40; *Wilderness Workshop*, 342 F. Supp. 3d at 1156; *San Juan Citizens All.*, 326 F. Supp. 3d at 1228. There are also many undecided cases involving failures to quantify indirect GHG emissions in the context of oil and gas production EAs—the key issue being that agencies are dismissing the significance of GHG emissions without a complete assessment of the GHG impact. *See* Complaint at 29–30, WildEarth Guardians v. U.S. Bureau of Land Mgmt., No. 4:18-cv-00073 (D. Mont. May 15, 2018) (failure to quantify downstream emissions in oil and gas leasing EAs); Complaint at 21, 39–40, Wilderness Workshop v. U.S. Bureau of Land Mgmt., No. 1:18-cv-00987 (D. Colo. Apr. 26, 2018) (failure to take hard look at indirect emissions from 53 oil and gas lease parcels—"BLM's Determinations of NEPA Adequacy for the lease auctions fail to consider or quantify any site-specific direct, indirect, and cumulative greenhouse gas emissions from leasing and their resulting climate change effects."); Complaint at 25, Ctr. for Biological Diversity v. U.S. Forest Serv., No. 2:17-cv-00372 (S.D. Ohio May 2017) (agency failed to take hard look at GHG emissions and climate impacts of oil and gas leasing in national forest).
[172] *WildEarth Guardians*, 368 F. Supp. 3d at 74.

from outside parties based on the use of [emission estimating] calculators, it must assess those estimates and explain why they are unreliable or otherwise inappropriate to use in its decisionmaking."[173]

2) Type of Proposal

Downstream emissions must be disclosed and analyzed in the context of both project-level leasing decisions and broader management plans and actions that authorize future fossil fuel development.[174] However, the required depth of the analysis and whether emissions must be quantified depends on whether the agency has projected or is capable of projecting the quantity of fuels to be produced. As noted in *High Country Conservation Advocates*, in which the court required quantitative disclosure of GHG emissions in the context of a rule amendment which would allow for coal leasing in previously designated "roadless" areas:

> The agency cannot—in the same FEIS—provide detailed estimates of the amount of coal to be mined . . . and simultaneously claim that it would be too speculative to estimate emissions from "coal that may or may not be produced" from "mines that may or may not be developed." The two positions are nearly impossible to reconcile.[175]

Courts have also required quantification of downstream (combustion) emissions in cases involving resource management plans where the agency had estimated the amount of coal, oil, and/or gas to be produced pursuant to those plans.[176]

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[173] *Id.* at 75.
[174] For examples of decisions requiring disclosure and analysis of downstream emissions in the context of broader planning actions, see *Citizens for a Healthy Cmty.*, 377 F. Supp. 3d at 1237; *W. Org. of Res. Councils*, 2018 WL 1475470, at *40 (BLM must quantify emissions from coal, oil, and gas combustion in RMP EISs); *Wilderness Workshop*, 342 F. Supp. 3d at 1156 (BLM must disclose emissions from oil and gas combustion in RMP EIS and also evaluate potential impacts of those emissions in light of revised total GHG projections).
[175] High Country Conservation Advocates v. U.S. Forest Serv., 52 F. Supp. 3d 1174, 1196–97 (D. Colo. 2014).
[176] *W. Org. of Res. Councils*, 2018 WL 1475470, at *13 (In light of the degree of foreseeability and specificity of information available to the agency while completing the EIS, NEPA requires BLM to consider in the EIS the environmental consequences of the downstream combustion of the coal, oil and gas resources potentially open to development under these RMPs. Without such analysis, the EIS fails to "foster informed decision-making" as required by NEPA"); *Wilderness Workshop*, 342 F. Supp. 3d at 1156 ("An agency may not avoid an obligation to analyze in an EIS environmental consequences that

3) Type of NEPA Documentation

Some agencies have justified decisions not to disclose or quantify downstream GHG emissions in fossil fuel leasing EAs on the grounds that the proposals will not generate significant GHG impacts and thus an in-depth analysis of GHG emissions is not warranted.[177] The problem with this argument is that it is impossible for an agency to gauge the significance of the GHG impact without analyzing the full scope of emissions that qualify as direct, indirect, and cumulative effects of the project. Courts have thus properly held that downstream emissions must also be disclosed and quantified in the context of fossil fuel leasing EAs.[178] One case dealt with a particularly egregious situation in which BLM had failed to quantify *any* GHG emissions (direct, indirect, or cumulative) in EAs and FONSIs issued for 282 oil and gas leases encompassing approximately 303,000 acres of land in Wyoming.[179] There, the D.C. district court held that BLM must quantify direct emissions from oil and gas production and also account for downstream emissions.[180] As we discuss in Part III, the failure to account for the full scope of GHG emissions that qualify as impacts of production proposals renders an agency's FONSI arbitrary and capricious.

A related question is whether an agency can ignore downstream emissions in a leasing EA or NEPA adequacy determination that is tiered to a broader PEIS. The answer depends on the level of detail with which GHGs were disclosed in the PEIS. If an agency fully quantified downstream emissions for a leasing area in a PEIS, it could potentially rely on that analysis in its tiered EA or adequacy determination. But if the programmatic analysis is too broad or too course (e.g., a purely qualitative analysis of potential GHG impacts) or out of date, then it would be

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foreseeably arise from an RMP merely by saying that the consequences are unclear or will be analyzed later when an [Environmental Assessment] is prepared for a site-specific program proposed pursuant to the RMP.") (quoting Kern v. U.S. Bureau of Land Mgmt., 284 F.3d 1062, 1072 (9th Cir. 2002) (internal quotation marks omitted)).

[177] We discuss the adequacy and reasonableness of such significance determinations in Part III. Here, we focus on whether the failure to disclose emissions can be justified by a finding of no significant impact.

[178] *WildEarth Guardians*, 368 F. Supp. 3d at 75; WildEarth Guardians v. Zinke, No. 1:17-cv-00080, 2019 WL 2404860, at *11 (D. Mont. Feb. 11, 2019); San Juan Citizens All. v. U.S. Bureau of Land Mgmt., 326 F. Supp. 3d 1227, 1228 (D.N.M. 2018); Mont. Envtl. Info. Ctr. v. U.S. Off. of Surface Mining, 274 F. Supp. 3d 1074, 1098–99 (D. Mont. 2017), *amended in part, adhered to in part sub nom.* No. CV 15-106-M-DWM, 2017 WL 5047901 (D. Mont. Nov. 3, 2017).

[179] *WildEarth Guardians*, 368 F. Supp. 3d at 55.

[180] *Id.* at 85.

necessary for the agency to conduct a more detailed examination of downstream GHG emissions when issuing lease sales.[181]

4) Type of Downstream Emissions

As noted above, transportation and processing emissions (including leakage that occurs during transport) also qualify as indirect effects of federal approvals for fossil fuel production. Unlike with combustion emissions, it is not always possible to quantify processing and transportation emissions even where the agency has projected the amount of fossil fuel production. Estimating transportation emissions, in particular, may be impossible if the agency does not know the route or mode by which the fuels will be transported to end-users. For this reason, agencies sometimes ignore transportation and processing emissions in NEPA documentation even where they acknowledge and disclose combustion emissions as indirect effects of proposals.[182] But NEPA requires more: agencies should discuss these emissions qualitatively at minimum[183] and should conduct a quantitative analysis where tools and data are available to do so. For example, where agencies know the rail routes and shipping destinations for coal that would be mined as a result of federal authorizations, the reviewing agencies must calculate the GHG emissions from rail transport.[184]

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[181] *See id.* There have been at least two instances in which courts have upheld the NEPA documentation (or lack thereof) for oil and gas lease sales that were tiered to programmatic reviews despite plaintiffs' contentions that the sales were issued without adequate analysis of downstream GHG emissions. But neither decision involved a careful analysis of whether such emissions qualified as indirect effects. In one case, the reviewing court did not even address plaintiffs' arguments about climate change. *See* N. Alaska Envtl. Cent. v. U.S. Dep't of the Interior, No. 3:18-cv-00030, 2018 WL 6424680 (D. Alaska Dec. 6, 2018). In the second case, the court held that BLM's very limited analysis of GHG emissions, which did not include downstream emissions, was sufficient because BLM had estimated that the emissions would represent only a small increase in state emissions and were therefore significant. Diné Citizens Against Ruining Our Env't v. Jewell, 312 F. Supp. 3d 1031, 1096 (D.N.M. 2018), *rev'd sub nom* Diné Citizens Against Ruining Our Env't v. Bernhardt, 923 F.3d 831 (10th Cir. 2019) (on appeal, the 10th Circuit did not reach the arguments related to GHG emissions because it concluded that Appellants had not provided a record from which it could assess the adequacy of BLM's air pollution analysis).

[182] *N. Alaska Envtl. Cent.*, 2018 WL 6424680; *Diné*, 312 F. Supp. 3d at 1031.

[183] 40 C.F.R. § 1502.22; *see also* Mid States Coal. for Progress v. Surface Transp. Bd., 345 F.3d 520, 549–50 (8th Cir. 2003).

[184] There are two decisions requiring further analysis of impacts from coal transport in the context of federal approvals for coal mining, but in both cases the agencies had already disclosed GHG emissions from transport and thus the decisions focused on the need to disclose other impacts (e.g., conventional air pollutants). These cases thus expand

One scope-related question which has not been directly addressed is whether non-$CO_2$ GHGs such as methane must also be disclosed in the downstream emissions analysis.[185] The answer is an obvious "yes"—there is no rationale for treating these differently than $CO_2$, although there may be instances in which it is not possible to quantify these emissions in the same fashion as $CO_2$.[186] Agencies may also argue against disclosure on the grounds that these emissions are relatively insignificant as compared with $CO_2$, but arguments about insignificance would need to be supported by the sort of quantitative analysis which considers not only the tonnage of non-$CO_2$ GHG emissions but also the global warming potential of those emissions.[187]

In sum: the cases generally support the proposition that downstream emissions fall within the scope of indirect impacts that should be disclosed in NEPA reviews for federal proposals that will result in the extraction of fossil fuels. The decisions also provide insight on the circumstances in which NEPA requires quantitative disclosure of such impacts. We return to questions about the adequacy and reasonableness of the technical assumptions and findings encompassed within the GHG disclosure in Part III.

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the obligation to evaluate transportation-related impacts to include non-GHG emissions. *See* WildEarth Guardians v. Zinke, No. 1:17-cv-00080, 2019 WL 2404860, at *7 (D. Mont. Feb. 11, 2019) (OSM must evaluate indirect and cumulative impacts caused by coal trains beyond the area near the mine, as there was sufficient data to support this analysis); Mont. Envtl. Info. Ctr. v. U.S. Off. of Surface Mining, 274 F. Supp. 3d 1074, 1098–99 (D. Mont. 2017), *amended in part, adhered to in part sub nom.* No. CV 15-106-M-DWM, 2017 WL 5047901 (D. Mont. Nov. 3, 2017) (non-GHG effects of coal transport and combustion must also be considered). There have not yet been any decisions on the failure to disclose or quantify processing emissions, but one can infer from the case law that these should also be disclosed and quantified where possible. There is also a pending lawsuit in which the alleged failure to account for downstream emissions appears to encompass processing as well as transportation emissions. Complaint at 5, S. Utah Wilderness All. v. Bernhardt, 2:19-cv-00266 (D. Utah 2019) (alleging that BLM's analysis of twenty oil and gas leases in Utah was flawed because it failed to address GHG emissions from activities that occur after production, but before combustion, such as fugitive emissions that leak from pipelines).

[185] There is one lawsuit involving BLM's issuance of twenty oil and gas leases in Utah in which plaintiffs have alleged that the NEPA analyses is flawed due to BLM's failure to disclose non-$CO_2$ GHGs, particularly methane. Complaint at 17, S. Utah Wilderness All. v. Bernhardt, No. 2:19-cv-00266 (D. Utah Apr. 19, 2019).

[186] Tools are available to calculate $N_2O$ and methane emissions from combustion, at a minimum. *See* EPA, GREENHOUSE GAS INVENTORY GUIDANCE: DIRECT EMISSIONS FROM STATIONARY COMBUSTION SOURCES, APPENDIX A (2016), https://www.epa.gov/sites/production/files/2016-03/documents/stationaryemissions_3_2016.pdf [https://perma.cc/YDH5-N7L8].

[187] *See* WildEarth Guardians v. Zinke, 368 F. Supp. 3d 41, 71–74 (D.D.C. 2019).

## B. *Fossil Fuel Transportation*

Both upstream and downstream emissions typically qualify as indirect effects of fossil fuel transportation projects.[188] These emissions are reasonably foreseeable because agencies know that the fossil fuels to be transported via the approved infrastructure will be extracted, and all or most of the fuels will be processed and combusted.[189] These emissions are also causally linked to the approval of the transportation infrastructure because: (i) agencies approve these projects based on findings that additional transportation capacity is needed to transport the fuels to end-users,[190] and one can therefore infer that (ii) without the necessary capacity addition, the same quantity of fuels would not be produced and transported to end-users.

Some agencies (primarily FERC) have argued that the approval of transportation infrastructure does not cause upstream production or downstream consumption because there are other ways in which fuels could be transported to end-users if a project is not approved.[191] The problem with this argument is that it assumes that transportation capacity exists elsewhere to transport the fuels to the market, which undermines the required determination that the project is necessary due to capacity constraints. It also ignores basic market principles of supply and demand. Relatedly, agencies have argued that upstream and downstream emissions are not reasonably foreseeable because of uncertainties about market impacts and energy substitution.[192] But this argument fails as well. As noted by FERC Commissioner Richard Glick in a dissent to a FERC order issuing a certificate for a natural gas pipeline project:

> It is reasonable to assume that building incremental transportation capacity will spur additional production and result in some level of combustion of natural gas, even if the exact details of the method or location are not definite. . . . [W]hen the nature of the effect (end-use emissions) is

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[188] WEBB, *supra* note 134, at 21.

[189] As discussed above, there are multiple end-uses for oil and gas but the vast majority of produced oil and gas is combusted for energy generation (whether in power plants, industrial sources, or vehicles) and agencies have nonetheless been able to estimate combustion emissions for these fuels.

[190] WEBB, *supra* note 134, at 17; Burger & Wentz, *supra* note 11, at 166.

[191] Burger & Wentz, *supra* note 11, at 109, 137.

[192] *Id.* at 132.

> reasonably foreseeable, but its extent is not . . . an agency may not simply ignore the effect.[193]

The case law generally supports the treatment of both upstream and downstream emissions as indirect effects of transportation infrastructure, but courts have not fleshed out or enforced the requirement to analyze these emissions with the same clarity or assertiveness as they have in cases involving fossil fuel production.[194] This may be due to the fact that there are fewer decisions on transportation approvals.[195] It may also be the case that courts are not enforcing NEPA requirements as assertively in this context because they do not think that the approval of transportation infrastructure is as significant a driver of fossil fuel consumption as federal fossil fuel leasing programs.

The early case law on the requirement to evaluate upstream and downstream emissions from authorizations of fossil fuel transportation infrastructure is illustrative. The first two decisions on this question both involved STB's approval of rail lines built to transport coal. In *Mid States Coalition for Progress v. Surface Transportation Board,* the Eighth Circuit Court of Appeals required the STB to evaluate downstream emissions from the combustion of the transported coal, and in *Northern Plains Resource Council, Inc. v. Surface Transportation Board,* the Ninth Circuit Court of Appeals required STB to consider upstream emissions from the mining of the coal.[196] In those cases, the courts confronted and dismissed several of the same arguments related to causation and foreseeability that were raised in the coal extraction cases.[197] In particular, the Eighth Circuit's decision in *Mid States Coalition* found that the development of infrastructure intended to transport coal would affect the price of coal relative to other energy sources and this would affect patterns of coal

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[193] Texas E. Transmission, LP, 164 FERC ¶ 61,037 (2018) (internal quotations omitted).
[194] Burger & Wentz, *supra* note 11, at 142–43.
[195] *Id.* at 143.
[196] Notably, in the case involving the failure to evaluate upstream emissions, petitioners argued that methane emissions and other environmental impacts from the connected coal mines should be analyzed as cumulative effects (these are typically treated as indirect effects). The court's analysis therefore focused on whether these effects were reasonably foreseeable, since a cumulative impact need not be "caused" by the project. N. Plains Res. Council, Inc. v. Surface Transp. Bd., 668 F.3d 1067, 1082 (9th Cir. 2011). But as discussed below, the rationale for concluding that a transport project "causes" downstream emissions applies in equal force to upstream emissions.
[197] *N. Plains Res. Council*, 668 F.3d at 1082; Mid States Coal. for Progress v. Surface Transp. Bd., 345 F.3d 520, 549 (8th Cir. 2003).

production and consumption, and thus downstream emissions were an indirect effect of the railway.[198]

However, courts reached different conclusions in early cases involving natural gas and oil pipelines. There were two early decisions finding that an analysis of upstream emissions (from production) was not required in the NEPA review for oil and gas pipelines because those pipelines would not cause upstream production.[199] A third decision which pertained to the scope of review for non-GHG air pollutants upheld FERC's review of a pipeline precisely because "FERC explicitly considered the environmental impact of downstream emissions and imposed what it reasonably believed to be effective measures to mitigate the impact."[200] At that time, neither courts nor agencies had offered a principled basis for why the scope of indirect emissions analysis should differ for coal rail lines and pipelines, nor had they offered a compelling argument for finding that pipelines do not affect natural gas production and consumption in the same fashion that coal railways affect coal production and consumption.[201] We argued then that the reasoning which controlled the outcome of the coal production and coal railway cases should apply in equal force to other forms of transportation infrastructure.[202]

There were also some early decisions on LNG export decisions which held that FERC need not address the indirect effects of natural gas exports in its NEPA review because it was DOE and not FERC that was ultimately responsible for approving those exports.[203] But in those cases, the D.C. Circuit made clear that it was not expressing any opinion on DOE's independent NEPA obligations to address such indirect effects in its review of LNG export authorizations.[204] Those decisions are the result

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[198] *Mid States Coal. for Progress*, 345 F.3d at 549.

[199] In one of those decisions, the court found that the Department of State's administrative record for an oil and gas pipeline contained at least some information to support this finding (e.g., about oil production rates and other transportation options). Sierra Club v. Clinton, 746 F. Supp. 2d 1025, 1045 (D. Minn. 2010). In the other (unpublished) decision, the court simply deferred to FERC's unsupported claim of perfect substitution for a natural gas pipeline without conducting any analysis whatsoever. Coal. for Responsible Growth & Res. Conservation v. FERC, 485 F. App'x 472, 474 (2d Cir. 2012).

[200] S. Coast Air Quality Mgmt. Dist. v. FERC, 621 F.3d 1085, 1093–94 (9th Cir. 2010).

[201] *See generally Coal. for Responsible Growth & Res. Conservation*, 485 F. App'x at 472, 474; *S. Coast Air Quality Mgmt. Dist.*, 621 F.3d at 1093–94; *Sierra Club*, 746 F. Supp. 2d at 1044.

[202] Burger & Wentz, *supra* note 11, at 109, 157.

[203] Sierra Club v. FERC, 827 F.3d 59, 68 (D.C. Cir. 2016); Sierra Club & Galveston Baykeeper v. FERC, 827 F.3d 36, 47 (D.C. Cir. 2016); EarthReports Inc. v. FERC, 828 F.3d 949, 952 (D.C. Cir. 2016).

[204] *Sierra Club & Galveston Baykeeper*, 827 F.3d at 45.

of the unique division of authority between DOE and FERC and are thus of little relevance to interpreting agency obligations in other contexts.

More recent decisions on natural gas pipelines and LNG export terminals have made it clear that downstream emissions typically fall within the scope of indirect impacts that should be evaluated in NEPA reviews for these projects.[205] One of the most important decisions on this issue was a D.C. Circuit case involving FERC's review of an interstate natural gas pipeline: *Sierra Club v. FERC*.[206] There, the D.C. Circuit Court of Appeals found that downstream emissions from natural gas combustion were an indirect effect of the proposed pipeline project, as they were both foreseeable and causally linked to the approval of the pipeline project.[207] In regards to foreseeability, the court noted that the project was intended to transport the gas to power plants in Florida, some of which already existed, others of which were in the planning stages.[208] Thus, the court noted that the combustion of the gas "is not just 'reasonably foreseeable,' it is the project's entire purpose."[209] With regards to causation, the court held that because FERC can act on information about GHG emissions and climate change impacts when deciding whether to issue a pipeline certificate, and because FERC can deny the certificate if it finds that the project would be too harmful to the environment, FERC's approval is a "legally relevant cause" of the downstream effects of combusting the gas.[210]

The court also held that quantification of the downstream GHG emissions was required.[211] FERC had argued that it is impossible to know exactly what quantity of GHGs will be emitted due to the approval of the pipeline because it depends on uncertain variables such as the operating decisions of individual plants and demand for electricity in the region.[212] The court disagreed, noting that NEPA requires "reasonable forecasting" and that FERC had already estimated how much gas the pipelines would transport and had provided no good reason as to why this number could not also be used to estimate combustion emissions.[213] The court explained that quantification was necessary because it would

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[205] Sierra Club v. U.S. Dep't of Energy, 867 F.3d 189, 192 (D.C. Cir. 2017) (Freeport LNG terminal); *Sierra Club*, 827 F.3d at 68; Indigenous Envtl. Network v. U.S. Dep't of State, No. 4:17-cv-00029, 2017 U.S. Dist. LEXIS 164786, at *68 (D. Mont. Nov. 8, 2018).
[206] Sierra Club v. FERC, 867 F.3d 1357, 1357 (D.C. Cir. 2017).
[207] *Id.* at 1374.
[208] *Id.* at 1371
[209] *Id.* at 1372.
[210] *Id.*
[211] *Id.* at 1374.
[212] *Sierra Club v. FERC*, 867 F.3d at 1373–74.
[213] *Id.* at 1374.

"permit the agency to compare the emissions from the project to emissions from other projects, to total emissions from the state or region, or to regional or national emissions-control goals" and "[w]ithout such comparisons, it is difficult to see how FERC could engage in 'informed decision making' with respect to the greenhouse-gas effects of this project, or how 'informed public comment' could be possible."[214]

The D.C. Circuit Court of Appeals decided another case, *Birckhead v. FERC*, in which it sought to clarify its position on FERC's obligation to address downstream emissions in its review of natural gas transportation infrastructure.[215] Plaintiffs alleged that FERC violated NEPA by failing to disclose emissions from the consumption of natural gas when the record contained information about the amount of gas to be transported (200,000 decatherms) and its destination (southeast markets).[216] FERC maintained that the emissions were neither caused by its approval nor reasonably foreseeable and that *Sierra Club v. FERC* was not apposite because FERC did not know the exact power plants at which the natural gas would be used.[217] The court quickly disposed of FERC's causation and foreseeability arguments, just as it had in *Sierra Club v. FERC*, and noted that it was "troubled . . . by the Commission's attempt to justify its decision to discount downstream impacts based on its lack of information about the destination and end use of the gas in question" because FERC had an affirmative obligation to at least attempt to obtain information necessary to fulfill its statutory duties and had made "no effort" to do so in this case.[218] But the court ultimately dismissed the complaint on the grounds that petitioners "failed to raise this record-development issue in the proceedings before the Commission."[219] In doing so, it implicitly accepted FERC's argument that additional information was needed to assess downstream emissions and the court mischaracterized the petitioners' complaint (which alleged a failure to estimate emissions based on information that was already on the record).[220]

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[214] *Id.* The court also rejected FERC's arguments about perfect substitution, which we return to in Part III.
[215] Birckhead v. FERC, 925 F.3d 510 (D.C. Cir. 2019).
[216] Final Opening Brief of Petitioners at 39–40, Birckhead v. FERC, 925 F.3d 510 (D.C. Cir. 2019) (No. 18-1218). Commissioner LaFleur actually performed this very calculation to demonstrate that it was feasible. *Id.* at 12.
[217] *Birckhead*, 925 F.3d at 518.
[218] *Id.* at 519–20.
[219] *Id.* at 520.
[220] One possible explanation for the court's approach is that it wanted to allow this particular project to go forward without formally curtailing NEPA requirements. The project at issue was a compressor station that would enhance the capacity of an existing

The decision in *Birckhead v. FERC* thus raises a number of questions for future litigants seeking to compel FERC disclosures of downstream emissions regarding the manner in which plaintiffs must frame their claims, the extent to which FERC can rely on claims about "uncertainty" or "inadequate information" to avoid disclosing downstream emissions, and the circumstances in which emissions from downstream natural gas combustion are not a reasonably foreseeable outcome of natural gas transportation infrastructure. But it does not disrupt or significantly modify the holding in *Sierra Club v. FERC,* which remains the primary authority on FERC's obligation to evaluate downstream emissions from natural gas pipelines.[221]

The same rationale for requiring analysis of downstream emissions applies to upstream emissions: if a transportation project causes an increase in fossil fuel consumption, then there must be a corresponding increase in fossil fuel production on the other end of the supply chain.[222] Thus, induced natural gas production is as much an "indirect effect" of the transportation infrastructure as induced consumption. As noted above, disclosure of upstream emissions has been explicitly required in the context of a federal approval of a coal railway. Although no decision has yet been issued finding inadequate analysis of upstream (i.e., production) emissions in the context of pipeline projects, there are at least two decisions finding adequate analysis *because* the agency incorporated quantitative analysis of upstream emissions in its review.[223]

First, in *Sierra Club v. U.S. Department of Energy,* the D.C. Circuit Court of Appeals held that DOE had adequately assessed the indirect emissions from LNG exports by incorporating general assessments of life-cycle GHG emissions from LNG exports (which included both upstream and

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pipeline, whereas the project at issue in *Sierra Club v. FERC* was a new multistate pipeline project. Although the court did not hold on what NEPA actually requires for a compressor station, it did state that emissions from downstream natural gas combustion are not "as a categorical matter" always a reasonably foreseeable outcome of natural gas transportation projects. *Id.* at 519. This conclusion is debatable: if the project is intended to meet a need for increased transportation capacity, then it will presumably enable increases in both natural gas production and consumption, and downstream emissions are thus a reasonably foreseeable impact even if there is uncertainty about the extent of the impact.

[221] *Id.*

[222] Burger & Wentz, *supra* note 11, at 113–14.

[223] Sierra Club v. U.S. Dep't of Energy, 867 F.3d 189 (D.C. Cir. 2017) (Freeport LNG terminal); Indigenous Envtl. Network v. U.S. Dep't of State, 347 F. Supp. 3d 561 (D. Mont. 2018).

downstream emissions).[224] Second, on *Indigenous Environmental Network v. U.S. Department of State,* the Montana district court held that the Department of State had adequately considered upstream emissions from tar sands oil production in its review of the Keystone XL pipeline by integrating the Canadian review (which encompassed such production) into its review.[225] Notably, there was no question about whether the Department of State must consider downstream emissions—it had already conducted an in-depth analysis of those as part of its review.[226] These decisions support the idea that *both* upstream and downstream emissions fall within the scope of "indirect effects" that should be considered under NEPA for projects involving fossil fuel transportation, and courts are likely to intervene where such emissions are omitted from the analysis altogether.[227]

However, the D.C. Circuit Court of Appeals upheld FERC's decision not to disclose upstream emissions for a natural gas compressor project in *Birckhead v. FERC.*[228] In that case, FERC justified its decision not to disclose upstream emissions on the grounds that pipeline approvals only cause upstream emissions where "the record demonstrates that the proposed project represents the *only* way to get additional gas from a specified production area into the interstate pipeline system."[229] Petitioners responded that FERC had determined there was a "need" for the project "based on the fact that [the production and shipping company] has executed a binding precedent agreement for . . . 100 percent of the design capacity" and that this was enough to show that the project would cause additional natural gas production.[230] The court held in favor of FERC, asserting that petitioners had identified no record evidence to: (i) "help [FERC] predict the number and location of any additional wells that would be drilled as a result of production demand created by the project" or (ii) prove that the natural gas would not be extracted in the absence of the project.[231] Regarding FERC's public need determination,

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[224] *Sierra Club v. U.S. Dep't of Energy*, 867 F.3d at 202. There are several unpublished opinions that rely on the analysis in this case: Sierra Club v. U.S. Dep't of Energy, 703 F. App'x 1 (D.C. Cir. 2017).
[225] *Indigenous Envtl. Network*, 347 F. Supp. 3d at 580.
[226] *Id.* at 576.
[227] *See, e.g.*, *id.* at 575–76; *Sierra Club v. U.S. Dep't of Energy*, 867 F.3d at 201–02.
[228] Birckhead v. FERC, 925 F.3d 510, 517 (D.C. Cir. 2019).
[229] *Id.*
[230] *Id.*
[231] *Id.* at 517–18. The court noted that it was "dubious of [FERC's] assertion that asking [the natural gas producer and shipper] about the origin of the gas would be futile" but

the court held that "just because [FERC] is satisfied that there is a market need for a given project does not necessarily mean that a shipper/producer would not have the ability to bring the gas to market via another channel were [FERC] to deny a certificate for the project."[232] The court thus held that petitioners had not presented enough evidence to rebut FERC's presumption that the project would not induce natural gas production.[233]

The court thus set an extraordinarily high bar for petitioners seeking to compel disclosure of upstream emissions, without actually deciding whether downstream emissions qualified as indirect effects of the project. The court's differential treatment of upstream emissions as compared with downstream emissions is baffling. As noted above, if a transportation project causes an increase in natural gas consumption then it also causes an increase in natural gas production—these are two sides of the same coin—the additional gas cannot be consumed if it is not produced. And upstream emissions can be estimated in the same fashion as downstream emissions (by multiplying the transported natural gas by an emissions factor).[234] There are also more sophisticated energy market modelling techniques which FERC could use to estimate the net increase in upstream production and emissions (we return to these in Part III).[235]

In our view, the D.C. Circuit has failed to justify its differential treatment of upstream and downstream emissions, and also erred in concluding that a binding precedent agreement for 100 percent of transportation capacity is insufficient to establish a causal link between the project and natural gas production.[236] NEPA requires "reasonable forecasting"

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that this was not dispositive in its ruling because petitioners had not claimed that FERC's failure to seek out additional information violated NEPA.

[232] *Id.* at 518.

[233] *Id.*

[234] *See, e.g.*, *GHG Emissions Associated with Two Proposed Natural Gas Transmission Lines in Virginia*, OUR ENERGY POL'Y 1, https://www.ourenergypolicy.org/wp-content/uploads/2016/02/GHG-Emissions-Associated-with-Proposed-Natural-Gas-Transmission-Lines-in-Virginia_Final-edit5-1.pdf [https://perma.cc/56T5-HFV4].

[235] Rick Glick & Matthew Christiansen, *FERC and Climate Change*, 40 ENERGY L.J. 1, 14 (2019), https://www.eenews.net/assets/2019/05/06/document_gw_02.pdf [https://perma.cc/BQ7F-2ZHA]. Commissioner Glick argued that FERC

> must also consider the secondary effects [of pipelines]. For example, an increase in interstate pipeline capacity may also, by decreasing the price of delivered gas, increase the demand for that gas and, in turn increase its production—which can lead to a significant increase in upstream emissions, through flaring of natural gas, fugitive methane emissions, etc.

[236] *Birckhead*, 925 F.3d at 517–18.

of probable impacts,[237] and it is highly probable that a fully subscribed transportation project will enable additional natural gas production. In sum: there are a number of cases which support the idea that upstream and downstream emissions fall within the scope of indirect impacts from fossil fuel transportation infrastructure.[238] However, there are some judicial interpretations which may pose challenges for plaintiffs seeking to enforce this requirement, especially as it applies to upstream emissions. In particular, the D.C. Circuit's interpretation of FERC obligations in *Birckhead v. FERC* places a significant burden on potential plaintiffs to rebut FERC assumptions that transportation projects do not cause an increase in upstream production[239] and also raises questions about how plaintiffs can adequately frame arguments about the requirement to disclose downstream emissions.

1. Upstream and Downstream Emissions as Effects of Connected Actions

Upstream and downstream emissions may also be conceptualized as the effects of "connected actions" when such emissions occur as a result of other federal approvals in the fossil fuel supply chain that must also undergo NEPA review.[240] As discussed in Part I, federal actions are "connected" if they: "(i) automatically trigger other actions which may require EISs, (ii) cannot or will not proceed unless other actions are taken previously or simultaneously, or (iii) are independent parts of a larger action and depend on the larger action for their justification."[241] The requirement to evaluate connected actions in a single NEPA review is often referred to as a rule prohibiting the "segmentation" of actions and their environmental impacts, reflecting the language in section 1508.27 of the CEQ regulations.[242]

The D.C. Circuit Court of Appeals has noted that "[t]he justification for the rule against segmentation is obvious: it prevent[s] agencies from dividing one project into multiple individual actions each of which individually has an insignificant environmental impact, but which

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[237] Scientists' Inst. for Pub. Info. v. Atomic Energy Comm'n, 481 F.2d 1079, 1082 (D.C. Cir. 1973).
[238] *See, e.g.*, Mid States Coal. for Progress v. Surface Transp. Bd., 345 F.3d 520, 549 (8th Cir. 2003).
[239] *Birckhead,* 925 F.3d at 518–19.
[240] Burger & Wentz, *supra* note 11, at 113–14.
[241] 40 C.F.R. § 1508.25(a)(1).
[242] 40 C.F.R. § 1508.27; Burger & Wentz, *supra* note 11, at 169.

collectively have a substantial impact."[243] Similarly, the Ninth Circuit has stated that the purpose of NEPA "cannot be fully served if consideration of the cumulative effects of successive, interdependent steps is delayed until the first step has already been taken."[244] Applying the regulatory standards, courts have held that agencies have a mandatory obligation to conduct a joint review of actions that either have no independent purpose or utility,[245] or "the dependency is such that it would be irrational, or at least unwise" to undertake one action if the other(s) were not also undertaken.[246]

Most of the cases involving claims that an agency failed to review connected actions pertaining to fossil fuels involve claims that an agency has improperly segmented its review of a pipeline (and different pieces of the pipeline), thus failing to evaluate all emissions (and other impacts) from the pipeline in a single, comprehensive review.[247] In one noteworthy case, *Delaware Riverkeeper Network v. FERC*, the D.C. Circuit held that four segments of a pipeline project were connected actions because they were physically connected, they were being constructed in relatively the same time period, and they lacked independent utility.[248] The pipeline

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[243] Del. Riverkeeper Network v. FERC, 753 F.3d 1304, 1314 (D.C. Cir. 2014) (citing NRDC v. Hodel, 865 F.2d 288, 297 (D.C. Cir. 1988) (internal quotation marks omitted)).
[244] Thomas v. Peterson, 753 F.2d 754, 760 (9th Cir. 1985).
[245] Custer Cty. Action Ass'n v. Garvey, 256 F.3d 1024, 1037 (10th Cir. 2001).
[246] Trout Unlimited v. Morton, 509 F.2d 1276, 1285 (9th Cir. 1974).
[247] *See, e.g.*, Twp. of Bordentown v. FERC, 903 F.3d 234, 250 (3d Cir. 2018) (two pipelines were not connected actions because they had independent utility); Sierra Club v. U.S. Army Corps of Eng'rs, 803 F.3d 31, 51 (D.C. Cir. 2015) (USACE not required to review multiple pipeline segments as connected actions because the other segments did not require federal approvals); Sierra Club v. Clinton, 689 F. Supp. 2d 1123, 1133 (D. Minn. 2010) (three pipelines were not connected actions because they had independent utility and different approval timelines); Hammond v. Norton, 370 F. Supp. 2d 226, 253 (D.D.C. 2005) (BLM must either review two pipe segments as connected actions or make a more thorough and factually supportable finding of independent utility).
[248] *Del. Riverkeeper Network*, 753 F.3d at 1308–09. That decision can be contrasted to *Standing Rock Sioux Tribe v. U.S. Army Corps of Engineers*, where the D.C. Circuit district court held that different federal approvals that were pending for the Dakota Access Pipeline had "substantial independent utility" as "each would allow a portion of pipeline to proceed as planned, while any denial would result in re-routing—with no apparent impact on the other federally regulated components of the project" and thus they did not constitute connected actions which must be reviewed in the same EIS. Standing Rock Sioux Tribe v. U.S. Army Corps of Eng'rs, 301 F. Supp. 3d 50, 68–69 (D.D.C. 2018). The court asserted that the "limited federal involvement with [the Dakota Access Pipeline] and the potential for re-routing" distinguished the case from the facts of *Delaware Riverkeeper*—and in particular, because this was an oil pipeline and not a natural gas pipeline, it was "not so beholden to overall federal approval." *Id.* But the

cases help to clarify some of the specific factors that are relevant to the segmentation analysis, such as whether the allegedly connected actions are subject to federal approval, whether they are occurring at roughly the same time, and whether they are physically connected (this last factor being informative but not dispositive in the analysis).[249]

The same factors are relevant when determining whether different types of infrastructure or activities within the fossil fuel supply chain (e.g., production and transport) are connected actions that must be reviewed in the same EIS. But the analysis of whether the supply chain components lack "independent utility" is trickier because these components are, in many cases, more interchangeable than pipeline segments.[250] Consider, for example, a situation in which the federal government is simultaneously reviewing and issuing approvals for a coal mining lease and a rail project that would transport coal from the mine to end-users. Whether these qualify as connected actions would depend on factors such as whether the coal mining "cannot or will not proceed" without the coal rail project, and whether the coal rail project will service other mines (or transport other goods).[251] There are only a handful of decisions that directly address the connected actions requirement in this context,[252] and two of them were dismissed because the allegedly connected action was not a "federal action" under NEPA.[253] The one case that dealt with two federal approvals, *Myersville Citizens for a Rural Community v. FERC*, involved FERC's review of an LNG export terminal and a natural gas storage project which

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court's decision in *Standing Rock* was clearly wrong, as it failed to substantiate its assumption that the pipeline would be re-routed in the absence of federal approvals—an assumption which, if applied to other oil pipelines, would render the prohibition against segmentation meaningless.

[249] *See, e.g.*, *Del. Riverkeeper Network*, 753 F.3d at 1308–09.

[250] Burger & Wentz, *supra* note 11, at 170–71.

[251] 40 C.F.R. § 1508.25.

[252] The complaint in *Diné Citizens* also alleged that OSM had violated the requirement to review connected actions in its review of a coal mining proposal when it failed to consider emissions from a connected power plant that would combust the coal, but the reviewing court held that it was unnecessary to reach that argument because it concluded that the combustion-related impacts were indirect effects of the proposal. Diné Citizens Against Ruining Our Env't v. U.S. Off. of Surface Mining, 82 F. Supp. 3d 1201, 1212 (D. Colo. 2015).

[253] Big Bend Conservation All. v. FERC, 896 F.3d 418, 424 (D.C. Cir. 2018) (holding that a natural gas pipeline which serviced an LNG terminal was not a connected action because it was not an interstate pipeline subject to federal jurisdiction); Wilderness Workshop v. U.S. Bureau of Land Mgmt., 531 F.3d 1220, 1221 (10th Cir. 2008) (holding that the authorization of a natural gas pipeline and "future gas well development" were not connected actions within the meaning of NEPA, because there was no imminent government action to develop natural gas resources that would also require an EIS).

were physically connected and under review by FERC at roughly the same time.[254] FERC asserted that the projects were not connected because the additional natural gas storage and transportation capacity associated with the storage project had been "fully subscribed" to other (domestic) uses.[255] Petitioners countered that the projects were connected because the storage facility would produce "excess natural gas capacity" that was destined for export through the LNG terminal.[256] Relying heavily on FERC's assertions, the D.C. Circuit Court of Appeals held that the projects were not connected actions because "neither depends on the other for its justification" and the two projects were not "financially and functionally interdependent."[257] This decision illustrates the challenge of establishing a lack of "independent utility" for interconnected fossil fuel supply infrastructure as well as the deference granted to agency conclusions on this issue. It does not entirely foreclose on the application of the rule prohibiting segmentation to other federal approvals, but makes clear that the circumstances in which courts will intervene to enforce this rule are relatively narrow.

### C. *Cumulative Emissions from Fossil Fuel Leasing and Transport Approvals*

Another key scoping question confronting federal NEPA reviews of fossil fuel projects is whether agencies must analyze the cumulative effects of decisions involving fossil fuel extraction or transportation. Whereas upstream and downstream emissions analyses look "vertically" at the fossil fuel supply (focusing on emissions associated with the same fuel as it moves from production to transport, processing, and combustion), cumulative emissions analyses look "horizontally" at the aggregate effect of multiple leasing and transportation infrastructure approvals.[258] One key difference between these two axes is that there is a causal relationship between different activities on the vertical axis,[259] but this is not necessarily the case for activities on the horizontal axis.

There are two provisions in the NEPA regulations that would potentially require an analysis of cumulative emissions in this context:

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[254] Myersville Citizens for a Rural Cmty., Inc. v. FERC, 783 F.3d 1301 (D.C. Cir. 2015).
[255] Dominion Cove Point LNG, LP, 148 FERC ¶ 61,244 (2014).
[256] *Myersville Citizens for a Rural Cmty.*, 783 F.3d at 1326.
[257] *Id.*
[258] Burger & Wentz, *supra* note 11, at 128.
[259] Without each "link" in the fossil fuel supply chain, the fuels would never be produced, transported to markets, or consumed.

(i) the requirement to evaluate cumulative effects, and (ii) the requirement to evaluate "cumulative actions" and "similar actions" in a single review. The precise legal obligations are murky under either framework, as the regulatory language is very broad; the case law under both provisions is sparse. We discuss both frameworks below.

### 1. Cumulative Emissions as Cumulative Impacts

The NEPA regulations require agencies to evaluate cumulative effects, which result from "the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions."[260] Cumulative effects "can result from individually minor but collectively significant actions taking place over a period of time."[261] As with other effects, agencies must take a "hard look" at cumulative impacts and the analysis and data presented should be "useful" to decision makers.[262] Such cumulative impacts must be taken into account when assessing the significance of an action's environmental impacts, and the regulations specify that "significance exists if it is reasonable to anticipate a cumulatively significant impact on the environment."[263]

The cumulative emissions from multiple decisions involving fossil fuel supply projects are precisely the sort of cumulative impact that should be evaluated under NEPA to help serve the twin goals of informed decision-making and public disclosure. There has been a series of decisions involving the federal government's responsibility to account for the cumulative emissions from fossil fuel leasing and transport approvals, including at least five cases involving production and one involving transportation (the Keystone XL pipeline).[264] Generally speaking, courts

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[260] 40 C.F.R. § 1508.7.
[261] *Id.*
[262] *See* League of Wilderness Defs.—Blue Mountains Biodiversity Project v. Allen, 615 F.3d 1122, 1135 (9th Cir. 2010); Kern v. U.S. Bureau of Land Mgmt., 284 F.3d 1062, 1075 (9th Cir. 2002).
[263] 40 C.F.R. § 1508.27(b)(7). For more on this point, see *infra* Section III.B.
[264] There are at least four pending cases alleging failures to quantify cumulative emissions in the context of oil and gas leasing and the decisions in those cases may help further shape agency obligations in this context. Complaint at 23–24, S. Utah Wilderness All. v. Bernhardt, No. 2:19-cv-002660RJS (D. Utah Apr. 19, 2019) (failure to consider cumulative effects of multiple oil and gas leases); Complaint at 33, Rocky Mountain Wild v. Zinke, No. 1:18-cv-02468 (D. Colo. Sept. 27, 2018) (BLM failed to take a hard look at cumulative climate impacts "in conjunction with other past, present, and future lease

are deferential to agency decisions about the proper scope of the cumulative impacts analysis because the regulatory requirement is so broadly worded, and agencies must therefore exercise discretion in deciding which past, present, and reasonably foreseeable actions to focus on.[265] But there are some examples of judicial intervention—specifically, where an agency has ignored the cumulative emissions of multiple leasing decisions that are simultaneously pending before the agency. Two more specific trends in these cases are (i) some courts have adopted a very narrow definition of what constitutes a "reasonably foreseeable" action, holding that agencies are not required to consider other pending approvals for fossil fuel production until a final EA or EIS has been issued for those approvals and (ii) in several instances, courts have conflated petitioners' arguments that agencies should evaluate cumulative *emissions* with arguments about the need to evaluate the actual effects of climate change caused by those emissions in the cumulative impacts analysis, and have held that quantification of the cumulative emissions was not required because quantification of actual climate impacts was not feasible. For reasons discussed below, we think courts have erred in both respects.

The D.C. Circuit Court of Appeals addressed the issue of foreseeability in *WildEarth Guardians v. Jewell.* There, plaintiffs argued that BLM's analysis of GHG emissions from a coal lease was inadequate because BLM failed to consider its cumulative impact along with emissions from eleven other pending lease applications in the Powder River Basin.[266] At the time the EIS was prepared, BLM had issued draft EISs for four of the eleven leases; the other seven leases were still in the scoping stage.[267] The D.C. Circuit held that the approval of the eleven other leases was not reasonably foreseeable at this stage and thus BLM was not required to evaluate them in its cumulative effects analysis.[268] This decision thus set a very high bar for what constitutes a "foreseeable" future action.

sales in the Uinta Basin"); Complaint at 24, WildEarth Guardians v. U.S. Bureau of Land Mgmt., No. 4:18-cv-00073 (D. Mont. May 5, 2018) (BLM "failed to quantify cumulative emissions" in oil and gas leasing EA); Complaint at 4, Wilderness Workshop v. U.S. Bureau of Land Mgmt., No. 1:18-cv-00987 (D. Colo. Apr. 26, 2018) (failure to account for cumulative effects of multiple oil and gas leases). There are also cases in which petitioners are primarily relying on the "cumulative effects" framework to argue that agencies should take a harder look at the actual impacts of emissions—that is, the impacts of climate change on human and natural systems. As such claims do not implicate the proper scope of the emissions analysis but rather the mode of analysis, we discuss them in Part III.

[265] Kleppe v. Sierra Club, 427 U.S. 390, 413–14 (1976).

[266] WildEarth Guardians v. Jewell, 738 F.3d 298, 309 (D.C. Cir. 2013).

[267] *Id.* at 310.

[268] *Id.*

This rationale for this standard is questionable, especially as applied to pending actions for which a draft EIS or EA has been prepared. The draft document is the final step in the agency review process before the agency commits to a final action,[269] and preparing this document requires a considerable commitment of time and resources[270]—and such, it is a strong indicator that an agency intends to proceed with the action. To illustrate this point, when *WildEarth Guardians v. Jewell* was being tried, BLM had already published EISs for all of the leases, issued Records of Decisions ("RODs") for three leases, had RODs pending for four leases, and held a sale for one lease.[271] This is such a narrow interpretation of "reasonably foreseeable future actions" that it almost eliminates the requirement to look at future federal actions altogether. If a proposal for which a draft EIS or EA has been prepared does not qualify as a "foreseeable future action," then what does? Only actions that have been approved but not yet implemented? This is too lenient an interpretation to support NEPA's goals of informed decision-making and public disclosure.

That being said, even under this very narrow interpretation, there is ample room for greater disclosure of cumulative emissions from fossil fuel supply projects. This is illustrated by a decision from the D.C. district court in a case involving BLM's failure to look at the cumulative effects of hundreds of oil and gas leases in Wyoming, Utah, and Colorado. In that case, the court found that BLM had violated NEPA by failing to quantify the aggregate emissions from eleven lease sales encompassing 473 oil and gas leases.[272] The court explained that "considering each individual drilling project in a vacuum deprives the agency and the public of the context necessary to evaluate oil and gas drilling on federal land before irretrievably committing to that drilling."[273] There was no question as to whether the 473 lease sales were "reasonably foreseeable" as the sales had already been issued. But the court also noted, consistent with the D.C. Court of Appeals standard, "[t]o the extent other BLM actions in the region—such as other lease sales—are reasonably foreseeable when an EA is issued, BLM must discuss them as well."[274] The court noted that BLM must "consider these cumulative impacts when assessing the contribution of the leasing program to climate change" even if it

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[269] *See* 40 C.F.R. § 1502.1.
[270] *See* 40 C.F.R. § 1502.2–1502.3.
[271] *WildEarth Guardians*, 738 F.3d at 310.
[272] WildEarth Guardians v. Zinke, 368 F. Supp. 3d 41, 55, 71 (D.D.C. 2019).
[273] *Id.* at 83.
[274] *Id.* at 77.

determined that each individual lease sale would have a "de minimis impact on climate change."[275]

The three other decisions on the required scope of cumulative emissions analysis for fossil fuel production approvals all illustrate how deferential courts are to agencies on this question. Two of these decisions were issued by the same judge in the Colorado district court.[276] In both cases, plaintiffs

> contended that NEPA required BLM to evaluate all emissions from its oil and gas leasing approvals in its cumulative impacts analysis.[277] The judge disagreed, finding that BLM had taken an appropriately hard look at cumulative impacts by providing a qualitative analysis of climate change and its potential impacts.[278] In the later of the two decisions, the judge cited two factors that informed its decision: (i) the general principle of deference to agencies ("it is not the role of the court to decide whether Defendants choices were ideal; I am merely tasked with determining whether Defendants' analyses met the minimum threshold necessary to constitute a 'hard look.'"); and (ii) BLM's determination that it was "impossible to attribute a particular climate impact in any given region to GHG emissions from a particular source" because "tools did not exist that would allow [BLM] to predict how a project's emissions would impact global, regional, or local climate because, at the time, government agencies did not have standardized protocols or specific levels of significance by which they could quantify climate impacts."[279] While this general principle of deference may be true, it appears that the court's deference in this context was misplaced insofar as the court was deferring to BLM's explanation of why it could not quantify climate *impacts* when deciding that BLM was not obligated to quantify cumulative emissions

[275] *Id.*
[276] Citizens for a Healthy Cmty. v. U.S. Bureau of Land Mgmt., 377 F. Supp. 3d 1223 (D. Colo. 2019); Wilderness Workshop v. U.S. Bureau of Land Mgmt., 342 F. Supp. 3d 1145 (D. Colo. 2018).
[277] *See, e.g.*, Plaintiffs' Opening Merits Brief at 16, Citizens for a Healthy Cmty. v. U.S. Bureau of Land Mgmt., 377 F. Supp. 3d 1223 (D. Colo. 2019) (No. 1:17-cv-2519-LTB-GPG).
[278] *Citizens for a Healthy Cmty.*, 377 F. Supp. 3d at 1239.
[279] *Id.* at 1239.

> from BLM leasing. The court's decision did not contain any assessment of whether such quantification would be feasible or and to what extent it was necessary for informed decision-making.

The Montana district court made a similar logical error in an unreported opinion involving BLM's cumulative impact analysis for oil and gas leasing. There, petitioners alleged that BLM should have quantified emissions from the entire mineral estate managed by BLM, or at minimum, eight revised RMPs that were approved by a single ROD on the same date (and thus there was no question about whether they were "foreseeable").[280] Petitioners also alleged that BLM should have used the global carbon budget and/or social cost estimates to evaluate the actual impacts of those cumulative emissions (but this was distinct from their claim that quantification was required).[281] The district court conflated these two arguments in its analysis, finding that "[a]nalysis of the cumulative impacts of climate change would require not only quantification, but a standard by which to measure the impacts," and although plaintiffs presented two possible standards (global carbon budget and social cost metrics), no courts had yet required the use of these tools in that manner.[282] At the same time, the district court stated that GHG emissions can be used as a proxy for the consideration of global climate change effects.[283] The reasoning behind this decision is dubious for several reasons. First, the court never explained why quantification of the cumulative emissions from leasing decisions should not be required as a "first step" in the cumulative impact analysis regardless of whether metrics were available to further evaluate the actual impacts of those emissions. Second, despite acknowledging that GHG emissions could themselves serve as a proxy for impacts, the court still held that quantification was not required. Third, if the court was correct that the cumulative effects analysis required an additional "standard by which to measure the impacts," then should not BLM be required to use the tools that were at its disposal (specifically the global carbon budget and the social cost of carbon) to perform a sound cumulative effects analysis? Ultimately, it

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[280] W. Org. of Res. Councils v. U.S. Bureau of Land Mgmt., No. CV 16-21-GF-BMM, 2018 WL 1475470, at *13 (D. Mont. Mar. 26, 2018), *appeal dismissed*, No. 18-3583618, 2019 WL 141346 (9th Cir. Jan. 2, 2019).
[281] *Id.* at *14.
[282] *Id.* at *13–14.
[283] *Id.* at *18.

appears that the court may have conflated the two arguments presented by the petitioners (that BLM should quantify cumulative emissions from fossil fuel leasing, and that BLM should look at the actual impacts of those cumulative emissions) and thus failed to adequately address the first argument about quantification.

Finally, the one case addressing the requirement to look at cumulative emissions in the transport context was *Indigenous Environmental Network v. U.S. Department of State,* which involved the environmental review for the Keystone XL pipeline.[284] There, the Montana district court found that emissions from two transboundary oil pipeline projects that were being reviewed by the State Department at the same time (Keystone XL and Alberta Clipper) must be considered in the cumulative impacts analysis for Keystone XL.[285] The two pipeline projects shared a geographic nexus in that they originated in the same region (Alberta oil sands) but transported the oil to very different markets in the United States.[286] This decision provides some insight on the minimum requirements for cumulative effects analysis in the pipeline context and suggests that NEPA also requires FERC to consider the emissions from multiple pipeline projects that are undergoing FERC review in its cumulative impacts analysis, particularly pipelines that are located in the same region and/or service the same natural gas production sites or end-user markets.[287]

2. Cumulative Emissions as Impacts of Cumulative and Similar Actions

The regulatory requirements for analyzing cumulative and similar actions together also provide a basis for arguing that agencies should look at the aggregated effects of multiple fossil fuel extraction and

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[284] Indigenous Envtl. Network v. U.S. Dep't of State, 347 F. Supp. 3d 561 (D. Mont. 2018).
[285] *Id.* at 577–78.
[286] *Id.* at 577.
[287] Granted, the facts underpinning *Indigenous Environmental Network* were somewhat unique: the State Department had treated the Keystone XL pipeline as a cumulative action in the Alberta Clipper EIS (and had calculated cumulative emissions from the two projects in that EIS), and thus it was irrational to take a different approach in the Keystone XL EIS. *Id.* at 578. But the scope of an agency's cumulative effects (or actions) analysis on one NEPA review should not be a dispositive factor in determining whether an agency has taken an adequately hard look at cumulative effects in another NEPA review. To hold that an agency is *not* required to evaluate certain cumulative effects because it did not evaluate them in a past review would be irrational and would undermine NEPA's core purposes.

transportation proposals. These provisions are useful because they require a more comprehensive review of the combined impacts of multiple federal actions—in effect, a joint EA or EIS that looks at the actions themselves in the aggregate, as opposed to just looking at certain effects in the aggregate.

The CEQ regulations require a joint review of federal actions that "have cumulatively significant impacts and should therefore be discussed in the same impact statement."[288] The regulations also recognize a prohibition of segmentation of reviews for cumulative actions, similar to that recognized for connected actions. Specifically, in the paragraph directing agencies to consider "whether the action is related to other actions with individually insignificant but cumulatively significant impacts," the regulations state that "[s]ignificance cannot be avoided . . . by breaking [the action] down into small component parts."[289]

In contrast, the regulations state that an agency "may wish" to analyze "similar actions" in the same NEPA document—similar actions being defined as those which "have similarities that provide a basis for evaluating their environmental consequences together, such as common timing or geography" and that an agency "should do so when the best way to assess adequately the combined impacts of similar actions or reasonable alternatives to such actions is to treat them in a single impact statement."[290] Due to the more permissive language here, courts have granted considerable deference to agencies' decisions about whether to prepare a single EIS for similar actions.[291]

Decisions striking down agency reviews due to failure to prepare a joint (or programmatic) EA or EIS for cumulative and similar actions are rare.[292] In the 1976 case *Kleppe v. Sierra Club*, the Supreme Court addressed whether the federal government was obligated to prepare a programmatic review for coal leasing in the Great Plains Region.[293] There, the Supreme Court explained that:

> A comprehensive impact statement may be necessary in some cases for an agency to meet [its duty to evaluate environmental impacts]. Thus, when several proposals for coal-related actions that will have cumulative or synergistic

[288] 40 C.F.R. § 1508.25(a)(2).
[289] § 1508.27(b)(7).
[290] § 1508.25(a)(3).
[291] *See* Burger & Wentz, *supra* note 11, at 173–74.
[292] *See id.* at 171–75.
[293] Kleppe v. Sierra Club, 427 U.S. 390 (1976).

> environmental impact upon a region are pending concurrently before an agency, their environmental consequences must be considered together. Only through comprehensive consideration of pending proposals can the agency evaluate different courses of action.[294]

However, in that case, the court held that PEIS for the Great Plains Region was not required because (i) all proposals for coal leasing were either national or local in scope (there was no regional development plan in the works), and (ii) the federal government had prepared a nationwide PEIS for a new national coal-leasing policy as well as EISs for proposed local coal leasing actions.[295] In this context, the Court held that it was appropriate to defer to the federal government's determination that "the appropriate scope of comprehensive statements should be based on basins, drainage areas, and other factors."[296]

The Ninth Circuit addressed the narrower question of whether the federal government had improperly piecemealed its analysis of coal mining operating in a particular leasing area in *Cady v. Morton*.[297] There, the Ninth Circuit Court of Appeals found that DOI had improperly isolated the impacts of coal leasing activities when it approved coal leases covering 30,876 acres of land and up to twenty years of mining but then prepared an EIS for a mining plan which covered only five years of mining on 770 acres.[298] DOI argued that the EIS was appropriate in scope because an EIS need not be prepared covering an entire project when an adequate EIS covering a discrete phase or segment thereof has been prepared, but the court disagreed, explaining that:

> While it is true that each mining plan prepared for tracts within the leased area is to a significant degree an independent project which requires a separate EIS with respect to each, it is no less true that the breadth and scope of the possible projects made possible by the Secretary's approval of the leases require the type of comprehensive study that NEPA mandates adequately to inform the Secretary of the possible environmental consequences of

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294 *Id.* at 409–10.
295 *See id.* at 399–401.
296 *Id.* at 414.
297 Cady v. Morton, 527 F.2d 786 (9th Cir. 1975).
298 *See id.* at 794–96.

> his approval. Westmoreland's massive capital investment and extended contractual commitments present a situation in which "it would be irrational, or at least unwise, to undertake the first phase if subsequent phases were not also undertaken." However, even were this not true, it cannot be denied that the environmental consequences of several strip mining projects extending over twenty years or more within a tract of 30,876.45 acres will be significantly different from those which will accompany Westmoreland's activities on a single tract of 770 acres.[299]

This case was decided before the CEQ regulations were promulgated and thus the court did not discuss whether these were "connected," "cumulative," or "similar" actions under 40 C.F.R. § 1508.25—but the analysis here suggests that the actions had some characteristics of connected actions but would best be characterized as "cumulative" or "similar" actions under the current regulations as they had a "significant degree" of independent utility.[300]

Federal approvals for fossil fuel production and transportation can be characterized as both "cumulative" and "similar" actions—most of these approvals have independent utility,[301] but these actions have "similarities which provide a basis for evaluating their consequences together" as well as "cumulatively significant effects" on fossil fuel use and the corresponding emissions. NEPA's twin aims of informed decision-making and public disclosure would also be best served through a comprehensive assessment.

However, as noted above, courts tend to be deferential to agency decisions about the scope of their NEPA assessments for cumulative and similar actions. One important factor is whether there is a statutory mandate compelling the agency to prepare and/or periodically update a national or regional program, which would in turn trigger NEPA review of the program. For example, the Outer Continental Shelf Lands Act requires BOEM to prepare five-year programs for offshore leasing covering broad geographic areas, and it would be plainly arbitrary and capricious for BOEM to forgo a programmatic NEPA analysis of those five-year programs.[302]

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[299] *Id.* at 795 (internal citations omitted).
[300] *See id.*; 40 C.F.R. § 1508.25.
[301] As discussed in Section II.B.1, authorized projects which lack independent utility would best be analyzed under the "connected actions" framework.
[302] Outer Continental Shelf Lands Act, 43 U.S.C. § 1344(a).

But there is no comparable requirement for onshore leasing or for fossil fuel transportation infrastructure. Prior to authorizing fossil fuel development on public lands, agencies are required to prepare RMPs,[303] but these plans cover much smaller geographic units than the outer continental shelf ("OCS") five-year program documents (and in many cases have not been updated with an analysis of potential GHG emissions from fossil fuel leasing). The result is that agencies are approving fossil fuel supply projects without any programmatic analysis on the cumulative effect of multiple approvals across broad geographic regions.[304]

Two other lawsuits challenging the federal government's failure to conduct an updated programmatic review of the federal coal leasing program to address climate impacts, among other things, are relevant.

In *Western Organization of Resource Councils v. Zinke*, the D.C. Circuit Court of Appeals held that BLM was not required to update the PEIS for the federal coal leasing program as there was no new proposal requiring NEPA review.[305] The "action" at issue in this case was the 1979 PEIS for the federal coal leasing program, and plaintiffs argued that this needed to be updated to reflect significant new information about climate change.[306] The D.C. Circuit noted that plaintiffs had raised a "compelling argument" for BLM to re-evaluate the federal coal leasing program in light of climate change concerns, but held that the action contemplated in the 1979 PEIS had been completed in 1979 and no new nationwide action had been proposed.[307] The court suggested that the plaintiffs might pursue these claims through an alternate approach:

> Appellants may, when appropriate, challenge specific licensing decisions on the ground that the EIS prepared in support of any such decision fails to satisfy NEPA's mandate to consider the cumulative environmental impacts of coal leasing. Such a claim might challenge any attempt by

[303] *See* 43 C.F.R. § 1610.
[304] While this may have been understandable at an earlier point in time, when adverse environmental effects were understood to be relatively local, or regional in some instances, at this point agencies understand that the GHG emissions from these approvals have a global effect and can be analyzed on a regional or nationwide basis. Congress could address this gap through legislation requiring programmatic reviews, but in the absence of congressional action, NEPA requirements can play a role in compelling such analysis. *See supra* Section I.C.
[305] W. Org. of Res. Councils v. Zinke, 892 F.3d 1234, 1245–46 (D.C. Cir. 2018).
[306] *Id.* at 1236–37.
[307] *Id.* at 1244–45.

> BLM to rely on (or tier to) the 1979 PEIS on the ground that it is too outdated to support new federal action.[308]

The court noted that such a lawsuit was not foreclosed by its decision in *WildEarth Guardians v. Jewell* (holding that eleven pending coal leases were not reasonably foreseeable), because that case did not involve any allegations about improperly tiering to an outdated PEIS.[309]

In *Citizens for Clean Energy v. U.S. Department of the Interior*, the Montana district court held that the Trump administration's decision to terminate the federal coal leasing moratorium was a major federal action with environmental implications requiring some form of NEPA review.[310] The court did not go so far as to require a PEIS but rather directed DOI to consider what form of NEPA documentation would be required for this action.[311] Granted, neither of these two decisions on the federal coal leasing program address whether there are "cumulative" or "similar" actions that must be reviewed in a joint PEIS—rather, they deal with whether there is a major federal proposal that triggers NEPA requirements—but they do bear on agency obligations to evaluate the cumulative effects of coal leasing decisions on a nationwide basis.

Two notable decisions address agency obligations to review connected, cumulative, or similar actions involving fossil fuel supply in the same EIS,[312] but both decisions were more limited in scope insofar as they dealt with only two potentially related actions of the same sort. In one case, a federal court found that emissions from two oil pipelines must

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[308] *Id.* at 1244.
[309] *Id.* at 1245.
[310] Citizens for Clean Energy v. U.S. Dep't of the Interior, 384 F. Supp. 3d 1264, 1271, 1279 (D. Mont. 2019).
[311] *Id.* at 1281.
[312] There are also at least two pending cases alleging that oil and gas leases sales were "cumulative actions" that should be reviewed in the same EIS due to their cumulatively significant impacts, and that BLM unlawfully segmented its analysis of the sales into multiple EAs thus underplaying the significance of the impacts. These complaints deal with approved oil and gas lease sales, thus avoiding the need to demonstrate that a pending sale is "reasonably foreseeable." The two pending cases alleging improper segmentation of oil and gas leasing EAs also allege inadequate analysis of cumulative effects, and it remains to be seen whether the courts will resolve these under the cumulative impacts framework (requiring supplementation of the existing EAs) or cumulative actions framework (requiring preparation of a comprehensive EIS). Complaint at 27, 30–31, WildEarth Guardians v. U.S. Bureau of Land Mgmt., No. 4:18-cv-00073 (D. Mont. May 15, 2018); Complaint at 76–77, W. Watersheds Project v. Zinke, No. 1:18-cv-00187 (D. Idaho Apr. 30, 2018).

be reviewed as cumulative impacts and also described these two projects as "cumulative actions"—but because the analysis focused on the requirements for assessing cumulative impacts rather than actions and the remedy was to update the cumulative impacts analysis for the one project, the decision does not provide much guidance on the question of when a joint EIS is required for cumulative actions.[313] In another case, a federal court held that BLM had not improperly piecemealed its analysis in a coal lease EA when it failed to prepare a comprehensive EIS encompassing (i) another mining plan modification that would expand the mine by another 498 acres and 48 million tons of coal and (ii) an application for another coal lease at the mine that would add 1,600 acres and 198 million more tons of coal to the mine.[314] The court reasoned that the plan modification was not a "reasonably foreseeable future action" at the time the EA was prepared because there it was only a pending application that had not yet been approved.[315] As discussed above, the rationale for adopting such a narrow definition of foreseeability is questionable—the entire purpose of the provisions directing agencies to review cumulative and similar actions in the same EIS is to facilitate consideration of the combined effects of those actions *before* an agency makes a final decision. Limiting the analysis of cumulative and similar actions to actions which have already been approved completely undermines this purpose.

## III. THE ADEQUACY OF GHG EMISSIONS ANALYSIS FOR FOSSIL FUEL SUPPLY PROJECTS

As questions about the proper scope of review for direct, indirect, and cumulative GHG emissions from fossil fuel supply projects are resolved, new questions naturally arise about the adequacy and reasonableness of agencies' calculations, disclosures, and determinations of the significance of GHG impacts. This section explores four key areas for environmental impact assessment of these projects: (i) the net impact of the proposal on fossil fuel use and corresponding emissions (i.e., the "energy

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313 Indigenous Envtl. Network v. U.S. Dep't of State, 347 F. Supp. 3d 561, 578 (D. Mont. 2018).

314 WildEarth Guardians v. Zinke, No. 1:17-cv-0080, 2019 WL 2404860, at *13 (D. Mont. Feb. 11, 2019); Complaint at 17, WildEarth Guardians v. Zinke, No. 1:17-cv-0080 (D. Mont. June 8, 2017).

315 WildEarth Guardians, No. 1:17-cv-0080, 2019 WL 2404860, at *5, *13. Oddly, the court did not address whether the other coal lease application was reasonably foreseeable, but this narrow definition of "foreseeable future action" would presumably exclude that pending application as well.

market analysis"); (ii) non-$CO_2$ emissions such as methane; (iii) the significance of GHG emissions; and (iv) alternatives and mitigation options to reduce GHG emissions. In reviewing the adequacy of environmental reviews, courts tend to be deferential to agencies, particularly as compared with situations where agencies have wholly omitted an impact from the scope of their review. Yet, judicial discretion to agency expertise only goes so far, and where an agency has clearly stepped outside the realm of reasonable analysis, it is proper for a court to intervene.

### *A. Energy Market Impacts and Net Emissions*

In assessing upstream and downstream GHG emissions of federally approved fossil fuel supply projects, agencies may seek to understand the net emissions impact of the proposal based on an assessment of how the projected increase in fossil fuel production or transport capacity will affect broader patterns of energy production and consumption. The net emissions analysis is essentially a comparison between emissions under the "no action" and "action" alternatives, although it is not always framed as such.[316] One approach to this analysis is to deflect it with a "perfect substitution" argument; that approach is born of faulty logic and has been roundly rejected by the courts. Another approach involves employing energy market models to quantify emissions effects; however, in some instances agencies have concluded that it is impossible to accurately project such effects, in others they have conducted analyses that put a thumb on the scale, and in others they have undertaken more rigorous analyses. The critical question is whether agencies are adequately supporting their findings, one way or the other. The validity of agency findings on energy substitution and net emissions depends on the nature of the proposal. The nationwide federal coal leasing program, for example, presumably has a much larger effect on net emissions than the approval of an individual pipeline. But even a single pipeline or lease approval may have some effect on fossil fuel prices and markets. Recognizing this, courts have flatly rejected "perfect substitution" in the context of coal leases and coal railways, and have made it clear that perfect substitution claims for other types of proposals must be supported by adequate analysis.[317] And

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[316] Courts have held that it is reasonable to use several different scenarios to frame the "no action" alternative where there is uncertainty about energy markets and substitution. *See, e.g.*, Indigenous Envtl. Network v. U.S. Dep't of State, 347 F. Supp. 3d 561, 574–75 (D. Mont. 2018).
[317] *See* Section II.A.1.

this is exactly what many agencies have begun doing: incorporating models and quantitative analysis into their NEPA documentation to support their findings on energy market substitution, and in some cases finding that the project will have little or no net impact on emissions. Agency arguments about energy market substitution can be difficult to parse because (i) the assumptions and calculations often are not fully disclosed in the NEPA documentation and can be easily manipulated to achieve an intended result; (ii) there is so much uncertainty in the results that it is difficult if not impossible to definitively say that an agency reached the wrong conclusion; and (iii) courts are deferential to agencies on such technical issues. There may be instances where the analysis of energy market impacts is so egregiously flawed that a court will remand the issue back to the agency for supplementation or revision of the analysis, but where agencies can show their math they often pass the test.

1. Fossil Fuels and "Perfect Substitution"

Federal courts have rejected perfect substitution arguments as irrational and/or unsubstantiated in a number of cases involving both fossil fuel production and transportation infrastructure. As a threshold matter, agencies cannot rely on unsupported assumptions of perfect substitution as a justification for ignoring downstream GHG emissions.[318] As the court in *High Country Conservation Advocates* explained, this assumption was "illogical" in the context of a coal lease approval because the production of coal resulting from the proposed action would "increase the supply of cheap, low-sulfur coal" and "this additional supply will impact the demand for coal relative to other fuel sources, and coal that otherwise would have been left in the ground will be burned."[319] Similarly, in *Mid States Coalition v. Surface Transportation Board,* the Eighth Circuit Court of Appeals held that downstream emissions must be disclosed in the context of a coal railway because the increase in coal transportation capacity would affect the price of coal relative to other energy sources and this would affect patterns of coal production and consumption.[320] In *Sierra*

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[318] As discussed below, the D.C. Circuit Court of Appeals' decision in Birckhead v. FERC raises questions about whether courts will defer to perfect substitution arguments as a justification for ignoring *upstream* emissions in the context of fossil fuel transportation approvals. *See supra* notes 215–23.
[319] High Country Conservation Advocates v. U.S. Forest Serv., 52 F. Supp. 3d 1174, 1197–98 (D. Colo. 2014).
[320] Mid States Coal. for Progress v. Surface Transp. Bd., 345 F.3d 520, 549–50 (8th Cir.

*Club v. FERC*, the D.C. Circuit Court of Appeals rejected FERC's argument that it need not quantify combustion emissions in the context of a natural gas pipeline review because some of the natural gas would replace dirtier fossil fuels, thus offsetting the project's emissions estimates.[321] The court found that a purely qualitative analysis of substitution was inadequate because "[a]n agency decisionmaker reviewing this EIS would . . . have no way of knowing whether total emissions, on net, will be reduced or increased by this project, or what the degree of reduction or increase will be."[322]

It is also arbitrary and capricious for agencies to estimate downstream emissions for the proposed action but then claim that the emissions impact will be identical under the "no action" alternative due to perfect substitution.[323] In one case involving an EA where OSM estimated downstream emissions from coal leasing but declined to estimate the social costs of those emissions based on its conclusion that the leasing program would have no effect on emissions due to substitution, the reviewing court explained that:

> This conclusion is illogical, and places the Enforcement Office's thumb on the scale by inflating the benefits of the action while minimizing its impacts. It is the kind of "[i]naccurate economic information" that "may defeat the purpose of [NEPA analysis] by impairing the agency's consideration of the adverse environmental effects and by skewing the public's evaluation of the proposed agency action."[324]

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2003). On remand, STB prepared an EIS in which it modelled the effects of the coal railway on coal production and use, and petitioners challenged the supplemental analysis on the grounds that STB continued to rely on the assumption that "not all of the . . . transported coal would represent new combustion, that some would be simply a substitute for existing coal supplies." Mayo Found. v. Surface Transp. Bd., 472 F.3d 545, 556 (8th Cir. 2006). But the Eighth Circuit upheld STB's review as the conclusions about market substitution were supported by quantitative analysis and energy market models. *Id.*

[321] Sierra Club v. FERC, 867 F.3d 1357 (D.C. Cir. 2017) (qualitative discussion of substitution not adequate).

[322] *Id.* at 1375.

[323] WildEarth Guardians v. U.S. Bureau of Land Mgmt., 870 F.3d 1222, 1235–36 (10th Cir. 2017); WildEarth Guardians v. Zinke, 368 F. Supp. 3d 41, 75 (D.D.C. 2019); Mont. Envtl. Info. Ctr. v. U.S. Off. of Surface Mining, 274 F. Supp. 3d 1074, 1103 (D. Mont. 2017).

[324] Mont. Envtl. Info. Ctr. v. U.S. Off. of Surface Mining, 274 F. Supp. 3d 1074, 1098 (D. Mont. 2017) (internal citations omitted). Notably, in an EA prepared on remand, OSM revised its annual production and emissions estimates downwards (from 23.16 million tons to 13.1 million tons $CO_2$ / year) even though the scope and duration of the action had not

Another decision which also involved OSM's review of coal mining impacts held that this rule was also applicable where OSM had declined to estimate the social costs of emissions because it was uncertain whether emissions would actually be reduced under the no action alternative due to the possibility of energy market substitution. While OSM had shifted its position from "no impact" to "uncertain impact" due to substitution, the court found that this was still "arbitrary and capricious" because the "alternative source substitution assumption is not supported by any market data, even though modeling systems exist to evaluate market effects of changes in coal supply."[325]

In addition, agencies cannot justify claims of perfect substitution by relying on incomplete or irrational analysis of energy markets. This was the focus of the Tenth Circuit Court of Appeals' decision in *WildEarth Guardians v. Bureau of Land Management*, which contained one of the most detailed assessments of an agency's perfect substitution argument to date. That case involved BLM's EIS for coal leases that would have extended the life of two coal mines (the "Wright Area" mines) that accounted for nearly 20 percent of U.S. annual domestic coal production.[326] BLM had quantified downstream emissions from combustion of the coal (approximately 382 million tons of annual $CO_2$ emissions—roughly 6 percent of U.S. total 2008 emissions) but concluded that the same amount of coal would be sourced from elsewhere if it did not approve the proposed leases and thus there was no difference between the proposed action and the no action alternative with respect to coal production and consumption.[327] Thus, as noted by the court, the issue was not that BLM had completely ignored the effects of increased coal consumption, but rather that it had analyzed them irrationally.[328]

The court found that BLM's "long logical leap presumes that either the reduced supply will have no impact on price, or that any increase in

changed and the total projected production of "saleable" coal had actually increased from eighty million tons to 86.8 million tons, and then replaced the statement about perfect substitution with a claim that the proposal would have a "very small impact" on emissions. This illustrates how easily agencies can adjust their quantitative analysis to achieve an intended result. *See* OFF. OF SURFACE MINING, U.S. DEP'T OF THE INTERIOR, BULL MOUNTAINS MINE NO. 1 FEDERAL MINING PLAN MODIFICATION ENVIRONMENTAL ASSESSMENT 2-9, 4-3 (2015); OFF. OF SURFACE MINING, U.S. DEP'T OF THE INTERIOR, BULL MOUNTAINS MINE NO. 1 FEDERAL MINING PLAN MODIFICATION ENVIRONMENTAL ASSESSMENT 18, 57–58 (2018).

325 WildEarth Guardians v. Zinke, No. 1:17-cv-00080, 2019 WL 2404860, at *11.

326 WildEarth Guardians v. U.S. Bureau of Land Mgmt., 870 F.3d 1222, 1226–27 (10th Cir. 2017).

327 *Id.* at 1228.

328 *Id.* at 1237.

price will not make other forms of energy more attractive and decrease coal's share of the energy mix, even slightly" and found that this assumption lacked any support in the administrative record.[329] The court explained:

> BLM did not point to any information (other than its own unsupported statements) indicating that the national coal deficit of 230 million tons per year incurred under the no action alternative could be easily filled from elsewhere, or at a comparable price. It did not refer to the nation's stores of coal or the rates at which those stores may be extracted. Nor did the BLM analyze the specific difference in price between PRB coal and other sources; such a price difference would effect [sic] substitutability.[330]

The court also noted that BLM's assumption was contradicted by one of the principle resources on which it relied: the EIA's 2008 Energy Outlook. While the report generally predicted an increase in coal production, it also found that different assumptions for coal mining and transportation costs affected delivered coal prices and demand, and that higher coal costs resulted in much lower U.S. coal consumption.[331] Thus, the court found that "the [EIA] report supports what one might intuitively assume: when coal carries a higher price, for whatever reason that may be, the nation burns less coal in favor of other sources."[332] The court held that BLM's "blanket assertion that coal would be substituted from other sources, unsupported by hard data[,]" did not provide sufficient information to permit a reasoned choice between the preferred alternative and the no action alternative.[333] In addition, the court noted that, even if BLM had hard data to support this statement, "we would still conclude this perfect substitution assumption arbitrary and capricious because the assumption itself is irrational (i.e., contrary to basic supply and demand principles)."[334] The court concluded that it was "an abuse of discretion" to rely on such a baseless economic assumption to distinguish between the no action and preferred alternatives.[335]

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[329] *Id.* at 1229.
[330] *Id.* at 1234.
[331] *Id.* at 1234–35.
[332] *WildEarth Guardians*, 870 F.3d at 1235.
[333] *Id.*
[334] *Id.* at 1236.
[335] *Id.* at 1237–38.

Another key takeaway from *WildEarth Guardians v. Bureau of Land Management* is that perfect substitution claims are readily distinguishable from other types of agency assumptions that warrant judicial deference. The primary authority on this issue is the Supreme Court's decision in *Baltimore Gas & Electric Co. v. NRDC*, which upheld the Nuclear Regulatory Commission's ("NRC") conclusion that permanent nuclear waste storage would not have a significant environmental impact, which was based on the Commission's assumption that waste repositories would perform perfectly.[336] There, the Supreme Court deferred to NRC's assumption because (1) it had a limited purpose in the overall environmental analysis (i.e., it was not the key to deciding between two alternatives); (2) overall, the agency's estimation of the environmental effects was overstated, so this single assumption did not determine the overall direction the NEPA analysis took; and (3) courts are most deferential to agency decisions based not just on "simple findings of fact," but in the agency's "special expertise, at the frontiers of science."[337]

Applying those factors to BLM's perfect substitution assumption, the Tenth Circuit Court of Appeals found that:

> Here, the BLM's substitution assumption appears to be quite different from the Commission's zero release assumption under the three factor analysis in *Baltimore Gas*. First, the BLM's perfect substitution assumption was key to the ultimate decision to open bidding on the leases. In each of the four RODs, the "Reasons for Decision" section first discusses the leases' effect on coal combustion in the nation overall, then lists the other facts that influenced its decision in bullet points. In each ROD, the discussion opens with the assertion that: "Denying this proposed coal leasing is not likely to affect current or future domestic coal consumption used for electric generation." Prioritizing the carbon emissions and global warming analysis in the RODs suggests that this question was critical to the decision to open the leases for bidding. Prioritizing the perfect substitution assumption within that analysis suggests it was critical to deciding between two alternatives: whether or not to issue the leases. The perfect substitution assumption

[336] Balt. Gas & Electric Co. v. NRDC, 462 U.S. 87, 103 (1983).
[337] *Id.* at 102–04.

> was more than a "mere flyspeck" in the BLM's NEPA analysis.
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> Second, the BLM's carbon emissions analysis seems to be liberal (i.e., underestimates the effect on climate change). The RODs assume that coal will continue to be a much used source of fuel for electricity and that coal use will increase with population size. We do not owe the BLM any greater deference on the question at issue here because it does not involve "the frontiers of science." The BLM acknowledged that climate change is a scientifically verified reality. Climate science may be better in 2017 than in 2010 when the FEIS became available, but it is not a scientific frontier as defined by the Supreme Court in *Baltimore Gas*, i.e., as barely emergent knowledge and technology. Moreover, the climate modeling technology exists: the NEMS program is available for the BLM to use.[338]

Although the court remanded to the agency to modify and supplement its analysis, it declined to specify the exact approach that BLM must take. The court held that: "NEPA does not require agencies to adopt any particular internal decisionmaking structure"[339] and that "[c]hoosing not to adopt a modeling technique does not render the BLM's EIS arbitrary and capricious; its irrational and unsupported substitution assumption does."[340]

Most of the case law addressing perfect substitution claims as applied to downstream emissions is consistent with the principles described above.[341] In sum, courts have rightfully rejected perfect substitution

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[338] WildEarth Guardians v. U.S. Bureau of Land Mgmt., 870 F.3d 1222, 1236–37 (10th Cir. 2017).
[339] *Id.* at 1238 (citing *Balt. Gas*, 462 U.S. at 100).
[340] *WildEarth Guardians*, 870 F.3d at 1238.
[341] There is one unpublished opinion from the D.C. Circuit Court of Appeals that does not fully reflect these same principles. That case involved a situation similar to that which has arisen in the context of coal leases. FERC quantified downstream emissions for a proposed pipeline project but then stated that: (i) actual emissions would be fully offset by other sources of natural gas, resulting in no change in GHG emissions, and (ii) the downstream effects are "not reasonably foreseeable" and "not indirect impacts" and the commission was merely quantifying downstream emissions "outside the scope of [its] NEPA analysis." Petitioners claimed that this was not an adequate assessment of downstream impacts. The D.C. Circuit, however, held that it was not necessary to consider Petitioner's arguments about whether an increase in downstream emissions was foreseeable

arguments in the context of both fossil fuel production and transportation approvals. However, FERC has nonetheless relied on unsubstantiated perfect substitution arguments as the basis for either excluding upstream and downstream emissions from its environmental reviews or else discounting their importance in its significance analysis. There have been a number of lawsuits pending against FERC due to this practice.[342] FERC's position has been that "a causal relationship sufficient to warrant Commission analysis of the non-pipeline activity [i.e., production and consumption] as an indirect impact would only exist if the proposed pipeline would transport new production from a specified production area and that production would not occur in the absence of the proposed pipeline (i.e., there will be no other way to move the gas)."[343] FERC has simultaneously argued "it is unknown—and virtually unknowable—whether the gas to be transported on [a specific pipeline] will come from new or existing production" and "absent that basic information, it is nearly impossible to assess whether there will be any additional production activities in connection with the gas to be transported on the Project."[344] In addition, FERC maintains that, "even accepting, arguendo, that a specific pipeline project will cause natural gas production, we have

because "FERC provided an estimate of the upper bound of emissions resulting from end-use combustion." Thus, the court upheld FERC's analysis without really confronting whether FERC's conclusions about perfect substitution were reasonable or supported by the record. *See* Appalachian Voices v. FERC, No. 17-1271, 2019 WL 847199 (D.C. Cir. Feb. 19, 2019).

342 Several of these lawsuits challenge unsubstantiated assumptions from FERC about the effect of pipeline authorizations on fossil fuel production and consumption, including assumptions that pipeline development does not induce upstream natural gas production (or downstream consumption) and assumptions that pipeline development may actually reduce emissions by offsetting the use of higher carbon emitting fuels such as coal and fuel oil. *See, e.g.*, Del. Riverkeeper Network v. FERC, No. 18-1128 (D.C. Cir. May 8, 2018); Allegheny Def. Project v. FERC, No. 17-1098 (D.C. Cir. Mar. 23, 2017); Catskill Mountainkeeper, Inc. v. FERC, No. 16-345 (2d Cir. Feb. 5, 2016). A lawsuit has also been filed against the U.S. Army Corps of Engineers (USACE) for authorizing activities required for the construction of an oil pipeline without conducting a NEPA analysis to evaluate, among other things, "the climate impacts of 'locking in' future reliance on fossil fuels with a massive infrastructure investment." Complaint at 23, Atchafalaya Basinkeeper v. U.S. Army Corps of Eng'rs, 715 Fed. Appx. 399 (5th Cir. 2018) (No. 18-30257). There are also numerous administrative challenges involving FERC's failure to quantify/disclose. *See* Dominion Transmission, Inc., 163 FERC ¶ 61,128 (2018); Atl. Coast Pipeline, LLC, 161 FERC ¶ 61,042 (2017); Algonquin Gas Transmission, 161 FERC ¶ 61,255 (2017).

343 Petition for Review at 72, N.J. Div. of Rate Counsel v. FERC, No. 18-1233 (3d Cir. Sept. 4, 2019).

344 Pamela King, *Climate impacts are 'virtually unknowable'—FERC*, E&E NEWS (Jan. 28, 2019), https://www.eenews.net/stories/1060118701/print [https://perma.cc/GL79-3XNZ].

found that the potential environmental impacts resulting from such production are not reasonably foreseeable."[345]

FERC's position with respect to both upstream and downstream emissions is untenable.[346] Granted, courts have not specifically accepted or rejected perfect substitution claims as applied to *upstream* emissions from natural gas transportation infrastructure,[347] and the D.C. Circuit deferred to FERC's conclusion that it lacked the information necessary to determine whether an increase in natural gas transportation capacity would cause an increase in natural gas production in *Birckhead v. FERC* (which is very similar to arguments that were rejected by other courts).[348] But in that case, the D.C. Circuit also stated that FERC was "wrong to suggest that downstream emissions are not reasonably foreseeable simply because the gas transported by the Project may displace existing natural gas supplies or higher-emitter fuels" and described this position as a "total non-sequitur."[349] The same finding should apply to upstream emissions.

For reasons discussed in Parts I and II, we believe that the differential treatment of upstream and downstream emissions in reviews for fossil fuel transportation projects is illogical: if the project causes an increase in consumption of a fuel, then there must be a corresponding increase in production of that fuel. Courts should therefore apply the same scrutiny to perfect substitution arguments used to justify omitting upstream emissions from the analysis.

### 2. Energy Market Analysis and GHG Emissions

In response to judicial decisions, agencies have also shown some greater reliance on energy market models to quantitatively estimate

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[345] Petition for Review at 73, *N.J. Div. of Rate Counsel*, No. 18-1233.

[346] The effect of natural gas transportation projects and consumption is reasonably foreseeable, and tools are available to estimate the effect of increasing natural gas transport capacity on fossil fuel production and consumption and the corresponding emissions. If FERC uses these tools and finds that a natural gas transportation project will have no impact on natural gas production or consumption because the gas will simply be transported via different channels, then this raises an important question about how FERC can justify a finding of public need for the pipeline project.

[347] The Ninth Circuit Court of Appeals did require consideration of upstream emissions in *Northern Plains Resource Council, Inc.* However, because petitioners argued that upstream emissions should be evaluated as cumulative rather than indirect effects, the court did not confront questions pertaining to causation and perfect substitution. N. Plains Res. Council, Inc. v. Surface Transp. Bd., 668 F.3d 1067, 1082 (9th Cir. 2011).

[348] Birckhead v. FERC, 925 F.3d 510, 515 (D.C. Cir. 2019).

[349] *Id.* at 518.

energy substitution and net emissions impacts. The highly technical nature of these energy market analyses stand in contrast to the blunt instrument of "perfect substitution" arguments and may well warrant more deference from the courts. Thus far, there have been at least three cases in which courts have issued decisions on the adequacy of such analyses,[350] as well as a number of undecided cases which will further reinforce and shape agency obligations in this context.[351]

There are several interrelated questions pertaining to the legal adequacy of agencies' energy market analyses: (i) whether the agency has made reasonable assumptions about the technical parameters used to project energy prices, demand, and consumption; (ii) whether and under what circumstances the agency has a duty to update or supplement its analysis to reflect new developments such as changes in climate policy; and (iii) whether the analysis is sufficiently tailored to the proposal under review. The latter two questions are most likely to arise where an agency has tiered its analysis to an earlier programmatic review.

Regarding the reasonableness of technical parameters, agencies must use parameters that are reasonably close to real-world conditions in their energy market models in order to generate findings that are accurate enough to support informed decision-making. Courts have only begun to define what is "reasonable" in this context with decisions addressing the adequacy of assumptions pertaining to energy substitutes and energy price and demand forecasts.

As a threshold issue, we argue that the inclusion of non–fossil fuel energy resources (particularly renewable energy) as potential energy substitutes is essential for an accurate analysis. Excluding other energy sources from the analysis is tantamount to assuming that we inhabit a world where fossil fuels are the only energy sources, and this assumption inevitably leads to underestimation of the effects of fossil fuel supply. Consider a proposal to increase natural gas supply: such a proposal would almost certainly decrease GHG emissions in a world where fossil fuels are the only energy source (as natural gas displaces higher emitting coal), but may actually increase GHG emissions in a world with other energy

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[350] Sierra Club v. U.S. Dep't of Energy, 867 F.3d 189 (D.C. Cir. 2017); High Country Conservation Advocates v. U.S. Forest Serv., 333 F. Supp. 3d 1107 (D. Colo. 2018); Indigenous Envtl. Network v. U.S. Dep't of State, 347 F. Supp. 3d 561 (D. Mont. 2018).

[351] *See* Complaint, Healthy Gulf v. Bernhardt, No. 1:19-cv-00707 (D.D.C. Mar. 13, 2019) (challenging BOEM's analysis as well); Complaint, Gulf Restoration v. Zinke, No. 1:18-cv -01674 (D.D.C. July 16, 2018) (challenging BOEM's analysis of energy market impacts from Gulf Leasing Program); *see also* challenges to FERC reviews, *supra* note 342 (pending perfect substitution cases noted above).

resources (as natural gas may displace zero-emitting renewable energy sources). There are a number of models available which account for the effects on renewables, many of which have been used by agencies in environmental reviews and regulatory impact analyses,[352] and it would therefore be arbitrary and capricious for agencies to use a model which does not account for those effects.

We recognize that this position is at odds with the only decision on the matter—specifically, the D.C. Circuit Court of Appeals' decision in *Sierra Club v. U.S. Department of Energy*.[353] That case involved DOE's obligation to evaluate and disclose indirect emissions from LNG exports.[354] DOE had relied on EIA studies projecting how LNG exports affect energy markets and also commissioned a report from the National Energy Technology Laboratory ("NETL") on the life-cycle greenhouse gas emissions of LNG exports.[355] The NETL report assessed the life-cycle emissions (production, transportation, consumption) of exported natural gas and compared these with emissions from electricity generated from coal or other sources of gas but did not consider possible substitution by alternative energy sources such as renewables.[356] The plaintiffs contended that the review was fatally flawed due to DOE's failure to account for the possibility that U.S. LNG exports would compete with renewable energy sources which are already quite prevalent in some of the regions where the LNG exports would be consumed (Europe and Asia).[357] The D.C. Circuit barely addressed this aspect of the plaintiff's argument—it merely concluded, in a cursory fashion, that it must defer to DOE's determination that adding other variables to the analysis would be too difficult and the results of the analysis would be too speculative to help inform decision-making.[358] For the reasons noted above, we believe that this is the wrong outcome.

Agencies must also use reasonable forecasts for energy prices and demand. There are two decisions that address what is "reasonable" in this context, both of which also addressed the question of whether and

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[352] *See* PETER H. HOWARD, INST. FOR POL'Y INTEGRITY, THE BUREAU OF LAND MANAGEMENT'S MODELING CHOICE FOR THE FEDERAL COAL PROGRAMMATIC REVIEW 1 (2016), https://policyintegrity.org/files/publications/BLM_Model_Choice.pdf [https://perma.cc/Q7WC-XX3T] (discussing different energy market models that could be used in programmatic analysis of federal coal leasing program).
[353] *Sierra Club v. U.S. Dep't of Energy*, 867 F.3d at 192.
[354] *Id.* at 195.
[355] *Id.* at 195–96.
[356] *Id.*
[357] *Id.* at 196.
[358] *Id.* at 202.

under what circumstances supplementation of an EIS is required to reflect new information. The NEPA regulations require supplementation if an "agency makes substantial changes in the proposed action that are relevant to environmental concerns; or there are significant new circumstances or information relevant to environmental concerns and bearing on the proposed action or its impacts."[359]

One decision dealt with the adequacy of the EIS prepared by USFS for coal lease approvals on remand from *High Country Conservation Advocates*.[360] The USFS had conducted a fairly detailed market impact analysis in which it estimated the net emissions increase from additional coal leasing as compared with a no action alternative.[361] Plaintiffs argued that the analysis was flawed because USFS failed to account for potential increases in electricity demand (and usage) in its energy market model (the model assumed fixed electricity demand regardless of how electricity prices changed).[362] The USFS had acknowledged in the EIS that an increase in total electricity production may occur as a result of lower fuel and electricity prices but explained that it believed this effect was too speculative to model because there were numerous factors other than fuel prices which affected electricity consumption (and USFS discussed these factors qualitatively).[363] The court found that USFS had adequately examined the issue of electricity demand and explained the basis for excluding this from its quantitative projections of energy consumption and corresponding emissions.[364]

Plaintiffs also alleged that USFS should have updated its analysis to account for new developments such as the repeal of the Clean Power Plan.[365] The court found that USFS did not need to supplement its analysis to reflect new developments such as the repeal of the Clean Power Plan.[366] With regards to the second point, the court noted that the agencies preparing the EIS had "disclosed and discussed numerous technological, regulatory, and other factors . . . that influence whether other fuels can be substituted for a particular type of coal" and that in light of the overall depth and scope of the analysis, the failure to supplement this

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[359] 40 C.F.R. § 1502.9(c)(1)(i)–(ii).
[360] High Country Conservation Advocates v. U.S. Forest Serv., 333 F. Supp. 3d 1107, 1131 (D. Colo. 2018).
[361] *Id.* at 1121.
[362] *Id.* at 1129–30.
[363] *Id.*
[364] *Id.* at 1130–31.
[365] *Id.* at 1131–32.
[366] *High Country Conservation Advocates*, 333 F. Supp. 3d at 1132.

analysis with new data was not a significant enough deficiency to warrant judicial intervention.[367]

The second case on technical assumptions and the duty to supplement involved the 2014 EIS for the Keystone XL Pipeline. In *Indigenous Environmental Network v. U.S. Department of State*, the Montana district court ordered the Department of State to supplement its analysis to reflect significant new information that had arisen since 2014 about oil markets, rail transportation, and GHG emissions.[368] The original market analysis, which found that the pipeline would have no impact on fossil fuel use and emissions, illustrates just how difficult it is to accurately assess energy market impacts of individual projects and how easy it is for agencies to predicate these assessments on incorrect assumptions and projections.[369] The Department of State had conditioned much of its analysis on the assumption that the price of oil would remain high—specifically, that the price would range from $100 per barrel to $140 per barrel over 20 years.[370] Shortly after the publication of the 2014 EIS, oil prices fell to nearly $38 per barrel, and EIA predicts the price of oil will remain below $100 for decades.[371] The Department itself conceded during litigation that the current price of oil is approximately $60 per barrel, well below the $100 threshold.[372] In presenting these facts, the court noted that the Environmental Protection Agency ("EPA") had even called upon the Department to revisit its conclusions about oil supply in its comments on the 2014 EIS.[373] The court concluded that this new information was significant enough and highly material to the Department's consideration of how Keystone would affect tar sands production (and consumption) and thus ordered supplementation of the 2014 EIS.[374]

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[367] The court also noted that the failure to supplement was not an actionable problem because "plaintiffs do not argue that the expected climate impacts of the lease modifications are anything other than an amount proportionate to the percentage of coal [subject to the lease]" and thus the information in the EIS was "informative of the climate impacts expected to occur under the lease modifications"—in effect, the court accepted the "literalist" approach to calculating indirect emissions here, and relied on this approach in holding that an updated energy market analysis was not required. *Id.*

[368] Indigenous Envtl. Network v. U.S. Dep't of State, 347 F. Supp. 3d 561, 575–79 (D. Mont. 2018).

[369] *See id.* (discussing problems with energy market assumptions).

[370] *Id.* at 576–77.

[371] *Id.* at 577.

[372] *Id.*

[373] *Id.*

[374] The district court enjoined further activity on Keystone pending supplementation of the EIS due to this and other deficiencies. But the Trump administration was able to circumvent this decision by (i) issuing Executive Order 13,867, which revised the permitting

At the time of this writing, there were also two pending cases where plaintiffs are alleging that EISs need supplementation due to technical problems with the energy market analysis, both of which deal with BOEM's NEPA analysis for offshore oil and gas leasing. The first, *Gulf Restoration v. Zinke*, involves a challenge to two oil and gas lease sales in the Gulf.[375] The BOEM prepared a PEIS for the Gulf leasing program and a subsequent EIS for the lease sales in which it projected the potential impacts of oil and gas leasing (incorporating certain assumptions about energy markets from the PEIS) on energy demand and consumption but also concluded that the exact same impacts would occur if it did not issue the two leases because the same activities would inevitably occur in the same manner and magnitude under an unspecified future lease sale.[376] Plaintiffs argue that the energy market projections rely on faulty assumptions—in particular, BOEM used an incorrect royalty rate (assuming royalties would be 18.75 percent instead of the new 12.5 percent rate) and also failed to account for the planned repeal of the Clean Power Plan—and as a result, its projections of oil and gas demand were arbitrarily low.[377] Second, plaintiffs argue that it was irrational for BOEM to assume that the same environmental effects would occur even if it did not hold the lease sales, and that it provided no support for its conclusion that an unspecified lease sale would be held in the future and would sell the same projected number of lease blocks as the proposed lease sale, or that the same manner and degree of impact-producing factors would result.[378] Plaintiffs note that the assumptions of identical future impacts were particularly unreasonable because the lease sales at issue in this case were of an "expansive scope" and BOEM's practice for the past four decades had been to offer smaller, discrete portions during lease sales.[379]

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process for transboundary projects and clarified that "[a]ny decision to issue, deny, or amend a permit under this section shall be made solely by the President" (this provision was aimed at avoiding a situation where the issuance of such permits was "final agency action" subject to NEPA review); and (ii) revoking the previous permit issued by the State Department for Keystone XL and replacing it with a permit issued directly by the President. Exec. Order No. 13,867, 84 Fed. Reg. 15,491 (Apr. 10, 2019). The Ninth Circuit Court of Appeals subsequently held that the litigation over the NEPA review of Keystone XL was moot due to the revocation of the State Department permit. Indigenous Envtl. Network v. U.S. Dep't of State, No. 18-36068, 2019 WL 2542756 (9th Cir. June 6, 2019).

[375] Complaint at 2, Gulf Restoration v. Zinke, No. 1:18-cv-01674 (D.D.C. July 16, 2018).

[376] *Id.* at 32.

[377] *Id.* at 30.

[378] *Id.* at 3.

[379] *Id.* at 32.

The second case, *Healthy Gulf v. Bernhardt*, involves a nearly identical challenge to another lease sale in the Gulf.[380]

As noted above, a third question is whether an agency has sufficiently tailored its energy market analysis to the project under review. This issue arose in *Sierra Club v. U.S. Department of Energy*, the case involving DOE's review of LNG exports.[381] The reports that DOE used in its analysis of life-cycle emissions from LNG exports did not consider the specific effects of the export authorization under review—rather, the analysis was generalized and applicable to all LNG exports (e.g., life-cycle greenhouse gas emissions from LNG exports were estimated per MWh of end-use generation, but there was no estimate of life-cycle emissions for the volume of the exports under review).[382]

One of the plaintiff's primary challenges to DOE's review was that it did not tailor the indirect and cumulative impacts analysis, including the greenhouse gas emission estimates, to the specific volume of exports that would be authorized under the proposal (which the Sierra Club argued should be evaluated as indirect effects of the proposal) or total amount of exports from that terminal as well as other pending and anticipated LNG export facilities (which the Sierra Club argued should be evaluated as cumulative effects).[383] The court agreed that DOE's "generalized impact assessment is not tailored to any specific level of exports," but nonetheless upheld the analysis.[384] It did not articulate a reason why DOE should not be required to estimate the greenhouse gas emissions for the specific exports under review.

The lawsuits filed to date illustrate some of the potential problems with agency energy market analyses and the need for careful scrutiny by courts to ensure that agencies are not relying on faulty assumptions, ignoring important developments, or manipulating the analysis to make the project's impacts appear less substantial. In many respects, the use of energy market models is an important and positive development—and certainly a better approach than relying on unsupported claims of perfect substitution. But focusing on the project's "net emissions" is not the only approach for evaluating upstream and downstream emissions. It would also be reasonable to treat gross downstream and upstream emissions as indirect effects of the proposal. Indeed, this is how most impacts are

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[380] Complaint at 2, Healthy Gulf v. Bernhardt, No. 1:19-cv-00707 (D.D.C. Mar. 13, 2019).
[381] Sierra Club v. U.S. Dep't of Energy, 867 F.3d 189, 192 (D.C. Cir. 2017).
[382] *Id.*
[383] *Id.* at 197.
[384] *Id.* (emphasis omitted).

evaluated under NEPA—agencies focus on the actual impacts of the proposal under review without attempting to project the possible impacts of other activities that may occur if the proposal is not implemented. For example, in NEPA reviews for proposals that involve timber harvests, agencies focus on the impacts of the harvest under review and do not project the extent to which timber would be sourced from elsewhere if the proposal were not approved and then use such projections to derive estimates of "net impacts."[385] Moreover, in NEPA reviews for fossil fuel supply projects, more local environmental impacts (e.g., air and water quality impacts) are also evaluated on gross terms.[386]

The Stockholm Environment Institute ("SEI") describes this approach of focusing on gross emissions as a "literalist" approach to emissions inventorying due to its specific focus on logic: because of a given project, a certain amount of fuel will be produced, transported, processed, and consumed, and this will generate a certain quantity of greenhouse gas emissions.[387] The "literalist" approach accounts for the greenhouse gas impact of the fuel handled by the project without considering how the project affects broader energy markets.[388] As such, it may be viewed as only a partial analysis of impacts. However, the net emissions analysis, which SEI characterizes as the "economist" approach, requires decision makers to "make assumptions about long-term economic responses that are difficult to assess"[389] and thus it is inherently speculative.

One rationale for treating GHG emissions differently than other impacts is that the effect of the emissions is the same regardless of where they are generated and thus it is possible to assess net emission impacts without more precise data about geographic location. But agencies, courts, and the public should question whether this is a strong enough rationale for making decisions based on highly uncertain findings about energy market impacts (or vague statements about possible substitution) as opposed to a straightforward inventory of gross emissions. The "net

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[385] *See, e.g.*, U.S. FOREST SERV., USDA, ENVIRONMENTAL IMPACT STATEMENT, NATIONAL FOREST SYSTEM LAND MANAGEMENT PLANNING vi (2008), https://www.fs.fed.us/emc/nfma/includes/planning_rule/eis.pdf [https://perma.cc/BE9Z-GEQK]; *Proposed RMP / Final EIS*, U.S. BUREAU LAND MGMT., DEP'T INTERIOR, https://www.blm.gov/or/plans/rmpswesternoregon/feis/ [https://perma.cc/9AFP-YAYC] (last visited Dec. 3, 2019).
[386] *See* JAYNI HEIN ET AL., INST. FOR POL'Y INTEGRITY, PIPELINE APPROVALS AND GREENHOUSE GAS EMISSIONS 31 (2019).
[387] PETER ERICKSON & MICHAEL LAZARUS, STOCKHOLM ENV'T INST., ASSESSING THE GREENHOUSE GAS EMISSIONS IMPACT OF NEW FOSSIL FUEL INFRASTRUCTURE 2–3 (2013).
[388] *Id.* at 2–3, 6.
[389] *Id.* at 6.

emissions" analysis may prove too speculative to truly help with decision-making. Granted, energy market models also have the potential to provide highly useful information to inform decision-making about fossil fuel supply proposals so long as the inputs, assumptions, and parameters are sound—particularly in the context of programmatic-level reviews. The critical question going forward is whether agencies are capable of setting reasonable parameters and making reasonable projections, particularly when conducting project-level reviews (as it becomes more difficult to model impacts at a smaller scale). It may be the case that the energy market modelling approach makes the most sense for programmatic reviews and that simply calculating the gross upstream and downstream emissions is sufficient for project-level reviews. Granted, some individual supply projects involve the production or transportation of very large quantities of fossil fuels, and the modelling approach may be warranted for those reviews as well.

As discussed above, there are ways in which agencies using energy market models can improve the accuracy and integrity of their analysis. To summarize, agencies should (i) consider all possible energy substitutes, including renewable energy at minimum (and ideally including nuclear energy and demand-side energy efficiency as well); (ii) consider multiple energy market scenarios, including scenarios consistent with 1.5 and 2°C futures; (iii) use the best available and up-to-date pricing information and projections; and (iv) be transparent about the assumptions and parameters of their analysis.

### *B. Significance of GHG Emissions*

The identification of significant impacts is an essential step in the NEPA process, critical not only to the decision to prepare an EIS but also for the purposes of informed decision-making and public disclosure and analysis of mitigation measures. Courts have begun to flesh out agency obligations with respect to significance determinations for fossil fuel supply projects. Below, we highlight four key principles from the regulations and case law (some of which overlap with themes we have already discussed): (i) agencies must account for the full scope of direct, indirect, and cumulative emissions when evaluating significance; (ii) agencies must use correct technical assumptions to estimate the magnitude of the emissions impact; (iii) agencies must apply the regulatory criteria for evaluating context and intensity; and (iv) agencies must conduct a balanced assessment of costs and benefits.

Notably, the decisions issued to date and the undecided cases all deal with the reasonableness of assumptions and analyses underlying significance determinations; there are no lawsuits directly challenging findings of insignificance on the grounds that the total magnitude of the emissions impact is too large to be viewed as insignificant. Such a challenge may prove difficult, as significance is a highly subjective concept and courts are deferential to agency conclusions on such matters.[390] That being said, while it is true that significance is subjective and it is difficult to draw a clear line between the level of GHG emissions that is and is not significant, there are also instances where the direct and indirect GHGs from a proposal clearly pass any reasonable threshold of significance, and in such contexts, courts should intervene.[391]

### 1. Agencies Must Take a "Hard Look" at the Full Scope of GHG Emissions

Section 1502.16 of the CEQ regulations requires agencies to discuss the significance of both direct and indirect effects, and section 1508.27, which outlines the criteria for assessing significance, makes it clear that cumulative impacts are also relevant to the significance determination.[392] Part II clarifies the potential scope of GHG emissions that must be accounted for in NEPA reviews for fossil fuel supply projects (and quantified where possible). These include direct, indirect, and cumulative emissions, as well as emissions from related actions, which may include connected, cumulative, and/or similar actions. There are a number of cases in which courts have remanded significance determinations—typically FONSIs—on the grounds that the agencies failed to quantify indirect or cumulative emissions.[393]

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[390] "A court's role in reviewing an agency's decision not to prepare an EIS is a limited one, designed primarily to ensure that no arguably significant consequences have been ignored." Mayo v. Reynolds, 875 F.3d 11, 15, 19–21 (D.C. Cir. 2017) (internal quotations omitted).
[391] *See, e.g.*, MONT. DEP'T OF ENVTL. QUALITY, OFF. OF SURFACE MINING, WESTERN ENERGY AREA F: FINAL ENVIRONMENTAL IMPACT STATEMENT 473–91 (2018) (the agency estimated that coal mining proposal would generate 235,355,989 tons of $CO_2e$ over the lifetime of the project but did not reach a conclusion as to whether this was a significant impact).
[392] 40 C.F.R. § 1508.27.
[393] *See, e.g.*, Sierra Club v. FERC, 867 F.3d 1357, 1375 (D.C. Cir. 2017) (remanding to FERC to evaluate significance of indirect emissions); WildEarth Guardians v. Zinke, 368 F. Supp. 3d 41, 83, 85 (D.D.C. 2019) (finding inadequate support for EA/FONSI); WildEarth Guardians v. Zinke, No. 1:17-cv-0080, 2019 WL 2404860, at *12 (D. Mont. Feb. 11, 2019); San Juan Citizens All. v. U.S. Bureau of Land Mgmt., 326 F. Supp. 3d 1227, 1249 (D.N.M. 2018) (finding inadequate support for EA/FONSI); Mont. Envtl. Info. Ctr. v. U.S. Off. of Surface Mining, No. CV 15-106-M-DWM, 2017 WL 5047901 at *6 (D. Mont. Nov. 3, 2017).

For example, in *San Juan Citizens Alliance v. Bureau of Land Management,* the New Mexico district court found that BLM's FONSI for oil and gas leasing was fatally flawed because BLM had failed to account for both indirect and cumulative emissions.[394] The court specifically emphasized BLM's duty to analyze significance in the context of cumulative effects, pursuant to 40 C.F.R. section 1508.7:

> It is the broader, significant "cumulative impact" which must be considered by an agency, but which was not considered in this case. Without further explanation, the facile conclusion that this particular impact is minor and therefore "would not produce climate change impacts that differ from the No Action Alternative," is insufficient to comply with Section 1508.7.[395]

In at least three other cases involving fossil fuel production, reviewing courts have remanded EAs and FONSIs because the agency did not quantify indirect emissions (and in some cases also cumulative emissions) and therefore failed to take a hard look at the severity of the emissions.[396]

The D.C. Circuit Court of Appeals also addressed FERC's obligations to discuss the significance of indirect and cumulative emissions in *Sierra Club v. FERC,* which involved FERC's failure to account for downstream emissions from a natural gas pipeline project.[397] There, the court held that FERC must amend its EIS to include not only a quantified inventory of indirect emissions but also "a discussion of the 'significance' of this indirect effect . . . as well as 'the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions.'"[398] The court noted that quantification would be essential to the evaluation of significance but did not otherwise specify what the significance analysis should include.[399]

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394 *San Juan Citizens All.*, 326 F. Supp. 3d at 1244.
395 *Id.* at 1248.
396 *WildEarth Guardians*, 368 F. Supp. 3d at 59, 85; *WildEarth Guardians*, 2019 WL 2404860, at *7; *Mont. Envtl. Info. Ctr.*, 2017 WL 5047901, at *6.
397 *Sierra Club v. FERC*, 867 F.3d at 1374.
398 *Id.*
399 *Id.* The court also noted that Sierra Club had "asked FERC to convert emissions estimates to concrete harms by way of the Social Cost of Carbon" in its rehearing request, but did not issue a ruling on whether such disclosure was required (as neither party explicitly raised this in their briefs). *Id.* at 1375. Rather, the court directed FERC to explain its position on using the Social Cost of Carbon in the amended EIS. *Id.*

The analysis prepared by FERC on remand from this case is illustrative of how agencies can avoid significance determinations and why further judicial intervention may be needed to ensure meaningful analysis of the significance of indirect and cumulative emissions under NEPA. FERC estimated that the combustion of natural gas from the pipeline would generate 8.36 million tons per year of $CO_2$ emissions, which is roughly equal to the emissions from (i) approximately 1.8 million passenger vehicles driven each year or (ii) approximately 1.25 million homes' electricity use for one year.[400] Nonetheless, FERC quickly dismissed the significance of the emissions on the grounds that it lacked a threshold for assigning significance to GHG emissions, and it further noted that the indirect GHG calculations did not alter its assessment of the project because:

> [T]he No Action Alternative would not result in predictable actions if the SMP Project were not built. For example, the project's shippers may seek to transport the same volumes of natural gas by expanding existing transportation systems or constructing new facilities. Because the No Action Alternative could result in lesser, equal, or greater GHG emissions than the SMP Project, we cannot use the quantified downstream GHG emissions from the SMP Project to meaningfully compare the two.[401]

FERC also declined to estimate the social cost of the emissions.[402] The supplemental analysis and significance determination (or lack thereof) has not been challenged in court, but we note that this analysis is very similar to arguments about possible perfect substitution that have been rejected in the context of production proposals.

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400 *Greenhouse Gas Equivalencies Calculator*, EPA, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator [https://perma.cc/VX3S-N72Z] (last updated Oct. 15, 2018).

401 FERC, SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT 9 (2018), https://www.ferc.gov/industries/gas/enviro/eis/2018/02-05-18-FEIS/02-05-18-FEIS.pdf [https://perma.cc/76G4-HHG4].

402 According to estimates set forth in our comments on the DSEIS, the social costs would be roughly $306 million during the first year of operation and would rise to approximately $492 million per year by 2040. COLUM. SABIN CTR. FOR CLIMATE CHANGE L., COMMENT LETTER ON DRAFT SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT (Nov. 17, 2017), http://columbiaclimatelaw.com/files/2016/05/Sabin_Center_Comments_Southeast_DSEIS.pdf [https://perma.cc/4YCS-46A4].

### 2. Agencies Must Use Sound Technical Assumptions When Measuring the Severity of the Emissions Impact

If the technical assumptions underlying an agency's emission estimates are unreasonable, this would render any significance determination predicated on that analysis arbitrary and capricious. Above, we discuss the legal adequacy of assumptions pertaining to energy substitution and net emissions, as that has been the focus of many lawsuits in recent years. But there are other types of technical assumptions that are also critical to accurate emissions quantification. Here, we focus on two examples which have been the subject of litigation: assumptions about the global warming potential ("GWP") of non-$CO_2$ emissions (which are relevant when converting those emissions to $CO_2$ equivalent ("$CO_2e$")),[403] and assumptions about the amount of methane emissions generated from natural gas wells and pipeline infrastructure.

Agencies frequently rely on estimates of $CO_2e$ to aggregate all types of GHGs, and using the right GWP is necessary in order to accurately estimate $CO_2e$ for non-$CO_2$ emissions. Three lawsuits have been filed against BLM for using an arbitrarily low GWP value to estimate the effects of methane in terms of $CO_2e$. Specifically, plaintiffs have alleged that (i) BLM relied on an outdated 100-year GWP of 21, instead of the IPCC's current 100-year GWP of 36; and (ii) BLM should have calculated methane emissions using the twenty-year GWP of 87, as this more closely corresponded with the anticipated project duration.[404] The consequence of choosing a lower GWP is dramatic: one complaint alleges that BLM underestimated the global warming effect of methane by a factor of four.[405] In *Western Organization of Resource Councils v. Bureau of Land Management*, the Montana district court held that BLM's "unexplained decision to use the 100-year time horizon, when other more appropriate time horizon remained available, qualifies as arbitrary and capricious."[406] There, the

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[403] The GWP is a measure of how much heat a GHG traps in the atmosphere over a specific amount of time (e.g., 100 years), as compared to $CO_2$. *Understanding Global Warming Potentials*, EPA, https://www.epa.gov/ghgemissions/understanding-global-warming-potentials [https://perma.cc/9GY3-KWM2] (last updated Feb. 14, 2017).

[404] Petition for Review at 24, Wilderness Workshop v. U.S. Bureau of Land Mgmt., 342 F. Supp. 3d 1145 (D. Colo. 2018) (No. 1:16-cv-01822); Complaint at 35, Wilderness Workshop v. U.S. Bureau of Land Mgmt., No. 1:18-cv-00987 (D. Colo. Apr. 26, 2018); Amended Complaint at 41, W. Org. of Res. Councils v. U.S. Bureau of Land Mgmt., No. 4:16-cv-00021-BMM, 2018 WL 1475470 (D. Mont. Mar. 26, 2018).

[405] Petition for Review at 24, *Wilderness Workshop*, 342 F. Supp. 3d 1145 (No. 1:16-cv-01822-WYD).

[406] *W. Org. of Res. Councils*, 2018 WL 1475470, at *15.

court noted that BLM had used the twenty-year GWP in other NEPA documentation, which demonstrated that BLM was aware of the evolving nature of the science regarding methane emissions estimation, and BLM had failed to provide a satisfactory explanation for using the 100-year GWP.[407] In contrast, in *Wilderness Workshop v. Bureau of Land Management*, the Colorado district court upheld BLM's use of a 100-year GWP of 21 where the court felt that BLM had adequately explained its basis for doing so.[408] The third case has not yet been decided.[409]

Agencies should also use the best available data to estimate methane emissions from oil and gas infrastructure. There has not been much litigation about this issue to date, but there is a growing body of research suggesting that the federal government has dramatically underestimated methane emissions from oil and gas infrastructure which may give rise to future lawsuits.[410] There is one case which addresses the adequacy of agency methane calculations. In *Wilderness Workshop*, plaintiffs also alleged that BLM made improper assumptions about the magnitude of methane emissions—specifically, that BLM used modeling data to estimate methane emissions that came solely from survey responses of oil and gas operators without confirming those answers, that the data was not based on current or historic emission rates but on forecast emissions in 2028, and that BLM improperly adjusted the emission rates on a faulty assumption about the implementation of control technologies on oil and gas sources.[411] The plaintiffs offered alternative calculations of methane emissions.[412]

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[407] *Id.*
[408] *Wilderness Workshop*, 342 F. Supp. 3d at 1161.
[409] Wilderness Workshop v. U.S. Bureau of Land Mgmt., No. 1:18-cv-00987 (D. Colo. Apr. 26, 2018).
[410] Ramón Alvarez et al., *Assessment of Methane Emissions from the U.S. Oil and Gas Supply Chain*, 361 SCI. 186, 186 (2018), https://science.sciencemag.org/content/361/6398/186 [https://perma.cc/M3QB-34NY]; Megan Geuss, *Study: US oil and gas methane emissions have been dramatically underestimated*, ARS TECHNICA (June 22, 2018), https://arstechnica.com/science/2018/06/study-us-oil-and-gasmethane-emissions-have-been-dramatically-underestimated/ [https://perma.cc/X54J-VPTD]; Ken Paulman, *Study finds EPA vastly underestimating methane emissions*, ENERGY NEWS NETWORK (June 22, 2018), https://energynews.us/digests/study-finds-epa-vastly-underestimating-methane-emissions/ [https://perma.cc/FDT9-2L62]; Bob Weber, *New study suggests oils and greenhouse gas emissions underestimated*, CANADIAN PRESS (Apr. 23, 2019), https://www.citynews1130.com/2019/04/23/new-study-suggests-oilsands-greenhouse-gas-emissions-underestimated/ [https://perma.cc/KBD5-RSL2]; *Major studies reveal 60% more methane emissions*, ENVTL. DEF. FUND, https://www.edf.org/climate/methane-studies [https://perma.cc/XS3F-3QTA] (last visited Dec. 3, 2019).
[411] *Wilderness Workshop*, 342 F. Supp. 3d at 1160–62.
[412] *Id.* at 1161.

However, the court held that the plaintiffs had not adequately supported their own calculations and that this left the court "with no reliable way to sufficiently judge Plaintiff's analysis on the issue" and, in addition, that plaintiffs had not persuasively explained how the use of industry data or assumptions underpinning BLM's analysis resulted in incorrect methane calculations.[413] It thus held that it must defer to BLM's calculations of methane emissions.[414]

### 3. Significance Must Be Assessed in Light of Regulatory Criteria

The NEPA regulations direct agencies to consider both context and intensity when assessing significance as well as a number of more specific factors relevant to gauging the intensity of the impact.[415] These include, *inter alia*, "[t]he degree to which the proposed action affects public health or safety"; "[t]he degree to which the effects on the quality of the human environment are likely to be highly controversial"; "[t]he degree to which the possible effects on the human environment are highly uncertain or involve unique or unknown risks"; "[t]he degree to which the action may establish a precedent for future actions with significant effects or represents a decision in principle about a future consideration"; and "[w]hether the action is related to other actions with individually insignificant but cumulatively significant impacts."[416] With regards to cumulative impacts, section 1508.27 notes that "[s]ignificance exists if it is reasonable to anticipate a cumulatively significant impact on the environment" and that "[s]ignificance cannot be avoided by terming an action temporary or by breaking it down into small component parts."[417]

The context for federal approvals of fossil fuel supply projects can be framed as follows: climate change is causing and will cause harm to public health and welfare, on scales ranging from the global to the highly local, and to address this problem the United States must rapidly reduce its dependency on fossil fuels. Where fossil fuel production takes place on private lands, the government's ability to address climate impacts is limited. But where the federal government has authority over production on public lands and transportation projects that require federal approval, the government has the opportunity to consider the potential GHG emissions and act on this information. With this in mind, agencies should look at

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[413] *Id.* at 1162.
[414] *Id.*
[415] 40 C.F.R. § 1508.27.
[416] *Id.*
[417] *Id.*

the proposal's impact on fossil fuel consumption and emissions in the context of global, national, regional, or state carbon budgets (or emission reduction targets) with an eye towards understanding whether the proposal can be implemented without undermining progress towards decarbonization. Granted, NEPA does not require an agency to avoid all significant impacts—and thus an agency may proceed with a fossil fuel supply proposal even if it is inconsistent with decarbonization or emission reduction goals—but this sort of analysis is needed in order for decision makers to make informed decisions about how to proceed with fossil fuel–related proposals when decarbonization is a critical social goal.

Agencies must also consider "intensity"—that is, the "severity of the impact."[418] There are several ways that agencies can assess the severity of the emissions impact. One option is to provide a qualitative description of climate change impacts and use the estimated GHG emissions as a proxy for the "severity" of the project's contribution to those impacts. This approach was endorsed in the rescinded CEQ guidance.[419] The one key limitation to this approach is that $CO_2e$ estimates do not, in of themselves, provide a clear picture of the potential magnitude of the impact on humans and ecosystems—and when the estimates are compared to global, national, or state emission totals, they inevitably appear relatively small.

Other tools are available to better understand the magnitude of the emissions impact. These include (i) the Social Cost of Carbon (SC-$CO_2$), Methane (SC-$CH_4$), and Nitrous Oxide (SC-$N_2O$) metrics that were developed through a federal interagency consultation process and approved by the courts, which can be used to assign a dollar value to the potential impacts of these emissions;[420] (ii) the EPA's quantification threshold

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[418] 40 C.F.R. § 1508.27(b).

[419] CEQ, Final Guidance Memo, *supra* note 49, at 4. Such a qualitative description of climate change impacts can also help to satisfy the requirement to look at "cumulative impacts" of the proposal combined with other foreseeable actions.

[420] The Social Cost of Carbon, Methane, and Nitrous Oxide, despite being officially "rescinded" by President Trump, are scientifically credible estimates of the societal costs of greenhouse gas emissions, developed through a lengthy process of interagency consultation and peer review, and that cost is absolutely relevant to assessing the nature and significance of the proposed program's environmental consequences. *See* Zero Zone Inc. v. U.S. Dep't of Energy, 832 F.3d 654 (7th Cir. 2016) (upholding use of methodology for calculating social cost of carbon used by the Interagency Working Group on the Social Cost of Carbon); INTERAGENCY WORKING GRP. ON THE SOCIAL COST OF GREENHOUSE GASES, TECHNICAL SUPPORT DOCUMENT: TECHNICAL UPDATE OF THE SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866 2 (May 2013, revised Aug. 2016); INTERAGENCY WORKING GRP. ON THE SOCIAL COST OF GREENHOUSE GASES, ADDENDUM TO TECHNICAL SUPPORT DOCUMENT ON SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866: APPLICATION OF THE METHODOLOGY TO ESTIMATE THE

of 25,000 tons per year of $CO_2e$ to identify major emitters for the purposes of GHG reporting (as noted by EPA, facilities that surpass this threshold are considered the "largest emitters" in the country);[421] (iii) the EPA's GHG Equivalencies Calculator, which can be used to compare emissions from the proposal with, for example, emissions from household electricity use or vehicle miles driven;[422] and (iv) evaluating the proposal and its emissions in the context of global, national, and (where applicable) state carbon budgets. As climate change attribution science progresses, it may also become possible to link the emissions from a particular proposal to specific impacts (e.g., a certain amount of sea level rise) based on the proportional contribution to global emissions.[423] Such an assessment may already be feasible in the context of a very large action, such as a programmatic review of federal coal leasing, as scientists are already linking very large emission sources to specific impacts, but would prove challenging for more discrete proposals with smaller emissions impacts.[424]

The intensity criteria set forth in section 1508.27 should also be used in this analysis. Many of these factors weigh in favor of a significance finding for GHG emissions from fossil fuel supply projects. For example, one could argue that the effect of these projects—particularly the effects on fossil fuel consumption and GHG emissions—are "highly controversial" because there are substantial disputes about the accuracy of agency assessments and the actual magnitude of the emissions impacts from these proposals. It could also be argued that these effects are "highly uncertain" and "involve unique or unknown risks" due to the level of uncertainty discussed in NEPA documentation as well as broader uncertainty about the potential magnitude and impact of climate change. The approval of fossil fuel extraction and transportation projects (and corresponding NEPA analysis) can also "establish a precedent for future actions with significant effects" and "represents a decision in principle about a future

SOCIAL COST OF METHANE AND THE SOCIAL COST OF NITROUS OXIDE 2–3 (Aug. 2016). *See also* Mont. Envtl. Info. Ctr. v. U.S. Off. of Surface Mining, 274 F. Supp. 3d 1074, 1094–95 (D. Mont. 2017) (requiring disclosure of GHG costs in NEPA review where benefits were also disclosed, and citing the federal Social Cost of Carbon as an available disclosure tool); High Country Conservation Advocates v. U.S. Forest Serv., 52 F. Supp. 3d 1174, 1178, 1187 (D. Colo. 2014) (also requiring disclosure of GHG costs in NEPA reviews where benefits were disclosed).

421 *Greenhouse Gas Reporting Program (GHGRP)*, EPA, https://www.epa.gov/ghgreporting/key-facts-and-figures [https://perma.cc/ESK5-KP33] (last updated Oct. 1, 2019).

422 *Greenhouse Gas Equivalencies Calculator*, *supra* note 400.

423 *See* Michael Burger, Radley Horton & Jessica Wentz, *The Law and Science of Climate Change Attribution*, 45 COLUM. J. ENVTL. L. (forthcoming Jan. 2020) (manuscript at 53–62).

424 *Id.* at 53.

consideration"—specifically, whether the United States should adopt supply-side constraints on fossil fuels to address climate change and whether the infrastructure will result in fossil fuel "lock in." And finally, there can be no doubt that each of these approvals is "related to other actions with individually insignificant but cumulatively significant impacts"—that is, the approval of other fossil fuel leases, RMPs, and transportation infrastructure—all of which contributes to the ongoing supply of and reliance on fossil fuels. As noted in section 1508.27, this last factor is dispositive: "Significance exists if it is reasonable to anticipate a cumulatively significant impact on the environment."

As discussed in Part I, agencies often fail to assess the significance of GHG emissions in light of the regulatory factors, and this has resulted in a number of lawsuits.[425] One decision from the D.C. Circuit district court contained a particularly detailed assessment of the regulatory requirements.[426] The critical question was whether BLM had adequately justified FONSIs that it issued for five oil and gas lease sales covering a total of 282 leases on 303,000 acres of federal lands in Wyoming.[427] The court explained that the key considerations are whether the agency:

> (1) has accurately identified the relevant environmental concern, (2) has taken a hard look at the problem in preparing its [FONSI or Environmental Assessment], (3) is able to make a convincing case for its finding of no significant impact, and (4) has shown that even if there is an impact of true significance, an EIS is unnecessary because changes or safeguards in the project sufficiently reduce the impact to a minimum.[428]

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[425] Sierra Club v. FERC, 867 F.3d 1357, 1375 (D.C. Cir. 2017) (remanding to FERC to evaluate significance of indirect emissions); WildEarth Guardians v. Zinke, 368 F. Supp. 3d 41, 76 (D.D.C. 2019) (finding inadequate support for EA/FONSI); San Juan Citizens All. v. U.S. Bureau of Land Mgmt., 326 F. Supp. 3d 1227, 1247 (D.N.M. 2018) (finding inadequate support for EA/FONSI). *See also* Atchafalaya Basinkeeper v. U.S. Army Corps of Eng'rs, 894 F.3d 692, 697–98 (5th Cir. 2018) (alleging that USACE "failed to assess the climate impacts of 'locking in' future reliance on fossil fuels with a massive infrastructure investment"); Complaint at 27, WildEarth Guardians v. U.S. Bureau of Land Mgmt., No. 4:18-cv-00073 (D. Mont. May 15, 2018) (alleging that agency failed to disclose social costs, and failed to evaluate context and intensity); Complaint at 2, 36, Wilderness Workshop v. U.S. Bureau of Land Mgmt., No. 1:18-cv-00987 (D. Colo. Apr. 26, 2018) (alleging that the agency failed to prepare EA or EIS for proposal and thus failed to evaluate significance of emissions in light of regulatory criteria).

[426] *WildEarth Guardians*, 368 F. Supp. 3d at 63–64, 66–67, 69–71.

[427] *Id.* at 55.

[428] *Id.* at 80.

Applying these factors, the court held that BLM could not support its FONSI because it had failed to take a hard look at all indirect and cumulative emissions.[429] However, the court also looked at two other significance factors—whether the action is highly controversial and whether it involves highly uncertain or unique or unknown risks—and found that these factors, standing alone, would not compel preparation of an EIS.[430]

With regards to controversy, the court said it could not conclude that the effects of leasing are highly controversial because controversy in the NEPA context "is not measured merely by the intensity of opposition" but whether there is "a substantial dispute . . . as to the size, nature, or effect of the major federal action" or "scientific or other evidence that reveals flaws in the methods or data relied upon by the agency in reaching its conclusions."[431] If there is opposition from other agencies with "special expertise" or stakes in the decision, this would also support a finding of controversy.[432] Regarding the EA at issue, the court noted that, although plaintiffs had shown that BLM's impact assessment was inadequate, they had not yet showed that there was a significant dispute as to the magnitude of the impact or the methods and data used in the analysis.[433] However, the court recognized that BLM's analysis on remand would "more fully illustrate" its position on the magnitude of the emissions impact.[434] Thus, having a more complete assessment which includes BLM's assessment of the significance of indirect and cumulative emissions may make it easier for plaintiffs to demonstrate controversy, particularly if BLM relies on questionable assumptions about market impacts to discount the significance of the emissions impacts.

With regards to whether the effects were highly uncertain, the court explained that this factor is implicated when an action involves new science or when an action's impact is unknown.[435] However, the court held that uncertainty about the magnitude of the emissions impact in this case was not enough to trigger the type of "uncertainty" contemplated by the regulations because all parties agree that GHGs contribute to climate

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[429] The court emphasized that the potential for cumulative effects was a key consideration in the significance analysis and found that BLM had failed to adequately assess those cumulative effects, pursuant to the criteria set forth in the CEQ regulations. *Id.* at 77.
[430] *Id.* at 80.
[431] *Id.* at 81 (internal citations omitted).
[432] *WildEarth Guardians*, 368 F. Supp. 3d at 82.
[433] *Id.* at 63, 74.
[434] *Id.* at 82.
[435] *Id.*

change and the impacts of climate change are known as a general manner.[436] Thus, the court held that this factor is only triggered where there is uncertainty about the *nature* of the impacts, not the severity.

Some litigants have also challenged agency significance assessments for failure to use some of the tools described above for better understanding the severity and context of emissions impacts. For example, some litigants have argued that agencies should disclose the social cost of emissions as this is an easier metric for decision makers and the public to understand than tonnage of $CO_2e$.[437] But under the Trump administration, agencies have consistently refused to disclose the social cost of GHG emissions.[438] The primary rationales for not disclosing social costs are (i) the metrics were developed for a rule-making context; (ii) NEPA does not require a cost-benefit analysis or monetization of costs; (iii) the metrics do not accurately reflect the incremental emissions impact of the proposal (because there is significant uncertainty about the actual cost of emissions and the social cost metrics do not capture all costs); and (iv) the metrics are not useful to decision makers because they are presented as a range of possible values and there is no criteria or thresholds against which to gauge the significance of those values.[439]

As discussed below, courts have only required use of the social cost metrics where agencies have also disclosed economic benefits,[440] but outside of that context, courts have deferred to agency rationales for not disclosing social costs without evaluating the merits of these arguments.[441] This is unfortunate, as there is good reason to be critical of these rationales.

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[436] *Id.* at 79.

[437] Although these metrics do not provide a way of disaggregating emissions impacts into specific identifiable impacts, they do provide a useful tool for conceptualizing the overall costs to society of the emissions associated with a proposal. FRANK ACKERMAN & ELIZABETH A. STANTON, CLIMATE CHANGE & GLOBAL EQUITY, CLIMATE RISKS & CARBON PRICES: REVISING THE SOCIAL COST OF CARBON 151–86 (2014).

[438] *See* Jessica Wentz, *New Draft Guidance on Climate Change and NEPA Reviews Unlikely to Significantly Affect Agency Practice or Judicial Interpretation of NEPA Obligations*, SABIN CTR. FOR CLIMATE CHANGE LAW, COLUM. L. SCH. (June 24, 2019), http://blogs.law.columbia.edu/climatechange/2019/06/24/new-draft-guidance-on-climate-change-and-nepa-reviews-unlikely-to-significantly-affect-agency-practice-or-judicial-interpretation-of-nepa-obligations/ [https://perma.cc/35HP-JTLY].

[439] *See, e.g.*, U.S. BUREAU OF LAND MGMT., DEP'T OF THE INTERIOR, COASTAL PLAIN OIL AND GAS LEASING PROGRAM DRAFT ENVIRONMENTAL IMPACT STATEMENT VOLUME II: APPENDICES F-2–F-4 (Dec. 2018).

[440] *See infra* Section III.B.4.

[441] *See, e.g.*, EarthReports, Inc. v. FERC, 828 F.3d 949, 956 (D.C. Cir. 2016); Appalachian Voices v. FERC, No. 17-1271, 2019 WL 847199, at *2 (D.D.C. Feb. 19, 2019).

With regards to the first argument, the metrics may have been developed for a rule-making context, but they can readily be used in an environmental analysis to better understand the potential costs associated with greenhouse gas emissions—and those cost estimates are a useful proxy for the actual impacts of climate change. The fact that the metrics were developed for rule-making is irrelevant to the question of whether they would be useful in NEPA analyses.

With regards to the second argument, while it is true that NEPA does not require cost-benefit analysis, the disclosure of social costs is nonetheless useful to decision makers and the public and a relatively easy exercise (as it simply entails multiplying emissions by social cost metrics). Agencies also frequently monetize benefits and should monetize costs for a fair and balanced assessment, even where the EIS does not contain a complete cost-benefit analysis.

With regards to the third argument (that the social cost metrics do not measure the actual incremental impacts of a project on the environment and do not include all damages or benefits from carbon emissions), this statement is partially incorrect. The SC-$CO_2$, SC-$CH_4$, and SC-$N_2O$ measure the actual incremental impacts of a project on the physical and human environment by specifying the incremental costs associated with an incremental increase in GHG emissions. These impacts are expressed as monetary costs rather than specific physical impacts because this is a reasonable and comprehensible way to aggregate many different impacts in a single metric. While it is true that the metrics do not capture all costs associated with GHG emissions, they at least capture a portion of those costs (and the agency can disclose the costs that are not covered).

With regards to the fourth argument (that the metrics are unhelpful because estimates are presented as a range of possible values and there is no threshold for significance), the fact that the estimates are presented as a range of values is actually beneficial, as it addresses uncertainty, and such ranges can be used to define the bounds of possible foreseeable outcomes. This sort of forecasting is common under NEPA. And although it is true that there is no significance threshold defined for GHGs or social costs, this is true for many different types of impacts that are evaluated in NEPA reviews—there are no bright line rules for assessing significance, and agencies typically must use their discretion to determine when impacts pass the threshold of significance. The monetization of climate change impacts, however, is useful in informing significance determinations insofar as it provides a standard metric for comparing different impacts.

The other main disclosure tool that agencies can and should use to evaluate the significance of emissions impacts is a carbon budget.

Estimates have been developed for both the global and national carbon budget, and some states have developed their own carbon budgets as well.[442] At least three of the lawsuits brought to date have also involved allegations that agencies should have examined emissions in light of a carbon budget.[443] The case law on this matter is less well-developed than the case law on social cost metrics. In one decision on this issue, *Western Organization of Resource Councils v. Bureau of Land Management*, the Montana district court held that BLM was not required to use a "global carbon budget" as the standard by which to measure emissions impacts because "Plaintiffs identify no case, and the Court has discovered none, that supports the assertion that NEPA requires the agency to use a global carbon budget analysis."[444] The D.C. district court in *WildEarth Guardians v. Zinke* also deferred to BLM's decision not to use the global carbon budget to evaluate the severity of the emissions, again citing the lack of any precedent requiring such an analysis in the NEPA context.[445] The third case has not yet been decided.[446]

It is unsurprising that courts are reluctant to require the use of a particular analytic tool, but this is one context in which judicial intervention may make sense. Courts in other countries have begun to enforce national emission reduction obligations based on carbon budgets,[447] and this is arguably the best way to understand the context and intensity (and thus significance) of both project- and program-level impacts. There is also a provision in the NEPA regulations which requires agencies to "discuss any inconsistency of a proposed action with any approved State or local plan and laws" which could be interpreted as requiring a disclosure of consistency with state and local carbon budgets or GHG reduction targets, particularly in states that have adopted policies to this effect.[448]

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[442] *See, e.g.*, Daniel J. Hayes & Rodrigo Vargas, *The North American Carbon Budget*, *in* SECOND STATE OF THE CARBON CYCLE REPORT: A SUSTAINED ASSESSMENT REPORT 71 (Cavallaro et al. eds., 2018); Corinne Le Quéré et al., *Global Carbon Budget 2018*, 10 EARTH SYS. SCI. DATA 2141 (2018).
[443] *See* WildEarth Guardians v. Zinke, 368 F. Supp. 3d 41 (D.D.C. 2019); Wilderness Workshop v. U.S. Bureau of Land Mgmt., No. 1:18-cv-00987 (D. Colo. Apr. 26, 2018); W. Org. of Res. Councils v. U.S. Bureau of Land Mgmt., No. 4:16-cv-00021-BMM, 2018 WL 1475470, at *1 (D. Mont. Mar. 26, 2018), *appeal dismissed*, No. 18-35836, 2019 WL 141346 (9th Cir. Jan. 2, 2019).
[444] *W. Org. of Res. Councils*, 2018 WL 1475470, at *13–14.
[445] *WildEarth Guardians*, 368 F. Supp. 3d at 79.
[446] *Wilderness Workshop*, No. 1:18-cv-00987 (D. Colo. Apr. 26, 2018).
[447] *See, e.g.*, Laura Schuijers, *Climate Change in Court*, PURSUIT (Mar. 3, 2019), https://pursuit.unimelb.edu.au/articles/climate-change-in-court [https://perma.cc/3MTB-3DCP].
[448] 40 C.F.R. § 1506.2(d) (2019).

This provision should be interpreted as requiring agencies to consider the consistency of fossil fuel supply projects not only with state policies in the state(s) where the project is located but also with any U.S. states with GHG reduction targets or carbon budgets. It should also be interpreted as requiring consideration of consistency with global and national carbon budgets, since exceedance of those budgets would undermine state efforts to reduce emissions and adapt to climate change.

4. Agencies Must Conduct Balanced Assessments of Costs and Benefits

Where an agency monetizes the benefits of the proposal, it must also monetize the costs of the proposal, including the costs of GHG emissions. This principle was first articulated by the Ninth Circuit Court of Appeals over a decade ago in *Center for Biological Diversity v. National Highway Traffic Safety Administration*, which held that it was arbitrary and capricious for an agency to ignore the impacts of GHG emissions in a regulatory impact analysis, even when there is uncertainty about those impacts: "[W]hile the record shows there is a range of values, the value of carbon emissions reduction is certainly not zero."[449] Applying this principle, the Colorado district court in *High Country Conservation Advocates v. U.S. Forest Service* held that USFS must monetize climate impacts from coal leasing where it had monetized economic benefits and directed USFS to use the social cost of carbon protocol in its cost-benefit assessment.[450] However, the application of this rule is not as straightforward as it may seem. Since *High Country*, there have been at least six decisions involving claims about agency failures to use the social cost of carbon in NEPA documents where benefits were monetized, all of which involved fossil fuel leasing proposals.[451] The decisions reveal that there is room for

[449] Ctr. for Biological Diversity v. NHTSA, 538 F.3d 1172, 1200 (9th Cir. 2008).
[450] High Country Conservation Advocates v. U.S. Forest Serv., 52 F. Supp. 3d 1174, 1193 (D. Colo. 2014).
[451] *See* Citizens for a Healthy Cmty. v. U.S. Bureau of Land Mgmt., 377 F. Supp. 3d 1223 (D. Colo. 2019); WildEarth Guardians v. Zinke, 368 F. Supp. 3d 41 (D.D.C. 2019); WildEarth Guardians v. Zinke, No. 1:17-cv-00080, 2019 WL 2404860 (D. Mont. Feb. 11, 2019); Wilderness Workshop v. U.S. Bureau of Land Mgmt., 342 F. Supp. 3d 1145 (D. Colo. 2018); W. Org. of Res. Councils v. U.S. Bureau of Land Mgmt., No. 4:16-cv-00021 -BMM, 2018 WL 1475470 (D. Mont. Mar. 26, 2018); Mont. Envtl. Info. Ctr. v. U.S. Off. of Surface Mining, No. 9:15-cv-00106, 2017 WL 5047901 (D. Mont. Nov. 3, 2017). There are also several pending cases which involve claims about the failure to use the social cost of carbon. *See* WildEarth Guardians v. U.S. Bureau of Land Mgmt., No. 4:18-cv -00073 (D. Mont. May 15, 2018); WildEarth Guardians v. Zinke, No. 2:16-cv-00167 (D.

disagreement on the point at which quantification of benefits rises to the level of a "cost-benefit analysis" requiring quantification of costs. In all cases, the reviewing agencies did quantify certain economic benefits in their NEPA documentation—such as labor income and royalty revenue—but argued that disclosure of social costs was not required because the agency had not conducted a complete "cost-benefit analysis" but rather an "economic impact analysis" (or "regional economic analysis")[452] or the social cost metrics would not provide a sufficiently accurate and precise cost estimate so as to be helpful to decision makers.[453] But in only two of these cases did the reviewing courts require disclosure of social costs.[454] In the other four cases, courts deferred to agency claims that their economic impact analysis was not a full cost-benefit analysis, and thus no quantification of GHGs was required.[455]

The two decisions requiring disclosure of social costs of GHG emissions were both issued by the Montana district court and both involved a relatively detailed analysis of the agency's justification for not disclosing these costs. In *Montana Environmental Information Center v. Office of Surface Mining*, the court scrutinized OSM's argument that it's "economic impact assessment" for a coal lease should be distinguished from a "cost-benefit analysis."[456] The court noted that OSM had disclosed the economic benefits of the proposal, including royalty and tax revenue and local employment impacts—for example, stating that "the proposed project could contribute $23,816,000 million [sic] annually in tax revenues to the states."[457] In this context, the court found that OSM's characterization of its analysis was a "distinction without difference where, as here, the economic benefits of the action were quantified where the costs were not."[458]

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Wyo. Apr. 21, 2017); WildEarth Guardians v. Zinke, No. 2:16-cv-00166 (D. Wyo. Jan. 27, 2017); WildEarth Guardians v. Jewell, No. 2:16-cv-00168 (D. Utah Sept. 11, 2015).

452 Agencies will refer to quantification of such benefits as a "regional economic analysis" or an "economic impact analysis" to avoid the requirement to treat costs and benefits equally in their analysis. *See, e.g.*, *Citizens for a Healthy Cmty.*, 377 F. Supp. 3d at 1239–40.

453 *See, e.g.*, Brief for Fed. Gov't, WildEarth Guardians v. Zinke, No. 1:17-cv-00080, 2019 WL 2404860 (D. Mont. Feb. 11, 2019).

454 *See WildEarth Guardians*, 2019 WL 2404860, at *12; *Mont. Envtl. Info. Ctr.*, 2017 WL 5047901, at *5–6.

455 *See WildEarth Guardians*, 368 F. Supp. 3d at 79; Wilderness Workshop v. U.S. Bureau of Land Mgmt., No. 1:16-cv-01822-WYD (D. Colo. Oct. 17, 2018); W. Org. of Res. Councils v. U.S. Bureau of Land Mgmt., No. 4:16-cv-00021-BMM (D. Mont. Mar. 26, 2018).

456 Mont. Envtl. Info. Ctr. v. U.S. Off. of Surface Mining, 274 F. Supp. 3d 1074, 1096 (D. Mont. 2017).

457 *Id.* (internal citations omitted).

458 *Id.* at 1096 n.9.

In *WildEarth Guardians v. Zinke,* the Montana district court addressed other rationales proffered by OSM for not disclosing social costs.[459] There, the focus of the decision was not whether a cost-benefit analysis was performed (OSM had quantified the benefits of the proposed action, and thus the court's prior decision was controlling), but whether OSM had a reasonable justification for not using the social cost of carbon in light of the fact that benefits were monetized.[460] The OSM's first justification was that "there is no consensus on the appropriate fraction of social cost of carbon tied to electricity generation that should be assigned to the coal producer."[461] The court found that this was not persuasive because "it misapprehends NEPA's mandate"—"[u]nder NEPA, agencies are not required to apportion responsibility for the impacts assessed, but rather, they must consider all reasonably foreseeable direct, indirect and cumulative impacts of a proposed action."[462] Second, OSM argued that it was "uncertain whether [GHG] emissions would actually be reduced if the coal associated with the proposed plan was not mined because power plants have alternative sources for coal."[463] The court quickly dismissed this as an unsupported perfect substitution argument.[464] Third, OSM argued that there were unspecified "uncertainties associated with assigning a specific and accurate social cost of carbon to the Proposed Action."[465] The court responded that, to the extent the uncertainties OSM cited referred to the fact that the social cost of carbon is expressed as a range of values, this was not a valid justification for not quantifying those costs.[466] Finally, OSM argued that, to provide meaningful insight, the broader benefits of coal production would need to be considered.[467] Again, the court found that this was not a persuasive reason for ignoring social costs because OSM had in fact attempted to quantify the economic benefits of the action while ignoring the costs.[468] The court also confronted an argument from the mining company (an intervenor) that the social cost of carbon protocol should not be used because it was rescinded by the Trump administration.[469] It responded that:

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[459] *WildEarth Guardians*, 2019 WL 2404860, at *8.
[460] *Id.* at *9–11.
[461] *Id.* at *11 (internal citations omitted).
[462] *Id.*
[463] *Id.*
[464] *Id.*
[465] *WildEarth Guardians*, 2019 WL 2404860, at *12 (internal citations omitted).
[466] *Id.*
[467] *Id.*
[468] *Id.*
[469] *Id.* at *12 n.7.

> Regardless of administration policies that ebb and flow with the political tides, agencies must nevertheless comply with their obligation to properly quantify costs when they have touted economic benefits of a proposed action. The Court's decision here does not mandate use of the SCC Protocol. But it does require OSM to comply with NEPA by either quantifying the costs associated with greenhouse gas emissions or by reasonably justifying why that cannot be done.[470]

The court's careful scrutiny of OSM's justifications in these two cases contrasted to other cases in which courts have deferred to agency decisions on this matter with relatively little analysis.

For example, in a case involving BLM's approval of an RMP that opened lands for fossil fuel development, the Colorado district court accepted BLM's argument that its economic impact analysis was not necessarily the "benefit" side of a cost-benefit analysis without discussing what exactly that analysis entailed.[471] But in the EIS at issue, BLM had quantified labor income, jobs created, and mineral royalty distributions from oil and gas leasing.[472] The court partially justified its decision on the grounds that BLM had not "expressly relied on anticipated economic benefits in its RMP"—but the economic benefits were discussed and appeared to be an important part of the comparison between alternatives (as evinced by statements about how royalties would be lower under certain alternatives).[473] Similarly, in another case which dealt with BLM's approval of several hundred oil and gas leases in Wyoming, Utah, and Colorado, the D.C. district court deferred to BLM's assertion that it had not conducted a full cost-benefit analysis when it discussed the economic benefits of oil and gas drilling in EAs covering the issuance of 282 oil and gas lease sales over more than 303,000 acres in Wyoming.[474] The court said that *High Country* was not controlling because the EIS at issue in that case predicted economic benefits of nearly a billion dollars, whereas the oil and gas lease sale EAs' discussion of economic benefits was more abbreviated and the quantified economic benefits were much smaller

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[470] *Id.*
[471] Wilderness Workshop v. U.S. Bureau of Land Mgmt., 342 F. Supp. 3d 1145, 1159 (D. Colo. 2018).
[472] *Id.*
[473] *Id.*
[474] WildEarth Guardians v. Zinke, 368 F. Supp. 3d 41 (D.D.C. 2019).

(e.g., one EA estimated that a lease sale would yield $152,364 in revenue).[475] The court also deferred to BLM's conclusion that the social cost estimates were "highly speculative" because they represented a "4,000 percent range in potential costs" under different production scenarios, and this would be "less than helpful in informing the public and the decision-maker."[476] The Colorado district court reached the same conclusion with respect to BLM and USFS's approval of oil and gas leasing in Colorado.[477]

### C. *Alternatives and Mitigation to Address GHG Impacts*

NEPA requires federal agencies to consider and disclose mitigation measures for any impacts which are deemed to be significant.[478] Agencies are not required to discuss mitigation for insignificant impacts.[479] Thus, in the absence of significance determinations for GHG emissions from fossil fuel supply projects, it is not possible to challenge agency failures to discuss mitigation options by relying exclusively on the regulatory provisions pertaining to mitigation. But the regulations also require agencies to "[r]igorously explore and objectively evaluate all reasonable alternatives, and for alternatives which were eliminated from detailed study, briefly discuss the reasons for their having been eliminated."[480] Plaintiffs have thus relied on this requirement in lawsuits seeking to compel federal agencies to consider ways in which fossil fuel leasing and transport proposals could be modified to reduce or eliminate emissions.

It is our view that agencies should more rigorously evaluate alternatives and mitigation measures aimed at reducing indirect as well as direct GHG emissions from fossil fuel supply projects, including the no action alternative and alternatives that involve smaller increases in fossil fuel supply (either production or transportation capacity). Federal agencies do sometimes consider alternatives that entail fewer emissions in NEPA reviews of fossil fuel supply projects. For example, in a NEPA documentation for a fossil fuel leasing proposal, an agency might consider different leasing scenarios which entail different acreage and levels of fossil fuel production. And in proposals for broader planning actions

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475 *Id.* at 78.
476 *Id.* at 79 (internal citations omitted).
477 Citizens for a Healthy Cmty. v. U.S. Bureau of Land Mgmt., 377 F. Supp. 3d 1223, 1247 (D. Colo. 2019).
478 40 C.F.R. § 1503.3(d) (2019).
479 40 C.F.R. § 1508.13 (2019).
480 40 C.F.R. § 1502.14(a) (2019).

such as RMPs, an agency may compare alternatives with renewable energy production as well as fossil fuel production. But in many instances—particularly where agencies are approving leases or transportation infrastructure—agencies do not give meaningful consideration to alternative approaches for meeting energy demand.[481] Such alternative approaches may be briefly discussed (for thoroughness) but then quickly dismissed from further consideration. This often occurs where the purpose and need of the proposal are framed narrowly—for example, in an EIS for coal leasing, BLM described the need in terms of the public interest ("to meet the nation's future energy needs") and the purpose in terms of the applicant's interest ("to allow the applicant mines access to a continuing supply of low sulfur compliance coal").[482] Notably, in the purpose and need statement, BLM also asserted that "the continued extraction of coal is essential to meet the nation's future energy needs"—effectively foreclosing arguments that the public need for energy could be met through other means.[483] This is a problematic position, as it assumes a need for increasing fossil fuel supply at a time when scientific research clearly indicates that we need to reduce fossil fuel consumption.

The Department of State took a similar approach with the Keystone XL pipeline, defining the purpose and need to reflect the developer's interest in developing the pipeline as well as the public interest in energy demand being met. In *Indigenous Environmental Network v. U.S. Department of State*, the Montana district court held that this practice was permitted under Ninth Circuit case law, and that it was therefore reasonable for the agency to dismiss alternatives that did not satisfy both the public and private interests at stake.[484] The court also held that it was not necessary to consider a "more environmentally beneficial alternative" but rather only those alternatives that are "necessary to permit a reasoned choice" in light of the purpose and need.[485] The problem with

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[481] *See, e.g.*, City of Grapevine v. U.S. Dep't of Transp., 17 F.3d 1502, 1506 (D.C. Cir. 1994).
[482] NAT'L SYS. OF PUB. LANDS, FINAL ENVIRONMENTAL IMPACT STATEMENT FOR THE SOUTH GILLETTE AREA COAL LEASE APPLICATIONS 1–19 (2009).
[483] *Id.*
[484] Indigenous Envtl. Network v. U.S. Dep't of State, 347 F. Supp. 3d 561, 573 (D. Mont. 2018).
[485] *Id.* at 574. Another lawsuit has since been filed challenging the approval of the Keystone XL pipeline which alleges, among other things, that the EIS was flawed because it did not consider an alternative route to avoid the sovereign tribal territory (which was contemplated in the scoping report). That complaint also argues that the Department of State's approval of the Keystone XL Pipeline violates the APA because the Department failed to justify its reversal in light of the previous factors which led it to deny the permit,

this interpretation of NEPA is that it allows agencies to define the project need so narrowly based on private interests that they can avoid any real consideration of alternatives that may better serve the public interest.

The decision in *Indigenous Environmental Network* can be contrasted to several decisions finding that BLM failed to take a hard look at alternatives that would have decreased fossil fuel leasing on federal lands, all of which reflect a more functional interpretation of NEPA requirements for the alternatives analysis.[486] First, in *New Mexico ex rel. Richardson v. Bureau of Land Management*, the Tenth Circuit Court of Appeals held that BLM violated NEPA by failing to consider an alternative in an RMP that would have closed the managed area to future minerals development, since such an option was within the scope of BLM's discretion as well as BLM's statutory mandate to manage lands on a mixed use basis.[487] The case did not entail any claims related to climate change or GHG emissions, but it set the stage for two additional decisions which focused on the need to restrict leasing options in order to reduce the emissions impact. In one case, the Montana district court found that BLM had failed to take a hard look at coal leasing alternatives in two RMP EISs that would have decreased the amount of coal available for leasing based on climate concerns.[488] The BLM had examined a total of nine alternatives in the two EISs, all of which entailed the same acreage available for leasing and the same projected coal production.[489] The court held that BLM had discretion to reduce or eliminate areas from lease sales, and thus the lower production scenarios were reasonable management

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in particular its assessment of climate change impacts, but the NEPA claims focus on the lack of assessment of impacts on and alternatives to the route through tribal lands. Complaint at 51, Rosebud Sioux Tribe v. U.S. Dep't of State, No. 4:18-cv-00118 (D. Mont. Sept. 10, 2018).

[486] There is another pending case, *Diné Citizens Against Ruining Our Environment v. Bureau of Indian Affairs*, in which plaintiffs have alleged that the federal government unlawfully truncated its alternatives analysis for a connected coal mining and coal plant operation. There, plaintiffs are arguing that the purpose and need statement ("to continue operations of the Navajo Mine and the Four Corners Power Plant") is unduly narrow, thus preventing meaningful consideration of lower GHG alternatives. The case was dismissed by a district court due to failure to join an essential party and the Ninth Circuit upheld the dismissal. Diné Citizens Against Ruining Our Env't v. Bureau of Indian Affairs, 932 F.3d 843, 848 (9th Cir. 2019).

[487] N.M. *ex rel.* Richardson v. U.S. Bureau of Land Mgmt., 565 F.3d 683, 703 n.23 (10th Cir. 2009).

[488] W. Org. of Res. Councils v. U.S. Bureau of Land Mgmt., 2018 WL 1475470, at *13–14, *appeal dismissed*, No. 18-35836, 2019 WL 141346 (9th Cir. Jan. 2, 2019).

[489] *Id.* at *19–20.

options which should be considered to provide a reasoned basis for decision-making, particularly in light of the potential emissions from the fossil fuels produced pursuant to the RMPs and public comments outlining concerns about the climate impacts.[490] However, the court did not agree with another claim advanced by plaintiffs with respect to the alternatives analysis—specifically, that BLM must also consider alternatives to reduce methane pollution from oil and gas development contemplated in the RMPs. The court held that consideration of such measures was not required at the RMP stage—it characterized the RMP EISs as "programmatic" reviews—and noted that BLM would retain the ability to impose specific methane mitigation measures at the leasing stage.[491]

Similarly, in *Wilderness Workshop v. Bureau of Land Management*, the Colorado district court held that BLM should have considered an oil and gas leasing alternative that would "meaningfully limit" oil and gas production development.[492] Notably, BLM had considered various alternatives that entailed less oil and gas leasing—but none of them closed more than 25.7 percent of the study area to future leasing—and much of the area left open for leasing under all alternatives had only "moderate or low" potential for oil and gas development.[493] The court held that BLM must consider an alternative in which more of the lands were closed to leasing so that it could better evaluate alternate land management options for the "moderate or low" potential areas—thus, the court's decision was predicated more on the need for BLM to meaningfully implement the principle of "mixed use" on public lands than on the need to evaluate a more environmentally friendly alternative.[494]

These three decisions thus demonstrate that courts may intervene to enforce the requirement that agencies take a "hard look" at alternatives that entail different levels of fossil fuel production at the land use planning stage, but may be more deferential to agencies about the scope of other emission mitigation measures reviewed at this stage. The Colorado district court addressed the obligation to consider methane mitigation measures at the leasing stage in the context of the EIS prepared for coal leasing on remand from *High Country Conservation Advocates*.[495] In the

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[490] *Id.*
[491] *Id.* at *28.
[492] Wilderness Workshop v. U.S. Bureau of Land Mgmt., 342 F. Supp. 3d 1145, 1164 (D. Colo. 2018).
[493] *Id.* at 1166.
[494] *Id.* at 1153.
[495] High Country Conservation Advocates v. U.S. Forest Serv., 333 F. Supp. 3d 1107, 1124 (D. Colo. 2018).

leasing EIS, USFS had briefly discussed methane flaring as a potential mitigation measure, but put off the decision on whether to require methane flaring to a later point in time. The USFS stated that it had not considered methane flaring in detail "because it, like all other methane mitigation measures, requires detailed engineering and economic considerations that would occur later in the process."[496] The USFS also incorporated lease stipulations requiring "additional analysis" of the feasibility of methane use or capture.[497] The court held that USFS's treatment of methane mitigation measures was adequate and that USFS had satisfied its obligation to "briefly discuss" why the option would eliminate from detailed consideration as an alternative.[498]

## CONCLUSION

The contribution of fossil fuel supply projects to GHG emissions and climate change is precisely the sort of environmental impact that requires a "hard look" under NEPA. As detailed in this Article, there are now numerous court decisions fleshing out the required scope and nature of the GHG analysis that must be performed for fossil fuel projects. In particular, courts have made it clear that agencies must carefully evaluate indirect emissions from such proposals, at minimum considering the effect of the proposal on downstream consumption of fossil fuels, and that emissions must be quantified wherever tools and data are available to do so. There are also a number of cases addressing other aspects of the GHG analysis, such as the proper scope of the cumulative emissions analysis, the adequacy of technical assumptions underpinning estimates of net emissions, and the contexts in which the social costs of emissions must be disclosed. These cases show that courts are generally deferential to agencies regarding decisions about how to best analyze GHG impacts, but that courts will intervene as needed to ensure that agencies do not wholly ignore GHG impacts or analyze them in an irrational way. Here, we summarize some recommendations to agencies and courts on the best approach for analyzing GHG emissions from fossil fuel supply projects under NEPA,

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[496] *Id.*

[497] *Id.*

[498] *Id.* at 1120–21 (citing 40 C.F.R. § 1502.14(a)). The Court affirmed USFS's decision to rule out methane flaring and capture as infeasible at the same mine, because the intervening years have provided "additional evidence . . . that flaring operations are safe" and plaintiffs provided a report showing that methane flaring would be economically feasible. *Id.* at 1125. *See also* WildEarth Guardians v. U.S. Forest Serv., 828 F. Supp. 2d 1223, 1239 (D. Colo. 2011).

recognizing that there is not yet judicial consensus that all of these elements are required under NEPA, but that it makes sense to err on the side of greater disclosure for public policy reasons as well as legal reasons.[499]

First, agencies should include a complete inventory of direct and indirect emissions in NEPA documents for fossil fuel supply proposals, including all downstream and (if applicable) upstream emissions from other activities on the supply chain. Emissions should be quantified wherever possible, and in particular, combustion emissions should be quantified using emission factors whenever the agency is able to project the amount of fuel to be produced.[500] For larger proposals, agencies may also supplement this gross GHG inventory with a quantitative or qualitative discussion of energy market substitution and net emissions, provided that the agency uses the best available data on energy markets and substitutes and is transparent about all assumptions, model parameters, and limitations to that analysis. Where agencies model energy market impacts, they should use multiple scenarios to account for uncertainty.[501]

Second, we recommend that agencies consider the effects of other reasonably foreseeable fossil fuel supply projects in their cumulative effects analysis for such proposals. Ideally, this analysis should encompass federal activities at both the regional and national scales (e.g., other federal leases for coal, oil, and/or gas) and should help decision makers and the public understand both the incremental contribution of the proposal under review and the aggregate impacts of federal decision-making on similar projects. One goal of this analysis should be to evaluate whether the proposal is prudent and whether impacts may be significant in light of other federal leases or approvals for fossil fuel supply projects. Agencies should also account for such cumulative impacts when modelling energy market impacts and net emissions (and should consider whether the market impact analysis should be integrated with the cumulative effects analysis).

Third, agencies should carefully evaluate the significance of the emissions impacts in light of the regulatory criteria outlined in the NEPA regulations. Agencies should not avoid reaching a determination on

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[499] Most of these recommendations are written in terms of what agencies should do, but that these are also intended to provide guidance to courts when assessing whether agencies have met their obligations under NEPA.

[500] See Burger & Wentz, *supra* note 11, for more detailed guidance on the preparation of a GHG inventory for direct and indirect emissions, including a list of tools available to quantify upstream and downstream emissions.

[501] See *supra* Section III.A.2 for more detailed recommendations on the use of energy market models.

significance due to a lack of predetermined significance thresholds for GHG emissions. Rather, agencies should use all available tools to evaluate the magnitude of the emissions impact and reach a reasonable conclusion about significance based on that analysis. Although courts have not required agencies to disclose the social costs of emissions except where agencies have conducted a cost-benefit analysis, agencies should consider using the social cost metrics regardless to aid in their evaluation of significance. When determining whether such social costs must be disclosed, courts should closely scrutinize agency claims that the disclosure of key economic benefits (such as government revenue or job creation) does not constitute the "benefits" side of a "cost-benefit analysis." The relevant inquiry is not how the agency has labelled the analysis, but rather whether the agency has put its "thumb on the scale" by inflating or emphasizing benefits and downplaying costs.

Fourth, we recommend that agencies carefully consider alternatives to fossil fuel supply proposals that will help meet energy demand without generating the same amount of GHG emissions in their NEPA analysis. Agencies should not narrowly frame the purpose and need of proposals to exclude such alternatives from consideration, particularly in light of the urgent public need to transition from fossil fuels to alternative energy sources.

# The Economics of Canadian Oil Sands

Anthony Heyes,* Andrew Leach,† and Charles F. Mason‡



## Introduction

The large-scale extraction of unconventional oil resources, including Canadian oil sands, together with the exploitation of shale gas (natural gas trapped in shale formations), has significantly reshaped the global energy landscape over the past two decades. Canadian oil sands have attracted significant attention because of their rapid growth, their significant share of Canadian exports and foreign direct investment, and their greenhouse gas (GHG) emissions and other environmental impacts. The Canadian oil sands sector highlights many of the key issues we examine in economics and, as we will discuss here, the sector remains ripe for further research.

Oil sands are a subsurface hydrocarbon deposit that contains a type of oil (called bitumen) that is mixed with sand, water, and clay. The world's largest oil sands deposits are in Canada, but there are also important deposits in Venezuela, the United States, Russia, and several other countries. Canada's oil sands are concentrated almost entirely in the province of Alberta, with the three largest deposits originally estimated to contain up to 1.8 trillion barrels of oil in place (Swart and Weaver 2012). Oil sands operations produce bitumen—a black, viscous mixture of hydrocarbons—which is denser and higher in sulfur than most crude oils produced globally. Oil sands bitumen can either be processed into synthetic crude oil for use as a substitute for lighter crude oils or refined directly in complex refineries.

Commercial exploitation of Canadian oil sands began in 1967, but the most rapid growth has occurred since the turn of the century, when oil sands were part of a wider commodities boom in the Canadian economy.[1] In 2017, oil sands production averaged 2.9 million barrels per day, an almost fourfold increase over production levels in 2000.[2] Between 2000 and 2015,

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[1]Over the last two decades, the exploitation of Canada's oil sands deposits has coincided with the dramatic rise of oil production from shale, particularly in the United States (see Kilian 2016, 2017). See Appendix figure 1 for details on oil sands production trends and projections.
[2]Canadian data used in this report are generally presented in cubic meters ($m^3$). One barrel of oil is equivalent to 0.1589 $m^3$ of oil.

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more than 270 billion Canadian dollars (Can$) were invested in Canadian oil sands, and direct employment in the sector grew to more than 70,000 employees (Petroleum Human Resources Council of Canada 2014; Alberta Energy Regulator 2018). The effects on employment in the broader economy were much larger, with Kneebone (2014) estimating oil sands as directly or indirectly contributing 400,000 jobs in Canada by 2014.

More recently, the Canadian oil sands industry has been in a period of upheaval. World oil prices dropped more than 50 percent between June 2014 and June 2016, reaching prices that failed to cover the variable costs of production for some oil sands production facilities (see, e.g., MEG Energy 2016).[3] While oil sands production continued to grow during the downturn, capital investment and production growth expectations have both fallen significantly since 2014. For example, Alberta Energy Regulator (2014) forecast bitumen production to grow from 2013 levels of 2 million barrels per day to 4 million barrels per day by 2023, with $250 billion in capital investment between 2014 and 2023. In contrast, Alberta Energy Regulator (2018) forecast production to reach 3.6 million barrels per day by 2023, with $160 billion in capital investment between 2014 and 2023.

This article analyzes the status of Canadian oil sands and examines the sector's future prospects. We start by discussing the key economic drivers of oil sands costs and how they affect supply decisions. Then we discuss transportation issues and the challenges of getting oil sands products to export markets. We next examine the likely impact of evolving climate change policy—both within Canada and outside—on operations, as well as other environmental issues that relate to oil sands operations. Finally, we highlight macroeconomic impacts and considerations, namely the resource curse and Dutch disease. Overall, we find the future prospects for the Canadian oil sands industry to be highly uncertain.

## Key Drivers of Canadian Oil Sands Costs and Future Supply Decisions

This section identifies the key financial variables that determine costs in the Canadian oil sands sector, and thus producers' supply decisions. We develop project-level cost estimates for the two most common extraction techniques—open pit mining and in situ extraction—and use them to project future supply decisions in response to potential changes in the key variables.[4] Following Dixit and Pindyck (1994), Mason (2001) characterizes the decision to develop a new resource extraction project under uncertainty as an option with a trigger price (the price at which production of a particular project becomes profitable), and this is how we frame our analysis. We define our trigger price in terms of the constant real dollar West Texas

[3]The significant weakening of the Canadian dollar against the U.S. dollar during this period cushioned the oil sands sector against further competitiveness losses. See Baumeister and Kilian (2016) for an analysis of the factors that contributed to the dramatic drop in oil prices.

[4]Open-pit mines tend to be larger, longer-lived, and have higher total initial capital cost per unit of production capacity. In situ facilities are smaller in production capacity and have shorter project durations. They rely on paired wells, with the first drilled to inject steam to heat the bitumen in the deposit to render it less viscous and the second drilled to produce the heated bitumen. In situ facilities generally rely on natural gas more than mines, while truck-and-shovel (i.e., open pit) mines rely more heavily on diesel fuel. Evaluating the two project types separately allows us to be sensitive to important differences between them in terms of typical time scales, environmental attributes, and cost structures.

Intermediate (WTI) oil price at which a prototypical new oil sands project would be expected to earn a 10 percent rate of return on capital.

## Capital and Operating Costs

Oil sands projects have significant construction and operating costs. The only open pit mine currently under construction, Suncor's 180,000 barrels per day Fort Hills facility, is expected to cost a total of $16.2 billion (Suncor 2018). In situ projects tend to be smaller and less costly per unit of production capacity; for example, the Kirby North project (40,000 barrels per day) is expected to cost $1.35 billion (Canadian Natural Resources 2016). We use these capital costs as benchmarks for our analysis. Operating and maintenance costs in the sector vary significantly across facility and type of extraction (Canadian Energy Research Institute 2015; Ollenberger, Murphy and Li 2016). Following central estimates from these sources, we assume operation, maintenance, and production-sustaining capital investment costs of $22 and $36 per barrel produced for in situ and mining extraction, respectively.

## Product Discounts

As noted earlier, bitumen is either converted to synthetic crude oil or diluted with natural gas liquids and shipped as diluted bitumen for processing in complex refineries. We will focus our analysis on diluted bitumen, as there are no projects planned that include integrated *upgraders* (basically a purpose-built refinery) to convert bitumen into synthetic crude. Like other heavier and higher-sulfur crude oil blends, diluted bitumen from oil sands is generally discounted relative to global benchmark oil grades. During 2017, the Canadian benchmark Western Canada Select diluted bitumen blend traded at an average of $12.77 per barrel below the WTI price, the North American benchmark for light crude; we use this value (adjusted for inflation) in our analysis and allow it to vary for sensitivity analysis.[5] The price discount is due to differences in quality and geographic characteristics: oil sands diluted bitumen is denser and thus more expensive to transport, more expensive to refine, and yields a lower-value slate of products than a light, sweet (low-sulfur) crude in the same location (Nimana, Canter, and Kumar 2015). Lower values for heavy crude are not exclusive to oil sands bitumen. For example, Mexican Maya crude traded on the U.S. Gulf Coast at a $6.98 per barrel discount relative to Louisiana Light Sweet Crude in 2017 (Bloomberg data, author's calculations). Transportation costs are also reflected in the price discounts for oil sands diluted bitumen, with the marginal market being the U.S. Gulf Coast.[6] The North American pipeline network has been affected by significant congestion, which has contributed to larger than expected discounts for Canadian diluted bitumen between 2010 and 2014 (Borenstein and Kellogg 2014; Oliver, Mason, and Finnoff 2014; Kilian 2016) and again in late 2017 and early 2018.

[5]We regard this as a conservative approach. The 5- and 10-year average discounts for bitumen relative to WTI have been $26.53 and $26.99 per barrel, respectively (Bloomberg data, authors' calculations). The differential has also been higher since November 2017. Thus we also include a high-differential sensitivity case.
[6]Thus Gulf Coast access costs $8.63 per barrel via the Enbridge system (National Energy Board 2018b) and $10.50 per barrel via the TransCanada system (National Energy Board 2018c).

## Royalties and Taxes

Among the major costs for oil sands operators are royalties paid to the government (which owns oil sands resources) and corporate income taxes. The oil sands royalty regime is a two-stage system. Initially the developer pays the government a price-dependent share of gross revenues until the project has produced a cumulative return on capital invested that is equal to the long-term government bond (this is referred to as *payout*), after which the project is subject to higher royalties based on a share of profits (Plourde 2009). At both stages, the share of production or profits payable as royalties depends on the WTI price per barrel in Canadian dollars. With the exception of financing costs, most project costs are used to calculate both the payout condition and the net revenue base on which royalties are calculated.[7]

In terms of corporate taxes, oil sands producers pay federal and provincial corporate income taxes at a current combined rate of 27 percent; they also benefit from special tax provisions available to all Canadian oil and gas production (KPMG 2015).

An unresolved issue is whether oil sands production is actually subsidized. Some researchers have evaluated the level of government support by examining tax expenditures provided to the oil industry (including oil sands), which they find to be Can$2–3 billion per year (Sawyer and Stiebert 2010). Others have argued that the marginal effective tax rate on capital is higher in Canadian oil and gas than other industries (McKenzie and Mintz 2011), suggesting that the combined effect of the current tax and royalty regimes has been to shift economic activity away from oil sands.

## Environmental Policies

Environmental policies also affect the costs faced by Canadian oil sands producers, and hence their supply decisions. First, prices on carbon are applied through a hybrid policy that has elements of both a carbon tax and a cap-and-trade regime (Leach 2012). Regulations in place through 2017 provided an output-based allocation of emissions credits based on each facility's historical performance. In 2018, the output-based allocations changed to a benchmark-based system under which firms receive credits based on the performance of the 25th percentile producer, with separate allocations for in situ and mined bitumen production.[8] Credits are bankable and tradable. If firms have insufficient credits to cover their emissions, then they may purchase credits from another firm, make a payment to the government in lieu of emissions reductions, or purchase regulated emissions offsets within Alberta. The possibility of compliance through a payment to the government sets the carbon price in Alberta. From 2007 through 2015, this price was $Can15 per tonne. The price was increased to Can$20 per tonne in 2016 and to Can$30 per tonne in 2017. Importantly, carbon charges and emissions abatement costs may be deducted from revenues in calculating both

[7]The initial gross revenue royalty rate is 1 percent when prices are below Can$55 per barrel and increases linearly to a maximum of 9 percent when oil prices reach Can$120. After the project is deemed to have reached payout, the royalty payable is the greater of the gross revenue royalty just described or a share of profits that increases from 25 percent (when the WTI price is less than Can$55 per barrel) to 40 percent (for oil prices at or above Can$120 per barrel).

[8]One of the authors of this article, Andrew Leach, chaired the Government of Alberta's Climate Leadership Panel, whose recommendations were largely adopted by the government (Leach et al. 2016). The updated regime in Government of Alberta (2017) forms the basis of our analysis.

the royalty and tax base, implying that such costs are partly shared with the federal and provincial government.

Oil sands facilities are also responsible for the reclamation of their sites after extraction has been completed. Based on a study by the Canadian Energy Research Institute (2015), which assumes a reclamation cost that is equivalent to 2 percent of total capital expenditures, we assume that the future cost of reclamation is Can$0.25 per barrel for all production.

## Results: Prospects for Future Oil Sands Supply

The future viability of oil sands production depends primarily on the expected evolution of global oil prices and low-cost access to markets. Using a discounted cash flow model of two prototypical oil sands facilities (one in situ and one mine) that produce diluted bitumen, and based on the assumptions just presented, we estimate the costs of new oil sands production. We then use these costs to estimate the critical (or trigger) oil price at which new production would be viable.[9] The trigger prices that we derive are substantially higher than realized prices for much of 2015–2017, with the bitumen mine requiring revenue levels that would be expected with WTI prices of $84.62 per barrel in order to earn a nominal rate of return of 10 percent on invested capital, while the trigger price for the in situ plant is $58.06 per barrel WTI. These values translate to required revenues at the plant gate (i.e., before transportation) of $61.62 and $35.85 per barrel bitumen, respectively.[10] These estimates are consistent with estimates from Alberta Energy Regulator (2018), which reported a required WTI range of $75–85 per barrel for mines and $45–55 per barrel for in situ plants. These high trigger prices clearly indicate why new development of Canada's oil sands have slowed significantly since 2015.

Despite the drop in oil prices in late 2014, work on Canadian oil sands projects currently under construction has continued and those that began before the oil price crash are expected to enter production at close to their original schedules. Given the substantial sunk costs, expected oil prices would have to fall significantly from current levels for those projects currently under construction to be abandoned or operating projects to shut down. More specifically, using an analysis similar to the one used to estimate the costs of new oil sands production, we find that while a new in situ project would not be developed unless average oil prices were expected to remain above $58 per barrel, price expectations would have to drop below $45 per barrel to trigger the suspension of a project for which two-thirds of the construction costs had already been incurred. Other than projects currently under construction, the lowest-cost future development would be expansion of some existing facilities. For example, Ollenberger, Murphy and Li (2016) find that significant expansions of both existing in situ and oil sands projects are viable at average WTI prices below $50 per barrel. Our model predicts that a prototypical expansion of an in situ project would be viable at approximately $50 per barrel, depending on the assumed reduction in total capital costs due to already-sunk costs.

[9] Appendix table 1 presents a list of the assumptions underlying these estimates and Appendix table 2 presents the detailed cost estimates.

[10] This includes the costs of diluting and shipping a barrel of bitumen and the discount at which diluted bitumen trades to lighter oil blends.

## Getting Product to Market: Transport Challenges

The analysis just presented does not consider the evolving challenges to the large-scale transportation of oil sands product to markets, particularly for export. We discuss these challenges here.

Alberta Energy Regulator (2018) reports that of the 2.7 million barrels per day of total oil sands production in Alberta in 2017, 375,000 barrels per day were used within the province, while 650,000 barrels per day of upgraded oil sands product and 1.5 million barrels per day of nonupgraded bitumen were removed from Alberta.[11] The latter includes product shipped to U.S. markets and to Canadian markets outside the province. Most of these volumes move by pipeline, although some exports occur by rail.[12]

Export capacity is extremely tight. In December 2017, the largest export pipeline systems, Keystone (27 percent), Enbridge Mainline (5–21 percent), and Trans-Mountain (23 percent), were all oversubscribed (by the percentages shown in parentheses) relative to their maximum capacity (National Energy Board 2018). Although pipeline expansions are under way in the Enbridge system, even a conservative production growth case would lead to export volumes exceeding effective pipeline capacity unless additional new pipeline projects are undertaken (National Energy Board 2016b).

The construction of new oil sands pipelines has been a key issue in North America. Pipeline safety concerns were exacerbated by two spills of oil sands diluted bitumen (in Kalamazoo, Michigan, and Mayflower, Arkansas, in 2010 and 2013, respectively). These safety concerns, coupled with concerns about GHG emissions, resulted in increased opposition to pipelines, culminating in the United States with President Obama's rejection of the Keystone XL pipeline (in late 2015) and in Canada with major political battles and protests over pipeline proposals. Although President Trump reversed the Obama administration decision on Keystone XL in 2017, the pipeline continues to face regulatory challenges and stiff local opposition.

Several other pipeline projects have been proposed to increase capacity to ship oil derived from the Alberta oil sands. The TransMountain Expansion (590,000 barrels per day) to the Canadian West Coast and the Line 3 refurbishment and Line 67 expansion of the Enbridge system to the U.S. Midwest (370,000 barrels per day) have received Canadian regulatory approval.[13] The proposed Northern Gateway Pipeline (525,000 barrels per day) to the Canadian West Coast had its federal regulatory approval overturned by the courts and was subsequently denied by the Canadian government in 2016 (*Gitxaala Nation v. Canada* [2016], Government of Canada [2016]). The Energy East (1,100,000 barrels per day) pipeline, the only proposed oil pipeline to the Canadian East Coast, was cancelled and withdrawn from the regulatory process by TransCanada in 2017.

Shipping by rail presents the only plausible alternative to transport by pipeline. In general, shipping oil by rail costs substantially more per barrel-mile than shipping by pipeline. However, there are factors related to specific characteristics of the transportation of oil sands

[11] We use "removals" to indicate movements out of the province, including volumes shipped to other Canadian provinces. We use exports to denote shipments to destinations outside of Canada.

[12] In December of 2017, less than 5% of total crude oil exports were shipped by rail (National Energy Board, 2018).

[13] Note that construction is under way on Line 3.

bitumen that narrow the gap between pipeline and rail costs. The most important of these is that shipping bitumen by rail requires less dilution, thus reducing both the total volume of product shipped and the costs attributable to purchase of the diluting agent. Estimates of the per-barrel cost advantage of pipelines over rail vary from $3–4 (U.S. Department of State 2014) to $9 (TransCanada Pipelines 2016). Without new pipeline capacity, it is widely expected that oil sands production will be lower than would otherwise be the case, because net revenues will be lower if incremental production must rely on shipments by rail. For example, National Energy Board (2016b) estimates that a scenario with no new pipelines constructed would lead to an 8 percent reduction in total Canadian oil output and a 13 percent (400,000 barrels per day) reduction in peak oil sands output. These findings are driven by an estimated reduction of $9.20 in the price of diluted bitumen at the Hardisty, Alberta, hub. The U.S. Department of State (2014) found similar results concerning oil price levels in their analysis of the Keystone XL pipeline. Given these results, we recalculated our model results for a scenario with higher discounts for Canadian diluted bitumen and found that these discounts have significant impacts. More specifically, we found that under the U.S. Energy Information Administration's Reference Case for oil prices, a $9 per barrel additional discount on Canadian crude would reduce the rates of return on in situ projects from 17 percent to 13 percent and on mining projects from 8 percent to 5.5 percent.

Whether reached by pipeline or rail, the United States represents the most important market for any additional exports of Canadian oil sands production.[14] In 2017, Canada exported 2.7 million barrels per day of heavy crudes (including diluted bitumen) to the United States via pipeline, which represented 56 percent of total U.S. imports of this grade of crude oil (Energy Information Administration 2017a and b). Thus there is significant potential to increase shipments of nonupgraded bitumen to the United States. Although there are other markets for heavier crudes such as those produced from oil sands, the U.S. market remains the closest major market and is therefore likely to be served first.

## Canadian Oil Sands and Climate Change Policies

Climate change policies in Canada, the United States, and globally are evolving rapidly. As a producer of a carbon-based product, Canada's oil sands sector—and its future prospects—will clearly be affected by these policies.

### Climate Impact

Operations in the Canadian oil sands affect GHG emissions in two ways. One is the emissions generated in the process of extraction, processing, and transport. The other is the release of carbon when the product is finally used.

Oil sands operations in Alberta are a large and growing source of GHG emissions, with emissions increasing from 15.3 million metric tons of carbon dioxide equivalent ($MtCO_2e$) in 1990 to 69.3 $MtCO_2e$ by 2016 (Environment Canada 2018a). Oil sands accounted for 10.2 percent of total GHG emissions in Canada in 2016 and are projected

[14]Other potential markets include India and China, which could be served from the west or east coasts.

to increase to 15.9 percent (115 $MtCO_2e$) of total Canadian emissions by 2030 (Environment Canada 2018b).

Moreover, oil refined from oil sands has higher life cycle emissions than comparable products produced from most other crude sources (Brandt 2011; Bergerson et al. 2012; Cai et al. 2015; Gordon et al. 2015). More specifically, the California Air Resources Board (2015) estimates the carbon intensity values for refined products derived from Western Canada Select (the heavy oil blend price we have used to proxy for diluted bitumen values) to be 18.43 grams per megajoule (g/MJ), which is much greater than the 12.03 g/MJ estimated for WTI crude and the 8.71g/MJ estimated for North Dakota Bakken crude. The estimated carbon intensity of products sourced via oil sands production also varies significantly across facilities, ranging from 12.05 g/MJ for Kearl Lake bitumen to 37.29 g/MJ for Long Lake synthetic. This suggests that depending on how it is differentiated by source, carbon pricing applied to oil users could disproportionately affect the attractiveness of oil sands in general and the output of facilities generating more carbon-intensive output in particular.

Significant concerns have been raised about the impact of oil sands emissions on global climate change. Sometimes this has involved emotional language. For example, Hansen (2012) characterized the exploitation of oil sands resources as "game over for the climate," and high-profile environmentalist Bill McKibben (2011) has called oil sands "the biggest carbon bomb on the planet." The findings in the peer-reviewed literature have been less definitive on the potential role of oil sands extraction in exacerbating global climate change. Swart and Weaver (2012) find that if extracted and combusted, the entire oil sands resource would increase global average temperatures by 0.36°C and that combustion of current oil sands reserves[15] would increase global average temperatures by 0.03°C.

## Implications of Climate Policy for the Oil Sands Sector

Existing research is also mixed concerning the future of oil sands development if the world takes serious action on climate change. For example, McGlade and Ekins (2015) find that under cost-effective policies to reduce GHG emissions to levels consistent with a 2°C increase in global mean temperature, there would be no new oil sands development and existing production would be rapidly curtailed, with cumulative production falling sharply from the National Energy Board (2016) forecasts (i.e., from 38 billion barrels by 2040 to 7.5 billion barrels by 2050). Under similar global emissions constraints, McGlade and Ekins (2014) find that future oil sand production rates depend on whether carbon capture and storage (CCS) technology is readily available.[16] With CCS, production rates would increase to 4.1 million barrels per day in 2035, while remaining roughly constant at current levels if CCS technology is not viable. Chan et al. (2012) find that bitumen production increases fourfold in the absence of global action on climate policies but that "climate policy significantly dampens the prospects for Canadian oil sands development because global demand and the producer

[15]This is estimated to be approximately 100 years of production at 5 million barrels per day, which is just below the peak rate forecast in National Energy Board (2016b).

[16]CCS is the process of capturing waste carbon dioxide from large point sources, transporting it to a storage site, and depositing it where it will not enter the atmosphere, normally in an underground geological formation.

prices of oil are depressed, and the Canadian $CO_2$ policy adds to the cost oil sands production." Leach and Boskovic (2014) find that oil sands production is likely to continue under a global carbon price set at the social cost of carbon if and only if a significant share of the carbon cost is borne by oil consumers.[17]

While it is likely that global action on climate change would preclude significant expansion of oil sands production in the absence of significant technological advances, it is more difficult to assess the impact of climate change policies on the viability of *existing* projects in Canada. Higher domestic carbon prices have impacts that are analogous to lower oil prices or higher transportation costs, although with slightly different royalty implications. Carbon costs are deductible from both the tax and royalty base, so approximately 50 percent of any increased carbon cost is effectively passed through to provincial and federal governments through reduced tax and royalty payments (Boskovic and Leach 2017).

The production-weighted average emissions per barrel produced from oil sands (using 2014 Alberta government data) was 0.055 metric tons per barrel. This means that each dollar in average carbon cost would increase the average cost of existing oil sands production by $0.055 per barrel, suggesting that it is likely that existing operations could withstand significant increases in domestic carbon prices without inducing a significant shutdown of operations.

### Overall Impact of Climate Policies

Overall, we find that the impact of evolving climate policies on oil sands development is likely to be felt most acutely through the impacts of these policies on global oil prices. Since roughly 80 percent of the total life cycle emissions from the production and combustion of a barrel of bitumen occurs in refining, transportation, and final combustion, the impact of downstream emissions pricing will likely be greater than the impact of policies affecting only production emissions. This suggests that the greatest climate policy risks for oil sands are from the oil market impacts of global action on climate change, not domestic climate change policies.

## Other Environmental Issues Facing Canadian Oil Sands

In addition to climate impact, there are important local environmental and ecological impacts related to oil sands production, including the accumulation of mine tailings, land reclamation, and negative impacts on populations of caribou and other fauna.[18] In this section we discuss these issues in more detail as well as potential government actions aimed at mitigating them.

[17]The social cost of carbon is an estimate of the monetized damages caused by a 1 tonne increase in carbon emitted in a year.

[18]It is important to note that oil sands operations are concentrated in the northeastern corner of Alberta, a remote area where few people live or visit. Thus justification for governmental regulation of environmental and ecological impacts must often be based on *nonuse* values (i.e., the value that people assign to goods, including public goods, even though they have never and will never directly use them).

## Accumulation of Mine Tailings

After oil sands have been mined, the ore is mixed with hot water and chemical solvents to separate bitumen from sand, clay, and other impurities. The resulting slurry goes through an extraction process to remove the bitumen. The remaining components are called tailings. Tailings are transported and stored in large "ponds," engineered systems that involve dams and dikes. In 2015, tailings ponds in Alberta contained 1.18 trillion litres of fluid tailings and covered more than 220 square kilometers (McNeill and Lothian 2017). The appropriate management of these tailings, which contain many compounds that are potentially harmful to the environment, is a major issue for the oil sands sector.

### Environmental impacts

Tailings have a number of potential environmental impacts. The Council of Canadian Academies (2015)[19] identified problems that can arise from toxic seepage into groundwater and rivers and the potential ecological implications of catastrophic dike failures. However, empirical evidence concerning these impacts is rather limited. In one exception, Kelly et al. (2010) provide evidence linking elevated levels of 13 important pollutants in the Athabasca River system in northeastern Alberta to oil sands operations, including tailings. In the longer term, the extent to which successful reclamation of land contaminated by tailings is likely to be feasible, and at what cost, is also disputed (Pembina Institute 2008).

There is also comparatively little evidence concerning the contribution of tailings facilities to air pollution and the likely associated impacts. However, Galarneau et al. (2014) find that tailings ponds are a much more significant source of polycyclic aromatic hydrocarbons (PAHs), which can negatively impact human health, than previously believed. Moreover, the environmental implications of such discharges for *regional* ecosystems are not well understood.

### Government policies

Tailings are a classic stock pollution problem. Research and policy work have examined options for both stemming the rate of deposition of new tailings and reducing the stock as part of efforts to reclaim the affected landscape.[20] In an effort to slow the generation of tailings, Alberta Energy Regulator regulates oil sands producers to encourage reduced tailings deposition.

Although the underlying physical science regarding the short- and longer-term impacts of tailings on the environment of Alberta remains underdeveloped, attempts to actually monetize or otherwise weigh those impacts in a way that could be included in a benefit–cost analysis are essentially nonexistent. This points to an urgent need to support further research in this area to provide credible estimates of impacts in a form that can support policy evaluation and appraisal.

[19]The Council of Canadian Academies is a highly respected not-for-profit organization that conducts expert evidence reviews in support of public policy development in Canada. It includes three member academies: the Royal Society of Canada, the Canadian Academy of Engineering, and the Canadian Academy of Health Sciences.

[20]In terms of flow, the production of 1 barrel of synthetic crude oil requires approximately 2.5 barrels of water and 2 tonnes of oil sands ore, yielding around 3.3 barrels of raw tailings. While much of the water used is recycled from existing tailings ponds, the long-run equilibrium sees approximately 2 barrels of mature fine tailings produced for every barrel of oil (Hrudey et al. 2010).

## Reclamation of Tailings and Mine Sites

Oil sands companies are responsible for restoration of their sites after use. This includes tailings areas and land used for other purposes. There has been some progress in the remediation of existing tailings ponds. Suncor Energy became the first oil sands company to complete surface reclamation of a tailings pond. Reclaiming the 220 hectare site north of Fort McMurray involved moving more than 65,000 truckloads of soil and the planting of around 630,000 trees and shrubs (Marketwire 2010). However, the success of that project—that is, the extent to which the area returns to being a self-sustaining ecosystem—can only be assessed with the passage of time. Other reclamation technologies are in the test phase and thus not yet commercially viable.

There has also been significant work on the reclamation of oil sands mine sites, although the actual rate of reclamation is low. The total oil sands extraction area in Alberta is roughly 89,000 hectares, with only about 8,000 hectares of that at some stage of reclamation. Only 237.6 hectares of land (less than 0.5 percent of the total disturbed landscape) have been certified as reclaimed and returned to government jurisdiction (Alberta Energy Regulator 2017), indicating a substantial challenge for land restoration in the future.

There is significant research on the technical challenges of restoring oil sands landscapes to their original productive capacity after oil extraction has been completed (see, e.g., Hrudey et al. 2010). In addition to the challenges of reclaiming lands currently used as tailings ponds, reclamation of fenland, muskeg swamp, and boreal forest landscapes have all proven challenging. From an economic standpoint, we found nothing on the relative value of land restored to a productive but not fully restored landscape.

In order to provide financial assurance of reclamation, companies must provide security deposits to the government of Alberta to ensure the work is done. More specifically, companies are allowed to use the value of their extraction assets, which is a function of the price of oil, as collateral for their unfunded future reclamation liabilities. As of September 2017, the government of Alberta held just under $1 billion in financial security (Alberta Energy Regulator 2017), compared with the most recent public estimate of liability of $20.8 billion (Office of the Auditor General of Alberta 2015). Going forward, as with the decommissioning costs related to nuclear power projects, the future costs of restoring the oil sands areas of Alberta (after production ends), and the extent to which partial restoration will be socially acceptable, need to be given careful consideration when evaluating oil sands projects.

## Impacts on Caribou and Other Fauna

The negative impact of oil sands on faunal biodiversity has drawn significant media and public attention. The plight of the woodland caribou, in particular, has received a great deal of attention (Hervieux et al. 2013).[21]

Alberta is home to 15 herds of woodland caribou, and the caribou is listed as a threatened species under the Canadian Species at Risk Act. This regulation requires both the

[21]Two studies have used stated preference methods to estimate the value of the existence of caribou (Adamowicz et al. 1998; Harper 2012). The estimated willingness to pay for an increase in the number of herds is approximately Can$184 (to increase from two to three herds) or Can$268 (to increase from two to seven herds).

identification of key threats and the development of an intervention plan (Environment Canada 2012). Oil sands operations have been identified as factors in the decline of woodland caribou, but the magnitude of this influence is disputed. Hrudey et al. (2010) highlight the role of habitat fragmentation. Roads—many developed or used primarily for oil sands business—act as semipermeable barriers to caribou movement and pipeline rights-of-way allow predator movement into caribou territory (Dyer et al. 2002; Jordaan, Keith, and Stelfox 2009). Boutin et al. (2012) suggest a multistage process in which human disturbance in the oil sands region has led to habitat fragmentation and to increases in the deer population, which in turn has led to an increase in wolf populations. Latham et al. (2011a, 2011b) find that wolves' use of road and pipeline rights-of-way for movement has changed the predator–prey balance in a way that puts caribou at a disadvantage.

In June 2016, the government of Alberta introduced its Caribou Action Plan, which includes several proposed actions to ensure caribou recovery (Government of Alberta 2016). The current policy includes the expansion of protected areas as well as predator control, specifically through the culling of wolves. Schneider, Hauer, and Adamowicz (2010) recommend a three-pronged approach to management: habitat protection, restoration of disturbed areas, and predator control. Boutin et al. (2012) argue that although unpopular, the wolf culls are necessary because the other two approaches will not eliminate the causes of population decline in time to preserve viable herds.

Policies aimed at protecting caribou also affect the economics of oil sands. Boskovic and Nostbakken (2016a) find that, on average, regulations designed to protect caribou decrease the value of oil sands lands by 24 percent on average, or Can$192 per hectare, leading to a Can$1.15 billion reduction in government leases and royalties. Boskovic and Nostbakken (2016b) examine the impact on lands likely to see future regulation, finding that the value of leases in currently unregulated areas decreases by an average of 16 percent relative to geologically similar leases further from protected caribou areas. For areas within 5 kilometers of a currently regulated area, the value of the lease decreases by 22 percent.

In summary, oil sand operations may have important impacts on both the health of caribou populations and other fauna in Alberta. However, we found little or no economic analysis that allowed for these impacts to be included in a benefit–cost framework.

## Positive and Negative Macroeconomic Impacts

Next we examine the impacts of Alberta's oil sands sector on the wider economy. The channels for positive macroeconomic impacts are clear: employment, government revenues, and real wages in Alberta all increased well above national averages from the early 2000s through mid-2014, and wages, productivity, and employment in Alberta were still well above national averages in 2017. However, there is substantial literature that suggests that large resource endowments may have negative macroeconomic impacts on a jurisdiction and actually lower its well-being; some of these negative impacts have been studied in Alberta. Two concepts that have often been discussed in this regard are the resource curse and Dutch disease.

## The Resource Curse

Potentially the most pervasive of these macroeconomic impacts, the “resource curse” describes a deleterious effect of increased resource wealth on governance, educational attainment, and other socioeconomic impacts. Sachs and Warner (1995, 2001) and others have identified several channels through which the resource curse can occur. For example, the lure of significant wealth associated with the resource bounty induces rent-seeking behavior, often on the part of political actors; this effect is likely to be particularly pronounced when there are weak legal institutions (Brunnschweiler and Bulte 2008). Some have argued that such an effect has occurred in Alberta, pointing in particular to successive governments’ decisions to spend resource revenue for current consumption rather than saving it to a sovereign fund, as has been done in Norway (Parlee 2015).[22]

## Dutch Disease

Another possible negative macroeconomic effect of a large resource endowment is “Dutch disease,” whereby the presence of significant potential rents pulls resources away from other sectors. In particularly dramatic cases, the other sectors wither (Economist 1977). Sachs and Warner (1995) find that Dutch disease can be a source of anemic growth, “if there is something special about the sources of growth in manufacturing.” Here the market failure would be sector-level returns to scale that are not accounted for in individual decisions. Two questions remain unanswered in the debate over the potential rise of Dutch disease in Canada: first, did an additional decline in manufacturing occur as a result of the rise in resources and, second, does this substitution of economic activity away from manufacturing matter?

There is fairly compelling evidence indicating an accelerated decline in traditional manufacturing in Canada as the resource boom pulled resources into oil sands, causing an increase in prices of key related inputs and wages. There is also evidence that the appreciation of the Canadian dollar, in part due to the commodity boom, accelerated this transition. For example, Beine, Bos, and Coulombe (2012) estimate that 42 percent of the substantial appreciation in the Canadian dollar between 2002 and 2008 was due to the increased value of resource exports, especially, but not uniquely, oil sands. They also find that 31 percent (approximately 100,000 jobs) of all manufacturing job losses during the same period can be attributed to the rise in the exchange rate driven by Canadian economic activity. Krzepkowski and Mintz (2013) argue that the declines observed in the manufacturing sector are the continuing result of factors other than the resource boom and suggest that with or without the oil sands industry, the high-wage manufacturing jobs that had been the mainstay of central Canada’s economy for decades were unlikely to return.

Boadway, Coulombe, and Tremblay (2013) take a different approach, examining whether Canada’s institutions of fiscal redistribution have the capacity to deal with resource booms. They recommend changes to the system through which resource rents are collected and

[22] There is some evidence that educational attainment and the accumulation of human capital are adversely affected by resource booms (Parlee 2015). However, Emery, Ferrer, and Green (2012) found that although the oil boom in Alberta between 1973 and 1981 changed the timing of schooling, it did not affect total human capital accumulation over the long term.

redistributed within the country and through increased infrastructure spending in other regions to offset the economic pull of resource-rich regions; they also encourage more saving of resource rents in sovereign wealth funds.

Thus the literature consistently finds significant macroeconomic impacts of the oil sands boom, and more generally finds an increase in the overall standard of living, which is provided by the increase in natural resource wealth and activity due to the oil sands boom, at least since the early 2000s. However, the literature also finds significant transition and volatility costs, institutional failure, and a potential long-term impact of lost educational attainment due to the resource boom. It is important to further estimate the value of these impacts, but some values will only become clear in the longer term.

## Summary and Conclusions

This article has discussed key issues in the economics of Canadian oil sands. We find that production from Canadian oil sands requires that the WTI oil price exceed \$58 per barrel. While the oil price was markedly lower for a period of time, it has recently risen above \$60, suggesting the potential for substantial increases in oil sands production. We also find significant uncertainty due to potential transportation constraints. If currently proposed pipeline projects do not proceed, for example, because of legal hurdles and local regulatory processes, the required price to trigger investment in new oil sands projects is approximately \$9 per barrel higher than would otherwise be the case. Regarding the nonmarket costs associated with oil sands, there has been insufficient economic analysis concerning air quality, water quality, wildlife, and other environmental impacts. This gap in the literature presents a substantial challenge to conducting a thorough benefit–cost analysis of Canadian oil sands.

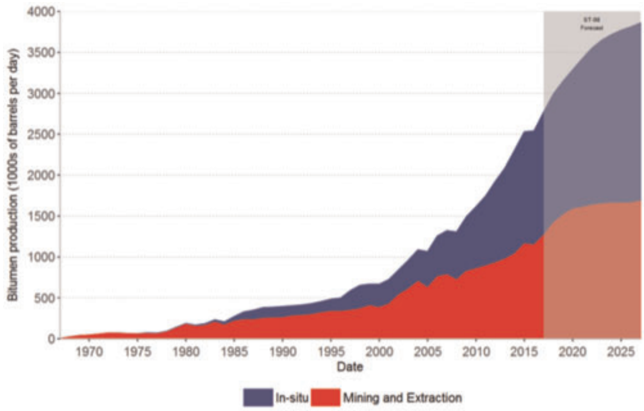
Due to space limitations, we have not discussed water quality and quantity policies (Schindler and Donahue 2006; Allen 2008), issues concerning airborne pollution deposition on land and water (Kelly et al. 2010), and the contribution of oil sands to particulate matter and acid rain–causing pollution (Hrudey et al. 2010). We have also omitted discussion of the complex relationship between Canada's First Nations and oil sands development. Many First Nations and Metis communities in the oil sands area have important commercial relationships with oil sands companies, and many First Nations communities have been supportive of proposed pipeline projects. However, there are also multiple legal actions by First Nations communities against oil sands operations, against the provincial governments for violations of historic treaty rights, and against pipeline projects currently under development.

If global oil prices continue to recover, oil sands production may be poised to play an increasing role in global markets. However, any expansion of oil sands is likely to lead to a host of external effects, including climate impacts, adverse impacts on local flora and fauna, and externalities associated with transportation.[23] On the other hand, increased production will add to the consumer surplus in downstream petroleum markets, and the associated expansion is likely to generate benefits to local economies. A full and careful comparison of these

[23]If pipeline capacity does not expand to keep pace with production, the increased production will most likely be shipped via rail; in turn, this increase in rail traffic is likely to yield external costs related to safety (Mason 2018) and local air pollution (Clay et al. 2017).

costs and benefits would be both timely and important. Our hope is that the discussions in this article will encourage such an analysis.

## Appendix




**Appendix Figure 1** Mined and in situ bitumen production from 1967 through 2017 and projections from 2018 through 2027.
*Source*: Alberta Energy Regulator (2018).

**Appendix Table 1** Key model parameters, project cost, and fiscal policy assumptions

| **Project parameters** | **In situ** | **Mine** |
|---|---|---|
| Capacity (barrels per day) | 40000 | 180000 |
| Build time (yrs) | 3 | 4 |
| Total years of production | 30 | 50 |
| Cumulative production (million barrels) | 385 | 3180 |
| **Costs ($CAD 2018)** | | |
| Construction Costs (millions) | 1350 | 16200 |
| Maintenance Costs ($ per barrel) | 5 | 3 |
| Operating Costs ($ per barrel) | 10 | 16 |
| Recurring Capital Costs ($ per barrel) | 9 | 6 |
| Deemed expenses for future reclamation ($ per barrel) | 0.25 | |
| **GHG Emissions (Carbon Dioxide Equivalent)** | | |
| Production emissions intensity (tonnes/barrel) | 0.058 | 0.038 |
| Life cycle emissions (grams/bbl) | 575 | 535 |
| Light oil life cycle emissions (grams/bbl) | 500 | |
| **Greenhouse Gas Policies** | | |
| Carbon price ($/tonne real) | 30 | |
| Output-based allocation rate (where applicable, t/bbl) | 0.055 | 0.035 |
| Carbon price escalation (annual increase in real price) | 2% | |
| Decrease in annual output-based allocation | 2% | |

| **Time trends** | **In situ** | **Mine** |
|---|---|---|
| Inflation | 2% | |
| Long term bond rate (for royalty calculation) | 2% | |
| Fuel use (diesel, natural gas) improvement per barrel | 1% | |
| Emissions intensity improvement (ex fuel) | 1% | |
| **Tax pool allocations for capital expenditure** | | |
| Capital Cost Allowance (Class 41, 25% of declining balance deductible each year) | 85% | 95% |
| Canadian Oil and Gas Development Expense (30% of declining balance deductible each year) | 15% | 5% |
| **Taxes** | | |
| Combined Corporate Tax Rate | 27% | |
| **Royalties** | **Gross** | **Net** |
| Minimum Royalty Rate | 1% | 25% |
| Maximum Royalty Rate | 9% | 40% |
| Lower limit, formula - C$/bbl | 55 | |
| Upper limit, formula - C$/bbl | 120 | |

**Appendix Table 2** Estimates of oil sands supply costs

| Oil sands supply costs and financial metrics | Projects under current prices and policies | | Projects under EIA (2018) Reference Case Prices, Current Policies | | Projects under EIA (2018) High Oil Price Case, Current Policies | | Projects under EIA (2018) Low Oil Price Case, Current Policies | | Projects under EIA (2018) Reference Case, Current Policies, High Differential | |
|---|---|---|---|---|---|---|---|---|---|---|
| | In-situ | Bitumen Mine | In-situ | Bitumen Mine | In-situ | Bitumen Mine | In-situ | Bitumen Mine | In-situ | Bitumen Mine |
| Project Financial Indicators | | | | | | | | | | |
| Internal Rate of Return (%) | 8.79% | N/A | 16.93% | 7.96% | 33.48% | 18.78% | −5.08% | N/A | 12.71% | 5.56% |
| Supply Cost (WTI equivalent $/bbl) | 58.06 | 84.62 | 67.70 | 109.13 | 68.47 | 109.54 | 52.94 | 84.37 | 77.59 | 119.40 |
| Supply Cost (plant gate bitumen $/bbl) | 35.85 | 61.61 | 41.24 | 81.43 | 41.99 | 81.84 | 32.03 | 62.51 | 41.68 | 82.24 |
| Revenues and Costs ($CAD 2018 per bbl bitumen) | | | | | | | | | | |
| Total Revenue | 41.00 | 40.95 | 74.02 | 83.66 | 190.90 | 219.54 | 25.92 | 31.56 | 60.88 | 70.52 |
| Capital and Debt Costs | 12.99 | 10.24 | 12.76 | 11.34 | 12.76 | 11.34 | 12.76 | 11.34 | 12.76 | 11.34 |
| Operating Costs | 15.34 | 32.96 | 16.69 | 35.60 | 17.94 | 42.51 | 17.41 | 33.58 | 16.69 | 35.60 |
| GHG Compliance Costs | 0.20 | 0.41 | 0.20 | 0.41 | 0.20 | 0.41 | 0.20 | 0.41 | – | – |
| Royalties | 4.84 | 3.08 | 17.83 | 15.33 | 64.31 | 66.61 | 0.97 | 2.06 | 0.20 | 0.41 |
| Taxes | 2.56 | – | 7.66 | 6.09 | 26.31 | 26.99 | – | – | 12.82 | 10.53 |
| Free Cash Flow | 5.06 | 5.74 | 18.89 | 14.88 | 69.37 | 71.69 | 5.41 | 15.83 | 5.47 | 3.96 |

(*continued*)

**Appendix Table 2** Estimates of oil sands supply costs (continued)

| Oil sands supply costs and financial metrics | Projects under current prices and policies | | Projects under EIA (2018) Reference Case Prices, Current Policies | | Projects under EIA (2018) High Oil Price Case, Current Policies | | Projects under EIA (2018) Low Oil Price Case, Current Policies | | Projects under EIA (2018) Reference Case, Current Policies, High Differential | |
|---|---|---|---|---|---|---|---|---|---|---|
| | In-situ | Bitumen Mine | In-situ | Bitumen Mine | In-situ | Bitumen Mine | In-situ | Bitumen Mine | In-situ | Bitumen Mine |
| Key Commodity Price Assumptions ($2018) | | | | | | | | | | |
| WTI Crude Oil at Cushing ($/bbl) | 55.96 | | 102.27 | | 231.21 | | 41.81 | | 102.27 | |
| Natural Gas at AECO/NIT ($/MMBtu) | 2.50 | | 4.46 | | 5.81 | | 3.98 | | 4.46 | |
| Diluted Bitumen at Hardisty ($/bbl) | 43.10 | | 89.50 | | 218.44 | | 31.70 | | 80.52 | |
| Bitumen value at plant gate ($/bbl) | 33.81 | | 78.45 | | 203.52 | | 24.12 | | 65.62 | |
| Diluted bitumen discount to WTI ($/bbl) | 12.86 | | 12.77 | | 12.77 | | 10.11 | | 21.75 | |
| $CAD/$US | 1.22 | | 1.03 | | 1.03 | | 1.3 | | 1.03 | |

Notes: The current prices and policies scenarios rely on WTI and Henry Hub natural gas 60-month forward curves as well as the 60-month forward curve for the Canadian dollar exchange rate as of March 22, 2018. The reference, high oil, and low oil price cases are from Energy Information Administration (2018). All commodity prices are in U.S. dollars. Henry Hub natural gas prices are converted to Alberta Energy Company/Nova Energy Transfer (AECO/NIT) hub prices using a $0.50 per gigajoule discount. Beyond 2023, forward curve prices for oil and natural gas are treated as constant in real terms and exchange rates are treated as constant.

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LETTERS

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# Impact of the Keystone XL pipeline on global oil markets and greenhouse gas emissions

Peter Erickson* and Michael Lazarus

**Climate policy and analysis often focus on energy production and consumption[1,2], but seldom consider how energy transportation infrastructure shapes energy systems[3]. US President Obama has recently brought these issues to the fore, stating that he would only approve the Keystone XL pipeline, connecting Canadian oil sands with US refineries and ports, if it 'does not significantly exacerbate the problem of carbon pollution'[4]. Here, we apply a simple model to understand the implications of the pipeline for greenhouse gas emissions as a function of any resulting increase in oil sands production. We find that for every barrel of increased production, global oil consumption would increase 0.6 barrels owing to the incremental decrease in global oil prices. As a result, and depending on the extent to which the pipeline leads to greater oil sands production, the net annual impact of Keystone XL could range from virtually none to 110 million tons $CO_2$ equivalent annually. This spread is four times wider than found by the US State Department (1–27 million tons $CO_2$e), who did not account for global oil market effects[5]. The approach used here, common in lifecycle analysis[6], could also be applied to other pending fossil fuel extraction and supply infrastructure.**

Globally, the International Energy Agency projects that nearly $700 billion per year will be invested in the upstream oil and gas sector over the next two decades[7]. The resulting infrastructure could contribute to carbon lock-in and further the problem of 'carbon entanglement'[8]. Accordingly, it is crucial to understand the implications of fuel supply infrastructure for future greenhouse gas (GHG) emissions[9]. Innovations such as extraction-based carbon accounting[10] have helped quantify the emissions associated with fossil fuel supply, not just consumption, as has traditionally been the focus. However, few analyses have quantified the incremental GHG emissions impact of new fossil fuel supply infrastructure.

Broadly speaking, construction of fuel supply infrastructure could result in several categories of GHG impacts, including emissions associated with project construction and operation[5]; 'lifecycle' emissions associated with fuel extraction, processing and transportation[5]; and emissions associated with increased fuel use and combustion, due to price effects[6], if the infrastructure increases global fuel supply. Furthermore, high-profile decisions such as the US government approval of Keystone XL could have indirect, political or structural effects, if they lead other decision-makers to reject new fossil fuel infrastructure on GHG grounds or, conversely, lead to a political backlash that inhibits other efforts to reduce emissions[11]. Although this last category may be the most significant, quantification is difficult and inherently speculative, so we do not further analyse it here.

The three categories of emissions impact can be reflected, sequentially, as:

$$\Delta\text{Emissions} = \text{Emissions}_{\text{const}} + \Delta\text{Production} * (\text{EF}_{\text{proj}} - \text{EF}_{\text{ref}}) + \Delta\text{Consumption} * \text{EF}_{\text{ref}} \quad (1)$$

where: $\text{Emissions}_{\text{const}}$ = Emissions associated with infrastructure construction and operation, in tonnes $CO_2$ equivalent ($CO_2$e); $\Delta$Production = Increase in production of fuel handled by infrastructure project; $\text{EF}_{\text{proj}}$ = Emissions factor, per unit of fuel handled, lifecycle basis; $\text{EF}_{\text{ref}}$ = Emissions factor, per unit of displaced, reference fuel, lifecycle basis; $\Delta$Consumption = Increase in fuel consumption resulting from increased production.

Factoring out the increase in production from the second two terms of equation (1) yields:

$$\Delta\text{Emissions} = \text{Emissions}_{\text{const}} + \Delta\text{Production} * \left( (\text{EF}_{\text{proj}} - \text{EF}_{\text{ref}}) + \left( \text{EF}_{\text{ref}} * \frac{\Delta\text{Consumption}}{\Delta\text{Production}} \right) \right) \quad (2)$$

For the Keystone XL pipeline, the State Department has estimated all terms in equation (2) except the final one, a ratio that expresses the extent to which expanding oil sands production may increase global oil consumption. This term, and the effect it embodies, has not received significant attention in discussions of Keystone XL (ref. 12), and is therefore the subject of this Letter.

Microeconomic theory provides the tools to examine the price effect of adding new production capacity to an existing market[13]. Our simple model simulates the interaction between global oil demand[14] and supply[15] for the year 2020, as depicted in Fig. 1.

Similar economic models have been used to analyse the oil market impact of other US policies—for example, for the proposed expansion of oil extraction from the Arctic National Wildlife Refuge[13], expanded production of US biofuels[6], or recent proposals for new coal export terminals that may open new markets for Powder River Basin coal that might otherwise be shut in[16].

For small shifts in supply (830,000 barrels per day (bpd) is less than 1% of global oil supply), and for which the supply and demand curves can be represented as linear, the ratio of increased consumption to increased production can be approximated as the elasticity of demand ($E_d$) divided by the difference between the elasticities of demand and supply ($E_s$; ref. 13):

$$\frac{\Delta\text{Consumption}}{\Delta\text{Production}} \cong \frac{E_d}{E_d - E_s} \quad (3)$$

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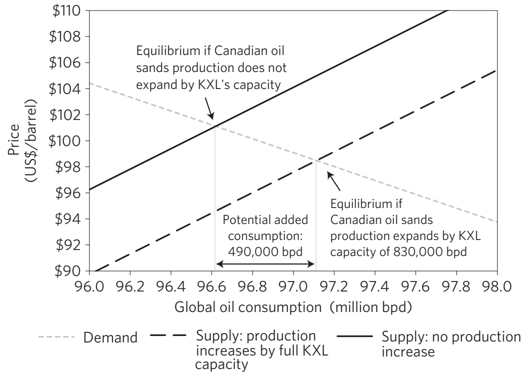


**Figure 1 | Simple model of global supply and demand for oil: how increasing global oil supply via Keystone XL would decrease prices and increase consumption.** We fix the demand curve, and adjust the supply curve to reflect the extent to which Keystone XL might affect Canadian oil sands production, from no effect to the full 830,000 bpd pipeline capacity.

**Table 1 | Increase in annual crude oil consumption per barrel of added Canadian oil sands production under a range of demand and supply elasticities.**

| | Supply elasticity | | |
|---|---|---|---|
| **Demand elasticity** | 0.1 | 0.13 | 0.6 |
| −0.054 | 0.35 | 0.29 | 0.08 |
| −0.20 | 0.66 | 0.59 | 0.25 |
| −0.36 | 0.78 | 0.73 | 0.38 |

Added consumption resulting from each unit of increased production ranges from 0.08 in the case of high supply and low demand elasticities to 0.78 in the case of low supply and high demand elasticities.

Using a long-run elasticity of supply of 0.13, as derived from a global oil supply curve for 2020[15] used by the International Energy Agency[7], and a long-run elasticity of demand of −0.20 from a literature survey[14], equation (3) results in an increase of 0.59 barrels of oil consumed for each barrel (bbl) of increased production. We use this ratio in equation (2); the value is similar to the market adjustment effect [0.5 (±0.2)] found in a recent modelling assessment of the impact of increased biofuel supply on global oil consumption[6].

To characterize uncertainties in the demand and supply relationships around the market-clearing price, we conduct a sensitivity analysis by varying demand elasticities by one standard deviation of values found in a literature survey[17] and supply elasticities across the values found in an OECD review[18], as shown in Table 1, and discussed further in the Methods section. In addition, there are a number of possible effects that our model does not capture—such as the increased availability of highly efficient vehicles, increased switching to non-petroleum transport fuels, or cartel behaviour among a small number of producers—although these effects, as noted in the Methods, are likely to be small.

For all other terms in equation (2), we use the State Department's findings. The GHG emissions impact of pipeline construction is minor, far less than 1 million tons $CO_2$e per year when spread over the pipeline's 50-year lifetime[5]. The GHG emissions of pipeline operation are similarly small, and slightly less than for alternative transport modes such as rail[19]. Because these net effects are small (less than 1 million tonnes $CO_2$e per year), we do not consider them further here.

The difference in lifecycle emissions between the oil sands and a reference crude may, however, be substantial. The State Department estimated the lifecycle emissions factor of oil sands ($EF_{proj} = EF_{oil\ sands} = 569$ kg $CO_2$e/bbl) to be 18% higher than that of the most likely alternative, reference crude, Middle Eastern Sour ($EF_{ref} = 481$ kg $CO_2$e/bbl). Equation (2) therefore suggests a GHG impact of 373 kg $CO_2$e $[(569-481)+481*0.59]$ for each barrel of increased production. It remains possible that the reference crude could have a lifecycle GHG emissions intensity more similar to the oil sands. For example, the State Department provides one set of estimates for oil sands ($EF_{oil\ sands} = 557$ kg $CO_2$e/bbl) and a reference, Venezuelan crude ($EF_{ref} = 552$ kg $CO_2$e/bbl), that differ by only 1% (ref. 5). In this case, the increase in emissions from the substitution of oil sands for the reference crude would be less, but the emissions associated with increased global consumption would be greater, yielding 331 kg $CO_2$e $[(557-552)+552*0.59]$ per barrel of increased production; 11% lower than if substituting for Middle Eastern Sour.

The overall GHG emissions impact of Keystone XL is determined, as shown in equation (2), by the extent to which Keystone XL leads to an increase in oil sands production. Here, the State Department concludes that owing to availability of other pipelines (for example, the proposed expansion of the Trans Mountain pipeline to Vancouver, British Columbia., or the proposed Northern Gateway pipeline to Kitimat, British Columbia) or rail for transporting oil sands crude, the rate of Canadian oil sands extraction would most likely be the same with or without Keystone XL ($\Delta$Production = 0), and therefore there is no GHG emissions impact. Other analysts suggest that the State Department may be overly optimistic, however, and that regulatory, environmental and local community barriers faced by other pipeline and rail options could ultimately restrict expansion of oil sands production[20,21].

The State Department also suggests a case in which the oil sands production could increase by Keystone's full capacity ($\Delta$Production = 830,000 bpd). If future oil prices are lower than expected, specifically $65–$75 per barrel, 'higher transportation costs (due to pipeline constraints) could have a substantial impact on oil sands production levels, possibly in excess of the capacity of the proposed Project'[5]. Oil prices could be lower than now forecast for a number of reasons. For example, technological progress in extraction and processing or the introduction of new low-cost supplies could increase competition among suppliers, shifting the supply curve to the right and lowering prices. Slower-than-expected growth in vehicle use in developing countries, or faster uptake of vehicle efficiency technologies, could shift the demand curve to the left, lowering prices. A combination of these and other factors could also present themselves, as in the US Energy Information Agency's (EIA) Low Oil Price projection, which falls within this range for nearly all of the next 20 years[22]. Furthermore, widespread implementation of GHG emission reduction policies would reduce demand for oil and, in turn, oil prices seen by producers, even though consumers might see higher prices under a carbon price[23–25].

The State Department calculates the GHG impact under the scenario where the Canadian oil sands production increases by the full amount of Keystone XL's capacity as 1.3–27.4 million t$CO_2$e per year, corresponding to the estimates of lifecycle emissions associated with oil sands relative to Venezuelan and Middle Eastern Sour reference crudes, respectively, as discussed above, and assuming perfect substitution of one fuel for another[5]. Using those same lifecycle emissions estimates and assumptions about increased oil sands production, our analysis suggests incremental GHG emissions of 100–110 Mt $CO_2$e, or four times the upper State Department estimate. The sole reason for this difference is that we account for the changes in global oil consumption resulting from increasing oil sands production levels, whereas the State Department does not. (We include results for all supply and demand elasticities

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considered, assuming a reference Middle Eastern Sour crude, in the Supplementary Information).

To put the scale of potential emissions increases from Keystone XL in context, consider that projected emission decreases in 2020 due to various US government climate policies under consideration are estimated to range from 20 to 60 Mt $CO_2e$ for performance standards on industrial boilers, cement kilns and petroleum refiners (combined), and from 160 to 575 Mt $CO_2e$ for performance standards on new and existing power plants[26].

Our simple model shows that, to the extent that Keystone XL leads to greater oil sands production, the pipeline's effect on oil prices could substantially increase its total GHG impact. Similar models are common in the lifecycle analysis literature. Methodological reviews have emphasized the importance of considering market-mediated effects in policy assessments, including in oil markets, and warned against the practice employed by the State Department of assuming perfect substitution of one fuel for another with no consideration of price and scale effects[27,28].

We see no indication that the State Department has considered these market effects in its assessment. The proprietary model it uses (EnSys' WORLD model)[5,29] is opaque with respect to key assumptions and features, such as global oil market response to changes in supply. By contrast, advantages of our simple model—using publicly available supply curves and peer-reviewed elasticities—are transparency and the ability to gauge the magnitude of possible price effects. Similar approaches could also be applied to other pending investments in fossil fuel extraction and supply infrastructure, such as deepwater oil rigs, new ports or rail lines to transport coal, or any of a host of investments under consideration that would expand global fossil-fuel supply[9].

The question of whether Keystone XL will 'significantly exacerbate the problem of carbon pollution' hinges on how much the pipeline increases global oil supply and, through price effects, global oil consumption. This Letter offers no new insights on whether Keystone XL will ultimately enable higher oil sands production levels: there are diverse viewpoints on whether alternative transportation options can fully substitute for Keystone XL. Instead, this Letter focuses on price effects and finds that, to the extent that Keystone XL may increase global oil supply, the State Department's assessment has overlooked the pipeline's potentially most significant GHG impact: increasing oil consumption as the result of increasing supplies and lowering prices.

## Methods

Our model of global oil supply and demand is based on the standard approach for supply and demand analysis, for example as outlined by Perloff[13].

We draw our global oil supply curve for 2020 from the work of Rystad Energy[15]. Similar to other oil supply curves[30,31], Rystad's curve starts with significant conventional oil production in lower-cost regions (such as the Middle East), followed by a more steeply rising segment of higher-cost, less conventional resources (such as deepwater, enhanced recovery, oil sands) that represent the marginal resource. For example, Rystad's curve shows the cost of oil supply in 2020 rising sharply after 90 million barrels per day (mbpd). At the assumed equilibrium consumption level of 96.62 mbpd in 2020, per the US EIA (ref. 22), the real oil price is $101 US$/barrel and the elasticity of supply is 0.13. (See Appendix 1 in the Supplementary Information for the full cost curve.) For simplicity, we assume that Rystad's cost curve does not already include the oil to be carried by Keystone XL. If it did already include it, we estimate that the elasticity of supply at the equilibrium consumption level would instead be 0.11.

To model a demand response, we use the results of a literature review that estimates a long-run demand elasticity of −0.2 (ref. 14) which we use to approximate a demand curve that intersects the supply curve at the equilibrium consumption level noted above.

Assuming small changes in supply, a change in consumption can be estimated as the shift in the supply curve (change in production) multiplied by the elasticity of demand divided by the difference between the elasticities of demand and supply, $E_d/(E_d - E_s)$ (ref. 13).

Demand elasticities tend to be greater in the longer term than in the shorter term[14], as there is more time to invest capital in alternatives such as biofuels or high-efficiency or electric vehicles. Uncertainties also exist on the supply side. Technological progress in oil extraction and processing could flatten the curve, increasing the price elasticity of supply. (The elasticity of supply could also be lower if overall demand was less, and hence the equilibrium price was lower). Alternatively, if depletion effects (whether in conventional or unconventional sources) are stronger than assumed by industry analysts, the curve could steepen, decreasing the elasticity of supply. To characterize these uncertainties, we also consider a range of supply and demand elasticities. For demand elasticities we use a range from one of the studies cited by the literature review we use for our central estimate[17]. For supply elasticities, we use a range reported by the Organization for Economic Cooperation and Development[18].

We do not consider substitution or market effects with other fuels because most oil is consumed in the transport sector, where few alternatives are currently available and where the literature on elasticities of substitution for the key alternative—biofuel—is sparse[32]. If this method were applied to other fossil fuels, however—for example, the expanded supply of coal, which in most sectors, such as power, competes directly with other fuels and energy sources such as natural gas or renewable energy—such substitution effects would need to be considered.

Last, this simple model may miss more complicated effects, such as cartel behaviour, in which a small number of producers may manipulate the oil supply and prices. However, our literature review and analysis of global oil price behaviour found little compelling evidence of effective cartel influence; in the case of recent price increases, we found that low demand price elasticity, low supply elasticity (or the 'failure of global production to increase'), and growing demand from emerging economies are the main determinants of price[14]. Just as underinvestment has tended to lead to price increases[33], investment in supply infrastructure will tend to lead to price decreases. Our simple model also misses any market, and consequent emissions, impact should increased oil sands production increase the supply and depress the prices of refining co-products such as petroleum coke, LPG, or electricity, increasing their consumption and substituting for lower or higher carbon fuels.

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## Author contributions
P.E. and M.L. designed the research. P.E. designed and constructed the spreadsheet model. P.E. and M.L. analysed the results and wrote the paper.

## 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 P.E.

## Competing financial interests
The authors declare no competing financial interests.

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LETTER

# Effect of subsidies and regulatory exemptions on 2020–2030 oil and gas production and profits in the United States

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Supplementary material for this article is available online

## Abstract

The United States has supported the development of its oil and gas industry since the early twentieth century. Despite repeated pledges to phase out 'inefficient' fossil fuel subsidies, US oil and gas production continues to be subsidized by billions of dollars each year. In this study, we quantify how 16 subsidies and regulatory exemptions individually and altogether affect the economics of US oil and gas production in 2020–2030 under different price and financial risk outlooks. We find that, at 2019 average market prices of oil and gas, the 16 subsidies could increase the average rates of return of yet-to-be-developed oil and gas fields by 55% and 68% over unsubsidized levels, respectively, with over 96% of subsidy value flowing to excess profits under a 10% hurdle rate. At lower 2020 prices, the subsidies could increase the average rates of return of new oil and gas fields by 63% and 78% over unsubsidized levels, respectively, with more than 60% of oil and gas resources being dependent on subsidies to be profitable under a 20% hurdle rate. Under all price scenarios analyzed, the highest-value subsidies include federal tax incentives that have existed since 1916, as well as less recognized forms of support such as cost exemptions related to well cleanup and hazardous waste management. Given that these results depend on our chosen definitions of what constitutes a subsidy and, in some cases, assumptions regarding what the unsubsidized practices should be, we also present results for selected subsets of subsidies. By showing which subsidies have the greatest effects in different producing regions of the country, our findings can help policymakers chart a schedule of targeted subsidy repeals and regulatory reforms that can contribute to reducing carbon dioxide emissions and achieving other sustainable development goals. Our results can also help inform how different choices about economic recovery measures in response to the COVID-19 pandemic can shape the US oil and gas industry in the years to come.

## 1. Introduction

In the United States, the federal and state governments have supported the oil and gas industry since the early twentieth century through fiscal, military, scientific, and other forms of support [1–4]. Although people benefit from this source of energy [5], the production and combustion of oil and gas are associated with harms to human health and the environment, including air, water, and hazardous waste pollution and climate change [6–10]. Since 2009, twenty major world economies—including the US—have pledged to eliminate 'inefficient' and 'wasteful' fossil fuel subsidies [11, 12]. However, fossil fuel producer subsidies persist in the US, with some estimates totaling $20 billion per year, though estimates can vary widely depending on the methodologies and definition [13, 14].

The US is currently the world's top oil and gas producer [15]; its crude oil and gas production have grown by over 100% and 65% respectively since 2005, largely owing to developments in horizontal drilling and hydraulic fracturing techniques [16]. While the role of the US government in developing these techniques is well understood [3], what is less appreciated is how numerous subsidies combine to boost profitability and, by extension, production levels of oil and gas. As a few studies have demonstrated [17–19], if these support mechanisms encourage more exploration and extraction than would otherwise be economically viable, they lock in higher greenhouse gas emissions and perpetuate health, environmental, and financial risks to local communities and the wider public [10, 20–22]. If they flow to profit, they are not fulfilling their stated economic purpose.

In this analysis, we consider subsidies to be those policy measures that confer a financial benefit from the government to a particular industry: here, US oil and gas producers. This definition of subsidy is modeled on that of the World Trade Organization. As in their definition [23], we likewise consider three categories of subsidies: forgone government revenues through tax exemptions and preferences; transfer of financial liability to the public; and below-market provision of government goods or services. These types of measures all reduce the financial costs of fossil fuel production along the supply chain and increase investor returns on a present-value basis [24, 25]. In addition, the industry benefits from regulatory exemptions that lower their production costs at the expense of the health and safety of workers and the public. Examples include, but are not limited to, exemptions and other special provisions under the Clean Air Act, the Safe Drinking Water Act, and the Resource Conversation and Recovery Act that reduce or eliminate the costs of complying with air pollution standards and disposal requirements for hazardous liquid and solid wastes [26, 27]. We contend that regulatory exemptions are another form of market-distorting government policies that benefit oil and gas producers [28].

In this study, we update and expand a previous study by Erickson *et al* [17] to evaluate the influence of 16 subsidies on the economics and investor returns of thousands of individuals fields in the US that are expected to start producing oil and gas between 2020 and 2030, using field-level production and cost estimates from Rystad Energy as of late 2019 [29]. This study incorporates recent changes to US tax law and builds upon the prior study by considering the effects on gas as well as oil production, and provides one of the first field-level assessments on the effects of several environmental regulatory exemptions on oil and gas profitability. Our results can help researchers and policymakers better assess how specific subsidy and regulatory reforms can contribute to achieving climate and other sustainable development goals. The methods used here could also be readily applied to other countries.

## 2. Methods

The methods used in this study are an update and extension of those published in Erickson *et al* [17], and further details, including what we consider as a subsidy and why, are available in that study and in our supplemental methods. Briefly, we develop an upstream cash flow model using field-level production and cost estimates from Rystad Energy's UCube database (November 2019 release) [29], combined with our own assumptions about commodity prices (see supplemental methods), to evaluate the combined and individual effects of the 16 subsidies and regulatory exemptions listed in table 1.

We apply discounted cash flow analysis to model future revenues and costs over a 40 year window in order to assess the economic viability and profitability of an oil- or gas-producing field *with* and *without* subsidies. Though by no means the only investment-appraisal tool used by the oil and gas industry, discounted cash flow analysis is the most widely used one [30]. Since the *with-subsidies* case is the one in place at present in the US, this case is modeled for each oil and gas field using the stream of operating costs, capital costs, and production foreseen by Rystad Energy. The *without-subsidies* case is then constructed by modifying this baseline case to account for each subsidy, one by one. This process results in a full set of cash flows for both the *with-subsidies* and *without-subsidies* cases, but also for each point in-between as each subsidy is sequentially peeled back. While our approach of comparing the *with-subsidies* and *without-subsidies* cases allows us to isolate the effect of the 16 measures we analyze, it should not be read as an assessment of whether or not the tax treatment of the oil and gas industry as a whole is 'neutral', which is a common—if much debated—concept in the petroleum taxation literature [31].

For regulatory exemptions, we note that quantifying the associated public health damages and risks (i.e. externalities) are beyond the scope of this study. Instead, we take a more limited view and estimate the value of these exemptions to oil and gas producers in terms of the costs firms would experience if such exemptions were removed. This approach therefore does not capture the full social and environmental costs (e.g. health damages) of these subsidies.

New, undeveloped oil and gas fields provide a prime opportunity for evaluating the influence of subsidies across the full life cycle of capital investment, operations, and field abandonment. Since the geologic and economic data for not-yet-developed fields in which oil and gas resources have already been discovered are more robust than for those with undiscovered resources, our analysis primarily focuses on 1076 'discovered' fields as of November 2019. We also extend our analysis to consider 2539 'undiscovered'

**Table 1.** List of support mechanisms analyzed in this study. Our central analysis (figures 1 and 2) includes all mechanisms listed. We also present some results for Subset A (marked with *), which only includes six federal subsidies that were identified in the US government's 2015 self-review for the G20 [13]; and Subset B (marked with §), which includes all subsidies listed except for Fed. rylt., State tax, Legacy cleanup, and Road maint.. See supplemental methods for modeling approach for each subsidy and further details.

| Category | Subsidy | Abbreviated subsidy name used in figure 1 | Applies to oil and/or gas producers? | Description |
|---|---|---|---|---|
| Forgone government revenues | Excess of percentage over cost depletion*§ | Pct. depl. | Oil, gas | Allows eligible producers to deduct a portion of the gross value of their production each year rather than standard deduction rules that limit deductions to invested capital over the producing life of the mineral deposit, thereby allowing deductions that may exceed actual investment. |
| | Expensing of intangible exploration and development costs*§ | IDC | Oil, gas | Allows producers to immediately deduct many drilling and field development costs that for other industries would be capitalized (and deducted over a longer time-frame). |
| | Accelerated amortization of geological and geophysical expenses*§ | Geo & Geo | Oil, gas | Allows independent producers to amortize geological and geophysical expenses over two years instead of recovering these costs through standard depletion. |
| | Tax exemptions for master limited partnerships (MLPs) *§ | MLP | Oil, gas | Enables firms to avoid corporate income taxes, a special allowance available predominantly to oil and gas transmission pipelines. As a result, producers experience reduced transport costs. |
| | Federal royalty exemptions for gas used on site, flared, or vented*§ | Free flare fed. | Oil, gas | Operators are not required to pay royalties on gas that is flared, vented, or consumed on site to the federal government. |
| | Below-market royalty rates on federal lands | Fed. rylt. | Oil, gas | Onshore fields located in federal lands are subject to below-market royalty rates on gross production. |
| | State severance and production tax exemptions for gas used on site, flared, or vented§ | Free flare state | Oil, gas | Operators are not required to pay taxes on gas that is flared, vented, or consumed on site to state governments. |
| | Below-market state severance, excise, and production taxes | State tax | Oil, gas | Some states (such as Pennsylvania, Ohio, and California) charge very low severance, excise, and production taxes on oil and gas production. |
| Transfer of financial liability to the government | Inadequate insurance coverage for offshore oil spills or accidents*§ | Offshore spill | Oil | Federal government requires proof of insurance to cover oil spill 'removal' but not for full extent of damages, thereby transferring risk to the public since other clean-up mechanisms (for example, Oil Spill Liability Trust Fund) are inadequate, under-pricing this risk to producers. |
| | Inadequate bonding requirements for site closure and reclamation§ | Ltd bonding | Oil, gas | In many states, oil and gas producers are required to post bonds to cover the risk of producers failing to adequately perform well closure and clean-up. However, jurisdictions routinely allow producers to provide assurance for less than the actual known costs of closure and reclamation of wells, transferring risk to the public. |

(Continued.)

**Table 1.** (Continued.)

| Category | Subsidy | Abbreviated subsidy name used in figure 1 | Applies to oil and/or gas producers? | Description |
|---|---|---|---|---|
| | Inadequate fees for legacy plugging and abandonment | Legacy cleanup | Oil, gas | Firms and state orphan well funds do not have to pay sufficient fees to address legacy plugging and abandonment costs. This liability is estimated to be more than $100 billion nationally. |
| | Inadequate liability insurance for oil train accidents[§] | Rail risk | Oil | Oil spills or other accidents can occur during oil transportation by rail, but are generally not adequately insured. This underpricing of liability for oil transport could affect the price producers receive and therefore be an indirect form of support. |
| Below-market government provision of goods and services | Public coverage of road damage costs | Road maint. | Oil, gas | Firms are inadequately charged for road maintenance and restoration relative to the damage caused by relatively heavy loads associated with oil and gas activities. |
| Inadequate regulations that endanger public health and safety | Regulatory exemptions for hazardous solid wastes from oil and gas production[§] | Solid waste | Oil, gas | Solid wastes (including drill cuttings and sediments/sludges associated with wastewater) are exempt from hazardous waste regulations under the Resource Conservation and Recovery Act (RCRA). |
| | Regulatory exemptions for wastewater from unconventional oil and gas production[§] | Wastewater | Oil, gas | Wastewater from unconventional oil and gas production is exempt from hazardous waste regulations under RCRA and its disposal via underground injection is exempt from the Safe Drinking Water Act (SDWA)'s Underground Injection Control program. |
| | Inadequate safety standards for oil transport by rail[§] | Rail safety | Oil | More than 60% of rail cars used to carry oil remain below new safety standards finalized in 2015, and these standards remain below the National Transportation Safety Board's recommendations. |

fields, as well as 3109 already-producing and 870 'under-development' fields in order to develop a more complete picture of future US oil and gas production.

We rely on three related investor return metrics: net present value (NPV), internal rate of return (IRR), and breakeven price. NPV is the sum of all future cash flows discounted to present value taking into account the company's investment hurdle rate. Hurdle rates of 10%–20% are often used in the oil industry [30]. Investors would expect a project with a positive NPV to make a net profit and one with a negative NPV to lose money. The breakeven price and the hurdle rate each correspond to the values that return an NPV of zero, whereby a firm would theoretically proceed if the project's IRR was at least greater than its hurdle rate or if the project's breakeven price was lower than the market oil or gas price.

The percentage of subsidy-dependent resource can be calculated from the volume of oil or gas resource with NPV < 0 in the *without-subsidies* case and NPV > 0 in the *with-subsidies* case out of the total volume of resource with NPV > 0 in the *with-subsidies* case. (All other fields with NPV < 0 in the *with-subsidies* case are assumed to not proceed). The fraction of subsidy value that goes towards excess profits can be estimated by tallying how subsidies affect the NPV of each field. For fields with NPV greater than zero in the without-subsidies case, all subsidy value goes towards excess profits. For fields in which the NPV is less than zero in the without-subsidies case and greater than zero in the with-subsidies case, subsidies provide economic viability up to the point at which NPV reaches zero, before flowing to excess profits thereafter.

We analyze the effect of subsidies on each field at a wide range of gas and oil prices and under two different hurdle rates. Since the majority of US fields co-produce oil and gas (as well as natural gas liquids (NGLs) and condensate), and since oil and gas prices are foreseen by the US EIA to increase roughly in tandem, we identify and assume simple linear relationships between Henry Hub gas prices and Brent oil prices, as well as for related NGLs and condensate liquids, based on historical and future prices projected by the EIA's 2020 Annual Energy Outlook [32]. We also test a price-sensitivity scenario in which oil and gas prices are more decoupled. This means that we test four different sensitivity scenarios in total (1-2): 'central' linear oil–gas price relationship at 10% and at 20% hurdle rates; and (3-4) 'alternative' more decoupled oil–gas price relationship at 10% and at 20% hurdle rates.

In addition, we perform two analyses that consider subsets of the 16 subsidies listed in table 1: (subset A) an analysis with six federal subsidies that were identified by the US government in its 2015 self-review to the G20; and (subset B) an analysis that excludes four subsidies for which there could be material differences of opinion on what the unsubsidized practice should be: below-market royalty rate on federal lands, public coverage of road damage costs, inadequate fees for legacy plugging and abandonment, and below-market state taxes on extraction. Further details on how we define these sensitivity and additional analyses and the associated results are provided in the supplementary methods.

Rystad Energy's UCube database is widely used for assessing future oil and gas investments, including in annual assessments by the International Energy Agency (e.g. *World Energy Investment 2020* and *Oil 2020* reports [33, 34]). Rystad gathers its data for US oil and gas fields from a mix of government sources (e.g. US Department of Energy statistics), publicly available company-specific information (annual reports, press releases, and investor presentations), and its own research and modeling. To our knowledge, Rystad's data have not been subjected to open peer review, but their estimates have been put to some scrutiny in academic and popular articles [35, 36]. Rystad's estimates of field-level costs used here include the capital and operating costs associated with developing and operating a new oil or gas field once it has already been accessed, explored, and appraised (see supplemental methods), and therefore exclude consideration of costs for (or subsidies that apply to) property acquisition and other 'sunk' costs that occur before final investment decision (e.g. debt related to prior investments).

## 3. Results

### 3.1. Effect of subsidies on investor returns

We first illustrate how the 16 subsidies considered here can increase the profitability of prospective oil and gas production across the US. Figure 1 shows the individual and combined effects of the 16 subsidies on the production-weighted IRR—a metric commonly used to estimate the profitability of potential investments—averaged across discovered but not-yet-developed oil and gas fields in the US and major-producer states, assuming oil and gas prices at average 2019 levels of $USD_{2019}$ 64/barrel of oil and $USD_{2019}$ 2.6/mmbtu of gas [37]. At a national level, the subsidies could altogether increase the IRR of these new oil fields by 16 percentage points (figure 1(a)), and of these new gas fields by 13 percentage points (figure 1(e)), representing increases of 55% and 68% over unsubsidized levels, respectively. At the individual field level, the median subsidy-induced increases in IRR are 8 percentage points for both oil and gas fields (with interquartile range of 4–15 and 4–14 percentage points respectively, and both with positively skewed distributions) (figure S1 available online at stacks.iop.org/ERL/16/084023/mmedia).

As can be seen in figure 1, at both the national and state levels, the subsidy with the greatest effect

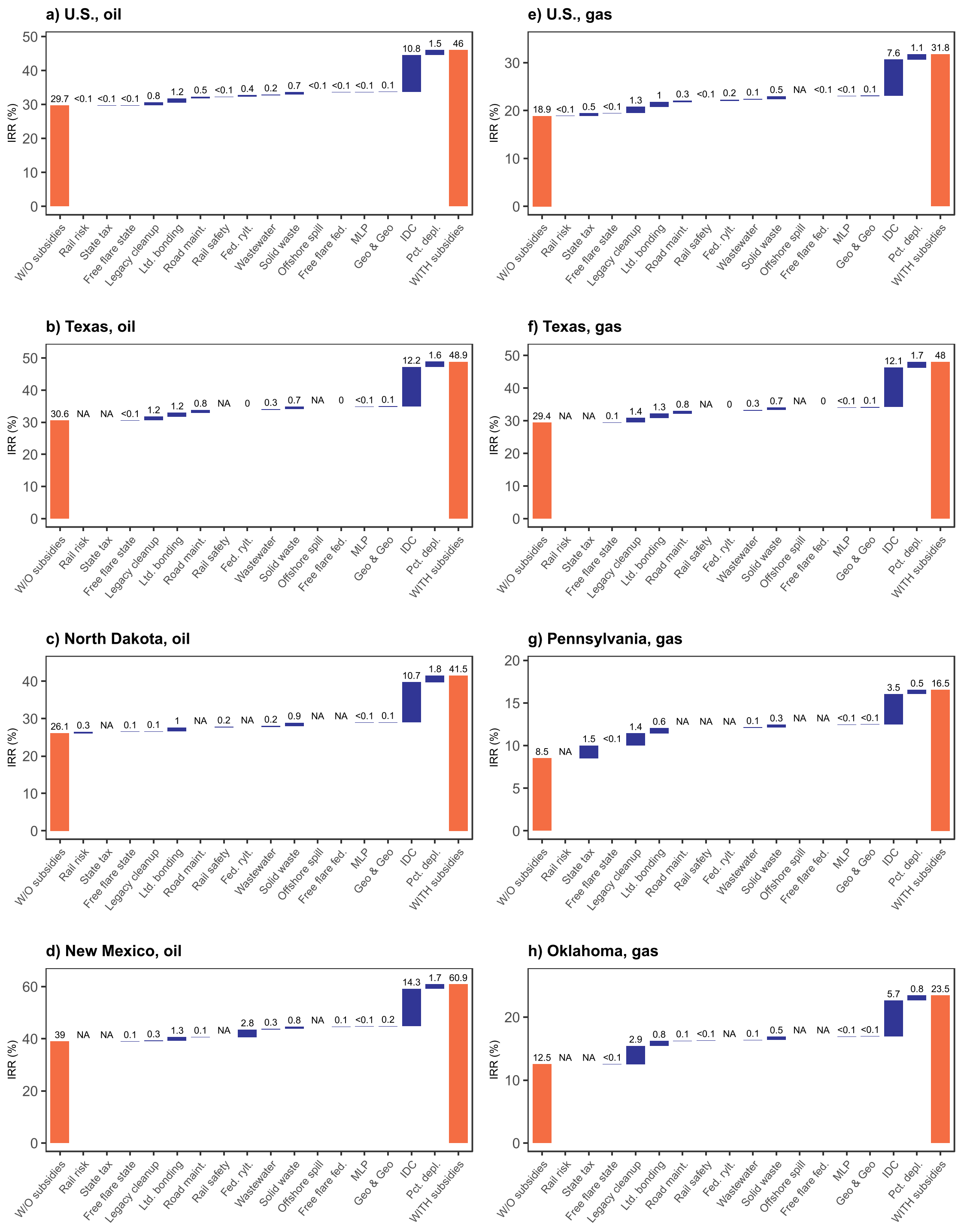


**Figure 1.** Average effect of each subsidy on the internal rate of return (IRR) of new, not-yet-producing oil and gas fields, at average 2019 prices of USD2019 64/barrel of oil and USD2019 2.6/mmbtu of gas. The charts on the left show the oil production-weighted average change across all oil-producing fields, and the charts on the right show the gas production-weighted average change across all gas-producing fields, in the US and in a given state. Fields that never reach a positive IRR (even with subsidies) are not included. 'NA' labels indicate that a given subsidy was not applied to that fuel and/or state. The underlying data for this figure, as well as for other major oil- and gas-producing states not shown, can be found in the supplemental materials.

by far is the expensing of intangible exploration and development costs (IDC), which increases US-wide average IRR by 11 and 8 percentage points for oil and gas fields respectively. Another tax incentive that is relatively beneficial at both the national and state levels is the excess of percentage over cost depletion allowance, which boosts average IRR by 1–1.5 percentage points. Additionally, other forms of forgone government revenues can also be important in applicable geographies. These include below-market taxes on oil and gas extraction in certain states such as Pennsylvania, as well as below-market royalty rate on federal lands, which has remained at 12.5% since 1920 [38], even as rates on non-federal land (and in federally controlled offshore waters) are known to be higher [39, 40].

Beyond these long-standing tax incentives, our results reveal that three other support measures can also yield relatively substantial benefits. The first two represent the transfer of financial liability for the costs of well closure and reclamation from the producers to the government, a loophole that has resulted in a large inventory of abandoned and unplugged wells across the US ('legacy cleanup'), and which will continue to grow as producers are allowed to drill new wells with insufficient bonding requirements ('Ltd bonding'). Our estimates suggest that for major producing states with large inventories of abandoned wells such as Texas, Pennsylvania, and Oklahoma, the legacy cleanup costs could amount to more than $10 billion in each state, which are vastly in excess of existing states' abandoned well funds. The third subsidy stems from an exemption under the Resource Conservation and Recovery Act that allows solid wastes from oil and gas extraction to be treated as non-hazardous, despite the fact that oil and gas wastes can be contaminated with hazardous chemicals (such as arsenic, lead, and barium) and naturally occurring radioactive materials [41, 42]. We estimate that this exemption reduces costs for operators by $60 000 per well on average.

Although the relative importance of the 16 subsidies analyzed in this study appears to be quite robust to the oil-gas price environment (figures (S2) and (S3)), the precise magnitudes by which they individually and altogether boost investor returns are sensitive to the oil and gas prices foreseen by investors and, ultimately, experienced by project developers. For example, the annual average 2020 Brent oil and Henry Hub gas prices were roughly $USD_{2019}$ 40/barrel and $USD_{2019}$ 2mmbtu, respectively. At these prices, the subsidies would altogether increase the IRR of new oil and gas fields averaged across the US by around 7 percentage points over unsubsidized values of about 11% and 9%, representing increases of 63% and 78% over unsubsidized levels, respectively (figures S2(d) and S3(d)). For individual oil and gas fields, the median subsidy-induced increases in IRR are 5 percentage points (figure S4).

The magnitudes by which the subsidies boost investor returns are also sensitive to which support mechanisms from table 1 are considered as subsidies. In our central case (e.g. as presented in figures 1 and 2), we consider all of them; some policymakers or other researchers may also be interested in particular subsets. For example, the six federal subsidies from table 1 that were flagged as such in the US governments' 2015 self-review to the G20 account for the majority of the combined effect of the 16 subsidies analyzed in our central case. Assuming prices at average 2019 levels of $USD_{2019}$ 64/barrel of oil and 2.6/mmbtu of gas, the 16 subsidies considered in our central case lead to a combined increase in US-wide average IRR by 16 percentage points for new oil fields and by 13 percentage points for new gas fields, of which 12 and 9 percentage points stem from the six federal subsidies in subset A for oil and gas fields, respectively (table S1). Table S1 also shows results for a different subset that excludes four subsidies from our central case: below-market royalties (Fed. rylt.) and state taxes (State tax), public coverage of road damage costs (Road maint.), and inadequate fees for legacy plugging and abandonment (Legacy cleanup). Excluding these four subsidies would lead to a combined subsidy-induced increase in average IRR of 15 percentage points for new oil fields and 11 percentage points for new gas fields (table S1).

### 3.2. Effect of subsidies on production

The extent to which the subsidy-induced increases in project returns affect decisions regarding new well drilling and field development and, ultimately, oil and gas production, will depend strongly on the oil–gas price environment. Such decisions will also depend on investor hurdle rates—the minimum IRRs investors are willing to accept in exchange for their provision of capital. Given these uncertainties, in this section, we translate the fundamentals of project returns into a comprehensive view of prospective US oil and gas supply using supply-cost curves. Cost curves are a common framework for assessing oil and gas production under alternative price outlooks, and for this reason may be a more flexible tool for assessing the effect of subsidies.

First, we calculate the breakeven economics for each of the 1076 'discovered' (but not yet producing) fields analyzed for figure 1. For each field, the breakeven oil or gas price is the price at which the field becomes economic, i.e. its NPV becomes zero. This metric allows us to assess which fields are likely to be developed or not for any given market price of oil or gas.

Next, to develop a more complete picture of future US oil and gas production, we expand our analysis of breakeven economics to include an additional 3109 already-producing fields, 870 fields that are 'under development' (will start producing soon), and 2539 'undiscovered' fields for which oil and gas reserves are unproven but believed to be economically recoverable (as of late 2019). We include these fields so that we can display a complete picture of prospective US oil and gas production in 2030 as cost curves, shown in figure 2. We pick the year 2030 to provide a sufficiently distant view on the effect of subsidies on the next decade's worth of new investments, as well as to align with the target year of current negotiations under the Paris Agreement on climate change, which could have substantial bearing over fossil fuel markets.

As shown in figure 2(a), at a hurdle rate of 10% and an example oil price of $USD_{2019}$ 64/barrel, most new oil fields would be developed with or without the subsidies analyzed here. This is because the breakeven price of oil in the major discovered and undiscovered

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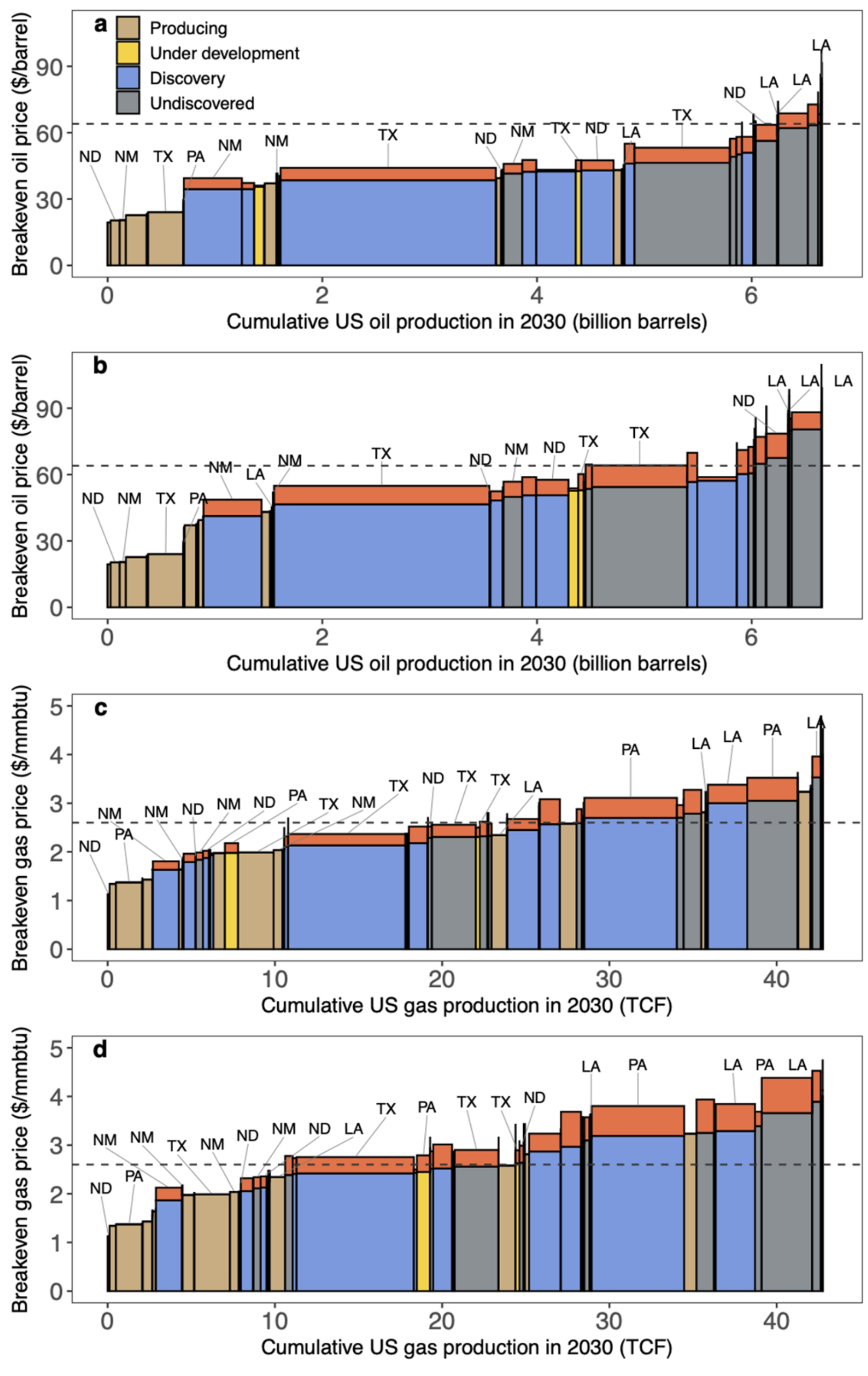


**Figure 2.** Cost curves of US oil and gas production in 2030 assuming a 10% (a), (c) versus 20% (b), (d) hurdle rate. Each bar represents the oil or gas production-weighted average of the breakeven price across all fields in a given US state and life-cycle stage. The red-shaded block above each bar shows the decrease in breakeven oil price ($USD_{2019}$/barrel, Brent basis) or breakeven gas price ($USD_{2019}$/mmbtu, Henry Hub basis) due to the cumulative effect of 16 subsidies applied in this analysis. The subsidies decrease the breakeven cost of new, not-yet-producing fields, moving the cost curve downward. The horizontal dashed line in each subplot shows the average 2019 oil or gas price of $USD_{2019}$ 64/barrel and 2.6/mmbtu, respectively. The cumulative production is shown in units of billion barrels of oil or trillion cubic feet (TCF) of gas.

oil deposits in Texas, North Dakota, and New Mexico is well below $USD_{2019}$ 64/barrel. In such a case, almost all of the subsidy value—shown as the red-shaded rectangle on each state's 'block' of oil—would go directly to producer profits, also called rents. As shown in figure 2(c), the economic outlook for gas production is not as strong, at least at the 2019 average gas price of 2.6/mmbtu. At this price, while gas co-produced on oil-dominant discovered fields in Texas, New Mexico, North Dakota, and other states would be profitable to produce, much of the discovered and undiscovered gas in the Appalachian states of Ohio, Pennsylvania, and West Virginia would not be viable, or just barely viable with subsidies.

As this example helps to illustrate, the cost curves for oil and gas can help analysts determine not just under what conditions oil and gas are profitable, but under what conditions subsidies make the most difference to economic viability and therefore spur additional production. Subsidies have the greatest effect on oil or gas field viability where each cost curve is 'flat'—that is, where small changes in breakeven price would lead to relatively large quantities of oil or gas becoming viable. For example, the gas cost curve (figure 2(c)) is relatively flat at 2.6/mmbtu, and 23% (4 out of 17 trillion cubic feet) of prospective 2030 gas production from discovered and undiscovered fields would depend on subsidies to proceed. For oil, the cost curve (figure 2(a)) is steep at $USD_{2019}$ 64/barrel, at which 6% (330 out of 5200 million barrels) of prospective 2030 oil production would depend on subsidies to proceed. Figures 2(b) and (d) show the 2030 oil and gas cost curves, respectively, at a higher hurdle rate of 20%. At this hurdle rate but the same prices of 2.6/mmbtu and $USD_{2019}$ 64/barrel, 31% and 21% of prospective 2030 gas and oil production would be subsidy-dependent, respectively.

Many oil fields co-produce gas and vice versa, as well as condensate and NGLs. This means that uncertainties in how oil and gas prices will co-vary in the future will also impact the cost curves shown. In figure 2, we assume that oil and gas prices increase linearly together, following the price outlook of the reference scenario in the EIA's 2020 Annual Energy Outlook. As one example of an alternative scenario in which oil and gas prices are more decoupled, we ran a sensitivity analysis in which oil prices are lower for a given gas price (see supplementary methods). Under such a scenario, the gas cost curve shifts upwards as the breakeven gas price generally increases, leading to a higher subsidy-dependence of prospective gas production (figure S5).

### 3.3. Effect of subsidies on market prices and $CO_2$ emissions

How subsidies to fossil fuel producers affect $CO_2$ (and other greenhouse gas) emissions depends on the extent to which subsidies depress the market prices for oil and gas below what they would otherwise be. Fully quantifying all of the possible changes in fossil fuel markets as a result of these price changes would require a comprehensive, multi-sector energy model, such as the National Energy Modeling System (NEMS) used by the US government or one of the numerous energy-economic models used to assess global energy markets and greenhouse gas mitigation options. Nonetheless, the cost curves shown in figure 2 can help to provide a rough indication of how subsidies make oil and gas cheaper than they otherwise would be, since the subsidies reduce the costs of developing new oil and gas fields and therefore, in turn, the market price of these fuels.

To estimate the combined effect of US subsidies on the consumer price of oil and, in turn, global oil consumption and $CO_2$ emissions, we situate the US oil fields analyzed here in a global oil cost curve for 2030 drawn from Rystad Energy [29]. US oil fields occupy about half of all oil in the upper part of the cost curve, i.e. above $USD_{2019}$ 50/barrel, and therefore function as future sources of supply growth that help set the long-run price of oil (figure S6). Under a 10% discount rate, the combined effect of the 16 subsidies analyzed here are estimated to reduce the breakeven price of 'discovered' and 'undiscovered' oil by an average of $USD_{2019}$ 6.24/barrel. This would translate into half as big of a decrease in the average, global breakeven price in this range, i.e. $USD_{2019}$ 3.12/barrel. (A more complete picture of the effect of subsidies would also consider similar decreases in breakeven prices in other countries' oil resources as a result of those countries' subsidies.) Assuming the oil market is effectively global, and using a simple oil-market model with an elasticity of global oil demand of −0.3 and of oil supply of 0.6 [25, 29], such a decrease in the cost of oil supply would translate into a decrease in the price of oil of $USD_{2019}$ 2.08/barrel, and an increase in oil consumption of 374 million barrels annually. This approach, while simplistic, allows for a transparent and straightforward means of estimating global effect on oil consumption. Further assuming about 0.4 tonnes $CO_2$ per barrel of oil [43], this translates into increased global emissions from oil combustion of about 150 million tonnes $CO_2$ annually. This figure would be proportionally less if fewer of the 16 subsidies considered here were included (table S2).

To estimate the combined effect of subsidies on the consumer price of gas, we similarly apply a simple economic model, parameterized by elasticities, and assuming the US gas market is effectively domestic. Specifically, assuming a long-run elasticity of US gas demand of −0.29 [44] and elasticity of supply of 2 (derived from the slope of the supply curve in figure 2(c)), a decrease in the cost of gas supply of $USD_{2019}$ 0.33/mmbtu due to the subsidies considered here (under a 10% discount rate) would translate into a decrease in the price of gas of $USD_{2019}$ 0.29/mmbtu and an increase in gas consumption of 0.83 Qbtu (0.80 TCF) in 2030. We do not translate this into changes in $CO_2$ emissions since, unlike for oil, which has few higher-carbon potential substitutes, gas competes both with coal (with roughly twice the carbon intensity per unit of energy) and renewables (with very low carbon) in the power sector, leading to counteracting, and highly uncertain, effects on emissions [45, 46].

### 3.4. Influence of oil-gas prices, financial risks, and other factors on the role of subsidies

As discussed, the benefits that subsidies confer to new oil and gas investments are sensitive to a number of external factors such as the oil–gas price environment, discount rate, and tax regimes, as well as to the underlying projections of future production versus capital and operating costs. Under market conditions and projections in 2016, Erickson *et al* [17] estimated that, at a 10% nominal discount rate and prices of $USD_{2016}$ 50/barrel for liquids and $USD_{2016}$ 2.65/mmbtu for associated gas, a similar set of subsidies increased average IRRs for discovered but not-yet-producing oil fields by 9 percentage points, with 47% of future oil production from these fields depending on subsidies to be economically viable.

Under the same prices and discount rate assumption (converted from $USD_{2016}$ to oil and gas prices of $USD_{2019}$ 54/barrel and 2.8/mmbtu respectively), this study estimates that subsidies increase average IRRs for discovered, not-yet-producing fields by 16 percentage points, such that 10% of future oil production from discovered fields would be dependent on subsidies. The greater effect on overall returns, but lower subsidy-dependence of oil projects in this study is consistent with general trends towards cost reductions and productivity improvements in the US shale industry over the last few years. Specific factors include (1): the reduction in the US corporate income tax rate from 35% to 21%; (2) cost reductions in the industry (mainly for proppant and pressure pumping) [47]; and (3) productivity improvements [48], which, combined with (2), lead to projections of lower operating costs per unit of production. All of these three factors have led to increased net profits, thereby reducing subsidy dependence. In addition, higher well productivity rates have amplified the value of the IDC subsidy by enhancing the difference between a *with-subsidy* case in which drilling costs can be immediately deducted and a *without-subsidy* case in which such costs would be deducted over time, in proportion to production volumes (see supplemental methods).

Nevertheless, the economics and, in turn, subsidy-dependence of the industry also depends on other factors, including the perceived risks of developing new oil and gas fields, whether due to reduced access to capital or due to uncertainty in market demand for oil and gas. Indeed, there is mounting evidence that the perception of risk for US oil and gas investments has increased markedly, even before the COVID-19 crisis hit in early 2020, such that investors may now be demanding higher minimum rates of return approaching 20% [49]. As previously described, at 2019 prices of $USD_{2019}$ 64/barrel of oil and 2.6/mmbtu of gas and a 10% hurdle rate, we estimate that only 4% and 22% of discovered but yet-to-be-developed oil and gas resources would be subsidy-dependent, respectively. Under these conditions, over 96% of subsidy value would flow directly to excess profits. On the other hand, at 2020 prices of $USD_{2019}$ 40/barrel of oil and $USD_{2019}$ 2/mmbtu of gas and a 20% hurdle rate, 61% of new oil and 74% of new gas resources would be subsidy-dependent for profitability. Under these conditions, around 75% of subsidy value would flow to excess profits. Figure S7 provides further details on how much future oil and gas resources from discovered fields would depend on subsidies, and how much subsidy value would flow to excess profits, under the four different scenarios of oil–gas prices and hurdle rates tested in this study.

## 4. Discussion and conclusions

How a country chooses to support different sectors of its economy involves a complicated set of considerations, driven as much by politics as economics or human needs. This study quantifies how existing oil and gas producer subsidies provided by the US federal government and some individual state governments could influence industry profitability, fossil fuel production, and global climate change over the next decade. These subsidies also have local health and environmental implications for communities living near oil and gas extraction or waste management sites. In the US, approximately 17.6 million people live within about a mile of at least one active oil and/or gas well [50]. A growing body of epidemiological studies have linked unconventional oil and gas development to harmful health outcomes, including but not limited to exacerbation of asthma and adverse pregnancy and birth outcomes from exposure to air pollutants [21, 22, 51, 52].

Our study demonstrates the large extent to which long-standing tax preferences for the oil and gas industry, namely the IDC and percentage depletion allowances, help to increase profits and/or boost production. This result is commensurate with the US government's findings in a 1980 assessment, which found that, 'By lowering the tax liability of oil producers, these incentives increased cash flow which in turn provides additional funds for capital formation' and, specifically, that these subsidies 'stimulated a large increase in output and had a depressing effect on the price of oil' [53]. The IDC subsidy has been in place since 1916 [54], and the percentage depletion allowance since 1926 [55]. While the terms of these subsidies have been modified over time, our analysis shows that they remain potent incentives for new investment.

In addition, our findings reveal that other indirect forms of government support can also confer financial benefits to the oil and gas industry. Specifically, oil and gas producers especially benefit from not having to pay the full costs of well closure and remediation, or those related to proper management and disposal of hazardous wastes generated from their operations. Instead, these avoided costs are transferred to taxpayers in the direct form of cleanup expenses as well as indirect public health risks.

The insights provided by our analysis can also help to illustrate how different choices about economic recovery measures in response to the COVID-19 pandemic can shape the US oil and gas industry and, potentially, broader fossil fuel markets. For example, if prices remain at low levels, our findings indicate that subsidies will mute the pandemic-related shock to the industry, while allowing more oil and gas to be produced than otherwise would be, resulting in increased global oil consumption and $CO_2$ emissions. By contrast, if prices rebound to pre-COVID-19 outlooks, our results indicate that the vast majority of fossil fuel subsidy value will instead go directly to industry profits, which itself would help fortify the industry's incumbent status and delay the low-carbon transition.

We note here that our approach of using discounted cash flow analysis and investor metrics, though appropriate for assessing prospective investments, does not capture all of the costs of running a business or the performance of previous investments. As has been widely reported, shale-focused US companies in recent years have, in aggregate, not generated profit on their investments [56, 57]. The modeled field-level returns reported here (e.g. as in figure 1) need not correlate with company or sector-wide performance of past investments.

Although this study considers most major subsidies to oil and gas identified by the US government [13], plus several others, the list of support measures analyzed is by no means exhaustive, and we cannot paint a complete picture of the role of subsidies in shaping the entire US energy system. How particular energy sources gain dominance is the subject of a complicated set of factors and conditions [58], and is also driven by learning effects and increasing returns to scale over time that our cash-flow approach cannot capture. Furthermore, we have not considered the effects of broader environmental and social externalities that effectively act as subsidies—for example, the public health damages associated with oil and gas production and consumption due to air pollution and climate change [10, 59], or the macroeconomic risks of over-reliance on fossil fuels [60, 61]. Nor have we considered that subsidies also apply to other aspects of the US energy system, such as for coal, nuclear, or renewable sources, and which may have overlapping, or competing effects as compared to the subsidies analyzed here for oil and gas.

Beyond the sensitivities to future price outlooks and investment risks, our results are also dependent on the definitions and methods used to quantify fossil fuel subsidies, which are themselves subject to different interpretations and uncertainties. The largest uncertainty in defining a given subsidy can come from articulating its counterfactual: that is, what costs an oil or gas producer would experience were the subsidy not in place. For some—such as the IDC subsidy—the special tax treatment and corresponding shifting of costs is clearly specified in the US tax code, and the counterfactual is relatively unambiguous. For others, such as the costs experienced in managing drill cuttings as hazardous waste (were they not exempted from regulation)—requires the construction of a counterfactual based on likely hazardous constituents and resulting treatment costs. Our rationale for each selection and the associated uncertainties are described in the supplementary methods. Further, we present results for two subsets of subsidies that exclude some of the support mechanisms. For example, at 2019 average prices, the overall subsidy-induced increases in expected returns of new oil and gas fields by the 16 subsidies in table 1 would be reduced by 24% and 32%, respectively, if only six federal subsidies that the US government previously reported to G20 were considered. Alternatively, the effect on expected returns would be less—about 11% and 18%, respectively, for oil and gas fields—if we excluded four subsidies for which there could be substantial differences of opinion on what the unsubsidized practice should be. Regardless, the excluded items could benefit from further scientific, economic, and legal research to clarify the counterfactual and, by extension, extent of each subsidy.

Overall, our results and approach can help to advance research methods for evaluating the effects of fossil fuel subsidies and their reform. For example, while several globally focused efforts have catalogued and quantified fossil fuel subsidies, relatively few have performed detailed, field-level analyses to evaluate how different government support measures may individually and in combination influence investment decision-making and profitability of fossil fuel projects [62]. Moreover, 'bottom-up' insights drawn from field-level cost information, like we do here, are important for developing more nuanced and accurate approaches to representing fossil fuel supply in 'top-down' national and global energy-economic models. Currently, most widely used integrated assessment models do not consider these types of 'real world' investment dynamics in oil and gas fields, and may therefore be under-estimating the potential contribution of fossil fuel subsidy repeal to the attainment of the emission-reduction goals of the Paris Agreement [25]. As our study reveals, fossil fuel subsidy repeal and associated increases in investor risk perceptions could reduce fossil fuel supply and, as a result, greenhouse gas emissions. Our methods could be applied to other countries to increase public transparency and understanding of how specific fossil fuel subsidies are undermining efforts to pursue climate mitigation [25] and other sustainable development goals, such as those related to responsible production

(SDG 13) [63] and to ensuring access to affordable, reliable, sustainable and modern energy for all (SDG 7).

## Data availability statement

Source data for figure 1 can be found in supplementary data 1. The data that support other plots within this paper and other findings of this study are available from the corresponding author upon reasonable request. The raw data analyzed by the authors are available from Rystad Energy in their UCube database, but restrictions apply to the availability of these data, which were used under licence for the current study, and so are not publicly available. Raw data are available from the authors upon reasonable request and with permission of Rystad Energy.

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**STATE OF MICHIGAN**
**MICHIGAN PUBLIC SERVICE COMMISSION**

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| In the matter of **Enbridge Energy, Limited Partnership's** declaratory request that it has the requisite authority needed from the Commission for the proposed Line 5 pipeline Project. | )<br>)<br>)<br>)<br>) | Case No. U-20763 |

## PROOF OF SERVICE

I hereby certify that a true copy of the foregoing **Direct Testimony and Exhibits of Peter Erickson, Direct Testimony and Exhibits of Peter Howard, Direct Testimony and Exhibits of Elizabeth Stanton, and Direct Testimony and Exhibits of Jonathan Overpeck** were served by electronic mail upon the following Parties of Record, this 14th day of September, 2021.

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