The Law and Science of Climate Change Attribution

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I. INTRODUCTION

There is overwhelming scientific agreement that human activities are changing the global climate system and these changes are already affecting human and natural systems. The observational record shows that the planet is getting significantly warmer, with eighteen of the nineteen warmest years on record occurring since 2001.[1] Other observed changes include rising sea levels, ocean warming and acidification, melting sea ice, thawing permafrost, increases in the frequency and severity of extreme events, and a variety of impacts on people, communities, and ecosystems. There

1. *State of the Climate: National Climate Report for January 2019,* NOAA NAT'L CENTERS FOR ENVTL. INFO., https://www.ncdc.noaa.gov/sotc/national/ [https://perma.cc/8BDB-CUP9] (last visited Nov. 30, 2019).

are multiple lines of evidence linking these changes to anthropogenic influence on climate.[2]

The consequences of climate change have received increasing attention in recent years, as communities around the world have been hit hard by climate-related natural disasters. The 2017 Atlantic hurricane season was the costliest on record: seventeen named storms, including six major hurricanes, pummeled the Caribbean and southern United States, causing unprecedented flooding and devastation totaling approximately $370 billion (USD) in worldwide damages.[3] That same year, Southeast Asia experienced unusually heavy monsoon rains which killed over 1,200 people and affected over 45 million people across Bangladesh, India, and Nepal.[4] There were also a number of record-breaking wildfires in 2017 and 2018, which claimed hundreds of lives, thousands of structures, and millions of acres in the Western United States, British Columbia, Europe, and Siberia.[5] Other disasters include chart-topping heat waves throughout the Northern Hemisphere, severe droughts in Central and South America and the Middle East, and record-breaking rainfall and flooding events across all continents.[6] Significant advances in

2. U. S. GLOBAL CHANGE RESEARCH PROGRAM (USGCRP), FOURTH NATIONAL CLIMATE ASSESSMENT: VOLUME II, 25–26 (2018).

3. Brian K. Sullivan, *The Most Expensive U.S. Hurricane Season Ever: By the Numbers*, BLOOMBERG (Nov. 26, 2017), https://www.bloomberg.com/news/articles/2017-11-26/the-most-expensive-u-s-hurricane-season-ever-by-the-numbers [https://perma.cc/VM95-LVU6].

4. *Press Release: 16 Million Children Affected by Massive Flooding in South Asia, with Millions More at Risk*, UNICEF (Sep. 2, 2017), https://www.unicef.org/infobycountry/media_100719.html [https://perma.cc/L285-MNNH].

5. *See, e.g.*, Luis Gomez, *California Wildfires: New Records Set by 2018 Fires*, SAN DIEGO UNION-TRIBUNE (Nov. 12, 2018), https://www.sandiegouniontribune.com/opinion/the-conversation/sd-california-2018-wildfires-burn-with-historic-impact-20181112-htmlstory.html [https://perma.cc/E5PV-V6YF]; Dale Kasler, *Worst Wildfire Year Since When? More California Acres Have Burned in 2018 Than the Past Decade,* SACRAMENTO BEE, Nov. 16, 2018, https://www.sacbee.com/latest-news/article221788220.html; *Facts and Statistics: Wildfires*, INS. INFO. INST. (2019), https://www.iii.org/fact-statistic/facts-statistics-wildfires [https://perma.cc/FJ5C-2R8N]; Melissa Etehad, *Wildfires Rage Across Europe as Countries Battle Intense Heat Wave*, L.A. TIMES (Jul. 28, 2018), https://www.latimes.com/world/la-fg-wildfires-europe-20180728-story.html [https://perma.cc/B56L-GBFM]; Andrew Freedman, *Heat Records Fall in the Arctic as Fires Erupt in Sweden and Siberia*, AXIOS (Jul. 19, 2018), https://www.axios.com/heat-wave-records-wildfires-sweden-norway-siberia-b351dce3-b3ef-41ee-b94e-e7833bd224e2.html [perma.cc/KQP2-2V9K].

6. *See* Daniel Levitt et al., *Deadly Weather: The Human Cost of 2018's Climate Disasters—Visual Guide,* THE GUARDIAN (Dec. 21, 2018), https://www.theguardian.com/environment/ng-interactive/2018/dec/21/deadly-weather-the-human-cost-of-2018s-climate-disasters-visual-guide [https://perma.cc/LCE7-JCYF]; Jason Samenow, *Red-hot Planet: All-time*

climate change detection and attribution science—the branch of science which seeks to isolate the effect of human influence on the climate and related earth systems—have continued to clarify the extent to which anthropogenic climate change causes both slow onset changes and extreme events.[7]

The spike in deaths and costs associated with extreme events and the prospect for slow onset changes with irreversible impacts has inspired a marked increase in the number of lawsuits seeking to hold different actors—particularly governments and fossil fuel companies—accountable for their contribution to or failure to take action on climate change. For example, state and local governments across the United States have filed over a dozen lawsuits against major oil and gas producers, alleging that they knowingly contributed to climate change by extracting and selling fossil fuels, obscuring the science of climate change, and fighting policies aimed at mitigating climate change.[8] In Germany, a Peruvian farmer has brought a lawsuit against RWE, the German utility, seeking compensation for damages associated with a melting glacier the farmer alleges are in part attributable to the defendant's direct GHG emissions.[9] Lawsuits have also been filed against various national governments seeking to compel regulations aimed at curtailing the production and use of fossil fuels and otherwise reducing national GHG emissions.[10] These are among the first, not the last, of these types of cases.

Attribution science is central to the recent climate litigation, as it informs discussions of responsibility for climate change. Indeed, detection and attribution science has long been central to climate litigation, from the lawsuit filed in 1986 by New York City and Los Angeles challenging the National Highway Transportation Safety

heat Records Have Been Set All Over the World During the Past Week, WASH. POST (July 5, 2018), https://www.washingtonpost.com/news/capital-weather-gang/wp/2018/07/03/hot-planet-all-time-heat-records-have-been-set-all-over-the-world-in-last-week/ [https://perma.cc/JY6A-DQAU].

7. U. S. GLOBAL CHANGE RESEARCH PROGRAM, CLIMATE SCIENCE SPECIAL REPORT, FOURTH NATIONAL CLIMATE ASSESSMENT (2017) [hereinafter NCA4]. For a more detailed definition, see Section II(A), *infra*.

8. Michael Burger & Jessica Wentz, *Holding Fossil Fuel Companies Accountable for their Contribution to Climate Change: Where Does the Law Stand?*, 74 BULL. OF THE ATOMIC SCIENTISTS 397 (2018).

9. Lliuya v. RWE AG, VG Essen 15.12.2016 (2 O 285/15) (Germany).

10. MICHAEL BURGER & JUSTIN GUNDLACH, U.N. ENV'T PROGRAMME, THE STATUS OF CLIMATE CHANGE LITIGATION 10–26 (2017).

Administration's decision not to prepare an environmental impact statement for the model year 1989 Corporate Average Fuel Economy standard, despite the standard's potential global warming impacts,[11] through the lawsuit filed in January 2019 by traditional cultural leaders from the Ksanka Band of the Ktunaxa Nation and various conservation groups challenging the U.S. Fish and Wildlife Service's decision to approve a silver and copper mine project in Montana without considering new data concerning the threats climate change poses to threatened grizzly bear and bull trout populations.[12] Climate science also plays a central role in policymaking and planning, particularly where decisions need to be made about how to allocate the costs of mitigating and adapting to climate change. Recently, researchers have been developing methodologies to link harmful impacts that were caused or exacerbated by climate change to specific emitters, with an eye towards holding emitters and other responsible parties accountable in court for their contribution to the harms.[13] As the science evolves, so too will its role in the courtroom and in policymaking.

This Article offers a comprehensive, of-the-moment survey of the roles attribution science plays in climate change law and litigation. Our purpose is to provide legal researchers and climate scientists alike with a roadmap and a rundown of the dynamic interactions between attribution science and climate change law, and to indicate some of the ways the fields might influence one another. Part II reviews the current state of attribution science with respect to both slow- and sudden-onset events. Part III describes the role that attribution science has played in recent litigation as well as policy-making and planning activities, focusing primarily on examples from the United States but also drawing on international examples. Part IV discusses future directions in the law and science of climate change attribution, addressing questions such as how attribution science can better support policy-making, planning and litigation; and how plaintiffs and courts can engage with attribution

11. City of L.A. v. Nat'l Highway Transp. Safety Admin., 912 F.2d 478 (D.C. Cir. 1990).

12. Complaint for Declaratory and Injunctive Relief, Ksanka KUPAQA XAʾŁȻIN v. U.S. Fish and Wildlife Serv., No. 9:19-cv-00020-DWM (D. Mont. Jan. 25, 2019).

13. *See, e.g.*, CLIMATE ACCOUNTABILITY INST., THE CARBON MAJORS DATABASE: CDP CARBON MAJORS REPORT 2017 (July 2017); B. Ekwurzel et al., *The Rise in Atmospheric CO_2, Surface Temperature, and Sea Level from Emissions Traced to Major Carbon Producers*, 144 CLIMATIC CHANGE 579 (2017).

science to help resolve questions of liability and responsibility for climate change.

II. SCIENTIFIC UNDERPINNINGS

Since the onset of the Industrial Revolution more than two centuries ago, human activities—especially fossil fuel combustion, land use change, and industrial production—have dramatically impacted earth's climate. As a result of human activities, concentrations of radiatively important agents such as GHGs and aerosols have increased significantly. Carbon dioxide (CO_2) concentrations, for example, have increased by more than 40 percent to levels not seen in at least 3 million years.[14] These changes in atmospheric chemistry have triggered widespread warming and other impacts. Global surface air temperature has increased by approximately 1.8° F since 1900, and ocean heat content has increased by approximately $33.5 \pm 7.0 \times 10^{22}$ joules.[15] As the planet has warmed, Arctic sea ice volume in late summer has decreased by more than 50 percent, mass loss from land-based ice sheets has accelerated, and sea levels have risen by approximately 8 inches since 19001 foot.[16] Warming is also leading to phenological changes, such as longer growing seasons, and impacting all human and natural systems.[17] The frequency, intensity and duration of many types of extreme events are changing dramatically as well. For example, record breaking high temperatures are now far more common than record breaking low temperatures, high water levels on coastlines are increasing dramatically, and the frequency of hydrometeorological extremes—both droughts and floods—is also increasing in many regions.[18]

As climate change has become more and more manifest, our understanding of the climate system has advanced dramatically.

14. WMO Greenhouse Gas Bulletin, No. 13 (Oct. 30, 2017).

15. NCA4 (2017), *supra* note 7, at 11, 82, 365. As a point of reference, the increase in ocean heat content is approximately 580 times larger than world total primary energy supply (TPES). *See* INT'L ENERGY AGENCY [IEA], KEY WORLD ENERGY STATISTICS (2018) (finding that world TPES in 2016 was 13,761 Mtoe, which is equivalent to 5.76×10^{20} joules).

16. *See* NCA4 (2017), *supra* note 7.

17. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE [IPCC], SPECIAL REPORT: GLOBAL WARMING OF 1.5°C (Valerie Masson-Delmotte et al. eds., 2018).

18. IPCC, WORKING GROUP II CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE IPCC, CLIMATE CHANGE 2014: IMPACTS, ADAPTATION, AND VULNERABILITY 982 (Fields et al eds., 2014) [hereinafter IPCC AR5 WGII].

Multiple lines of evidence, including increasingly robust observational data sets, paleoclimate data, process-models of increasing complexity, and physical understandings all point to the central role of human activity in the climate changes described above. For example, it has become clear that the spatial pattern of observed warming generally matches our theoretical understanding and model projections; specifically, high latitude regions are warming faster than the tropics, and the lower stratosphere is cooling.[19] The spatial pattern, or fingerprint, of the warming is thus consistent with increases in GHG concentrations, not alternative explanations such as volcanoes, incoming solar radiation, or internal climate variability. Our ability to link anthropogenically-induced global warming to local impacts has also improved dramatically. The leading scientific body for climate assessment, the Intergovernmental Panel on Climate Change (IPCC), periodically publishes a synthesis of existing research on climate change detection and attribution. In its most recent assessment, the IPCC concluded that "there is new or stronger evidence for substantial and wide-ranging impacts of climate change" across all climate zones and continents.[20] Similarly, the Fourth National Climate Assessment (NCA4) prepared by the U.S. Global Change Research Program (USGCRP) states that "[e]vidence for a changing climate abounds, from the top of the atmosphere to the depths of the oceans."[21]

Overall, the existing body of detection and attribution research is now quite large and the findings are sufficiently robust to support a wide variety of applications, including many of the policy, planning, and legal functions outlined in Section III. But there are also constraints to this research, such as data gaps and uncertainty about model projections, which make it difficult to identify a clear causal chain between a particular emitter or activity and specific impacts or harms associated with climate change.

Below, we summarize the current state-of-the-art in climate change detection and attribution science. We begin by defining core concepts and explaining the basic data sources and analytical techniques used in this research. Next, we discuss the status of

19. Gabriele Hegerl, Francis Zwiers & Claudia Tebaldi, *Patterns of Change: Whose Fingerprint Is Seen in Global Warming?*, 6 ENVTL. RES. LETTERS 4 (2011).

20. IPCC AR5 WGII at 982.

21. NCA4 (2017), *supra* note 7, at 36.

research with respect to different attribution questions and different types of observed impacts. For each attribution category, we discuss the areas where findings are relatively robust and then identify key challenges and takeaways for the utilization of this research in climate change law and litigation.

A. Core Concepts and Terminology

Generally speaking, detection and attribution is a two-step process used to identify a causal relationship between one or more drivers and a responding system. The first step—detection of change—involves demonstrating that a particular variable has changed in a statistically significant way without assigning cause.[22] This is typically accomplished using observational data and historical records. The second step—attribution—involves sifting through a range of possible causative factors to determine the role of one or more drivers with respect to the detected change. This is typically accomplished by using physical understanding, as well as models or statistical analysis, to compare how the variable responds when certain drivers are changed or eliminated entirely.

1. Scope of Detection and Attribution Research

Detection and attribution with regards to climate change can be broadly defined to encompass a range of research aimed at linking human activities to observed changes in the climate system and corresponding impacts on natural and earth systems. This area of research can be broken down into several interrelated parts or research streams:

> **Linking climate change to anthropogenic drivers:** How are human activities affecting the global climate system?
>
> **Linking impacts to climate change:** How do changes in the global climate system affect other interconnected natural and human systems?
>
> **Identifying the relative contribution of various emission sources and land use changes:** To what extent have different sectors, activities, and entities contributed to anthropogenic climate change?

22. David R. Easterling et al., *Detection and Attribution of Climate Extremes in the Observed Record,* 11 WEATHER CLIMATE EXTREMES 17 (2016); Gabriele C. Hegerl et al., *Good Practice Guidance Paper on Detection and Attribution Related to Climate Change*, *in* MEETING REP. OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE EXPERT MEETING ON DETECTION AND ATTRIBUTION OF ANTHROPOGENIC CLIMATE CHANGE 2 (Thomas Stocker et al. eds., 2010).

For the purposes of brevity, we refer to these three areas of research as *climate change attribution*, *impact attribution*, and *source attribution*, recognizing that these terms may be defined differently in other papers. This approach is roughly consistent with that taken by the IPCC in past assessments, specifically the division between Working Group I (WGI), which synthesizes research on the physical science basis for anthropogenic climate change, and Working Group II (WGII), which synthesizes research on the observed and predicted impacts of climate change. However, there is no IPCC analog for "source attribution" as that term is defined in this paper,[23] and this third research stream is commonly viewed as a field distinct from the "detection and attribution" research covered in the IPCC reports. Nonetheless, source attribution deals with a fundamental attribution question relevant to some of the law and policy issues described in Section III and therefore warrants discussion in this paper.

We also discuss *extreme event attribution* as a separate category of attribution research. This is because extreme events do not fit neatly into the "climate change attribution" or "impact attribution" categories. Weather is part of the climate system, but extreme events are often discussed as "impacts" of climate change, and there are unique challenges associated with efforts to ascertain the effect of climate change on a particular extreme event. (These challenges bear similarities to the challenges associated with impact attribution).[24]

The line between "changes in the climate system" and "the impacts of climate change" is not always clear. The IPCC defines the *global climate system* as "the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere, and the biosphere, and the interactions between them."[25] This broad definition is necessary to

23. The IPCC does compile some of this data in the WGI report but there is no systematic effort to synthesize research on the relative contributions of different actors or activities to climate change. There is also a third IPCC Working Group (WGIII) that assesses literature on the scientific, technological, environmental, and social aspects of mitigation of climate change.

24. *E.g.*, extreme weather events are discussed in the IPCC WGI report as a source of evidence for climate change attribution, but also in the IPCC WGII report as an example of how climate change will affect human and natural systems.

25. IPCC, WORKING GROUP I CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE IPCC, CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS 1451 (Stocker et al. eds., 2013) [hereinafter IPCC AR5 WGI].

capture the highly interconnected nature of these components: changes in ocean heat content (hydrosphere), sea ice (cryosphere), carbon sequestration (biosphere), and volcanic eruptions (lithosphere) can all affect the atmosphere and vice versa. The variables studied in this research are often referred to as *essential climate variables*.[26]

The IPCC defines *impacts* or *effects* to include *physical impacts* such as floods, droughts, and local sea level rise, as well as any other "effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period."[27] In many cases, a change in an essential climate variable (e.g., sea level rise) could be viewed as a "physical impact" of climate change. For the purposes of this paper, we classify studies on regional changes in essential climate variables as "climate change attribution" where the primary goal of the study is to better understand how humans are affecting the global climate system, and we classify studies on floods, droughts, and local sea level rise as "impact attribution" where the primary goal of the study is to better understand how climate change is affecting a particular region or locale.

It is also important to note that the IPCC uses a different definition of "attribution" when discussing research on climate change attribution (WGI) and impact attribution (WGII): whereas "attribution in WGI quantifies the links between observed climate change and human activity, as well as other external climate drivers," attribution in WGII "generally links responses of natural and human systems to observed climate change, *regardless of its cause*."[28] This reflects standard practice in impact attribution studies, wherein scientists focus exclusively on the relationship between global climate change and observed impacts without seeking to identify the relative contribution of human activity as compared with other external climate drivers.

These different streams of attribution science have begun to converge in recent years. There have been further advances in

26. *The Global Observing System for Climate Essential Climate Variables Data Access Matrix*, NOAA NAT'L CENTERS FOR ENVTL. INFO, https://www.ncdc.noaa.gov/gosic/gcos-essential-climate-variable-ecv-data-access-matrix [https://perma.cc/4ZSH-CMGX] (last visited Dec. 19, 2019).

27. IPCC AR5 WGII, Summary for Policy Makers, *supra* note 20, at 5.

28. *Id.* at 4.

attribution of climate change to anthropogenic activity, as well as burgeoning studies that go beyond the analysis of essential climate variables to examine adverse effects on human systems and public health.[29] Simultaneously, other researchers have been compiling data and developing techniques to identify the relative contribution of different sectors, activities, and entities to changes in atmospheric GHG concentrations.[30] Building on all three research streams, there is now a body of research which aims to link specific entities and/or activities to specific climate change impacts.[31] Below, we bring the streams together, contextualizing them within a broader climate science and risk management context.

2. Data Sources and Analytical Techniques

a. Climate Change, Extreme Event, and Impact Attribution

There are several key sources of information and analytical techniques which are used in the climate change, impact, and extreme event attribution studies. These include: physical understanding, observational data, statistical analysis, and models.[32]

Physical understanding refers to scientific understanding of physical properties and processes. A good example would be the heat trapping effects of GHGs, which can be tested using laboratory and modeling experiments. Physical understanding serves as the basis for developing experiments to evaluate potential interactions across variables in the climate system and related human and natural systems.

Observational data is data which can be observed and measured. Examples include in situ measurements of CO_2 concentrations, surface temperatures, and sea levels; satellite measurements of sea

29. Below, we use the phrase "attribution of harm" to describe studies seeking to link specific harmful impacts on public health and human systems to anthropogenic climate change. This is discussed as a subset of "impact attribution."

30. *See, e.g.*, B. Ekwurzel et al., *supra* note 13, at 579.

31. *See, e.g.*, Richard Heede, *Tracing Anthropogenic Carbon Dioxide and Methane Emissions from Fossil Fuel and Cement Producers, 1854–2010*, 122 CLIMATIC CHANGE 229 (2014).

32. *See, e.g.*, Sophie Marjanac & Lindene Patton, *Extreme Weather Event Attribution Science and Climate Change Litigation: An Essential Step in the Causal Chain?*, 36 J. ENERGY & NAT. RES. L. 265, 271–72 (2018) (noting that the "3 pillars of attribution science" are "(i) the quality of the observational record; (ii) the ability of models to simulate the event; and (iii) our understanding of the physical processes that drive the event and how they are affected by climate change.").

surface temperature, water vapor, precipitation, and sea ice; and aircraft measurements of cyclone wind speed. Observational data is primarily used in conjunction with statistical analysis to detect changes in the climate system, including changes in the frequency and severity of extreme events, and corresponding changes in natural and human systems—specifically, by comparing historical observational data sets with contemporary observations of a particular variable and determining whether there has been a statistically significant change in that variable. A statistically significant change would be detected in observations if the likelihood of occurrence by chance alone is determined to be small (e.g., less than 10%).[33]

Statistical analysis refers to mathematical formulas, models, and techniques that are used in empirical analysis of data. Statistical analysis is used in both the detection and attribution of climate change. For attribution, statistical analysis is used to quantify the probability of an observed change occurring with and without anthropogenic forcing on the climate. For example, scientists use linear regression methods[34] and variants such as "optimal fingerprinting" to determine whether a change in a climate variable is statistically significant or simply part of natural variability.[35] This analysis is part of the detection of climate change and corresponding impacts, but it can also be used to support attribution statements (e.g., a finding that the spatial pattern of warming in the atmosphere was likely caused by anthropogenic emissions because it is statistically unlikely that the spatial pattern would have occurred in the absence of anthropogenic forcing on the climate). This is sometimes referred to as "observation-based" attribution.[36]

In practice, there are very few studies that focus exclusively on observation-based statistical analysis for attribution due to short observation records and complex forcing changes over the

33. IPCC, CLIMATE CHANGE 2014: SYNTHESIS REPORT 121–22 (Rajendra K. Pachauri & Leo Meyer eds., 2014) [hereinafter IPCC AR5 SYR].

34. Linear regression is a statistical method used to summarize and study relationships between two continuous (quantitative) variables.

35. K. Hasselmann, *Optimal Fingerprints for the Detection of Time-Dependent Climate Change*, 6 J. CLIMATE 1957, 1957 (1993).

36. NAT'L ACAD. OF SCI., ENG'G, AND MED., ATTRIBUTION OF EXTREME WEATHER EVENTS IN THE CONTEXT OF CLIMATE CHANGE 51 (2016).

historical period.[37] Model approaches (below) are typically used because: (i) models allow scientists to separate out the effects of different forcings on the observed variable, and (ii) the observed record for many variables is too short to support reliable conclusions, especially given the large variability in the systems being analyzed. That said, observation-based attribution findings can serve as a useful supplement to model-based findings.[38]

Models use quantitative methods, including predictive equations and statistical techniques, to simulate interactions within the climate system. Scientists can thus set up different model experiments to evaluate the effect of one or more climate drivers (like greenhouse gases, aerosols, and solar flux) on one or more variables. For the purposes of attribution, experiments with climate models generally involve at least two sets of simulations, differing only in that one is meant to reflect the world that is, and the other is meant to reflect a "counterfactual" world without anthropogenic climate change (or without some component of anthropogenic climate change). These model simulations are typically run multiple times and for long duration, allowing scientists to better understand the most likely outcomes, as well as a fuller range of potential outcomes. Observational data and physical understanding provide the basis for calibrating and verifying models.

Several modeling centers have now developed standardized climate simulations designed for detection and attribution specifically, based on different parameters (e.g., researchers can evaluate the probability of an event or impact occurring both with and without certain observed changes in the climate, such as changes in sea surface temperature). Due to advances in parallel computing and model simplifications, these can be run rapidly and at high spatial resolution, yielding quick results. Indeed, when the above packages are combined with forecasts of variables with high predictability, such as sea surface temperature, results can be made available *in advance* of actual events. Furthermore, the tools and outputs, and models themselves, are increasingly being made publicly available. This has furthered the proliferation of

37. *Id.*
38. Andrew D. King et al., *Attribution of the Record High Central England Temperature of 2014 to Anthropogenic Influences*, 10 ENVTL. RES. LETTERS, May 1, 2015, at 1; Gabriele C. Hegerl, *Use of Models and Observations in Event Attribution*, 10 ENVTL. RES. LETTERS July 2, 2015, at 1.

attribution research in recent years, as well as an enormous amount of media coverage and public interest in the topic.[39]

Model-based approaches can support more robust attribution statements than the use of observational data and statistical analysis alone. However, models have limitations that should be kept in mind when considering their use in attribution studies. The usefulness of a model for attribution depends on how well the model can reproduce patterns associated with each climate forcing. However, there are uncertainties in our knowledge about how individual climate forcings affect the climate system. While comparing models to observations helps assess model skill, observations cannot tell us all we need to know, for three reasons. First, there is some uncertainty in observational measurements. Second, internal climate variability, unrelated to climate forcing, is difficult to disentangle from climate forcing. Third, because multiple anthropogenic and natural forcings have occurred simultaneously in the past, unpacking the relative contribution of each forcing is nontrivial.

The above challenges exist to a certain degree even for variables like global average temperature where the relationship between rising GHG concentrations and average temperatures is fairly direct. Inevitably, there will be some degree of uncertainty and room for error in model results due to the complexity of the physical systems being modeled.[40] But this does not mean that model results are unsound. To the contrary, uncertainty is prevalent across many scientific disciplines, including disciplines that are frequently relied upon in policy, planning, and litigation,[41] and scientists have tools for managing and communicating uncertainty. The IPCC, for example, uses (i) probabilistic language to describe the assessed likelihood of an outcome or result (very likely, likely, etc.);[42] (ii) terms to describe the availability of evidence to support particular findings (limited,

39. See, e.g., Jane C. Hu. *The Decade of Attribution Science*, SLATE (Dec. 19, 2019).

40. E.g., models may underestimate variability, which can lead to overestimation of the effect of human influence on extreme events, and models may under-sample the range of plausible outcomes.

41. E.g., epidemiology and forensic science.

42. The IPCC defines these probabilistic terms as follows: 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%. In some instances, the IPCC also uses the following terms: extremely likely 95–100%, more likely than not > 50–100%, and extremely unlikely 0–5%. IPCC AR5 WGI, *supra* note 25, at 4.

medium, robust); (iii) terms to describe the level of agreement about findings (low, medium, or high); and (iv) language describing its confidence in the findings (very low, low, medium, high, very high).[43] In individual attribution studies, uncertainty is typically managed and communicated using similar statements about confidence levels and intervals. For example, a study may conclude with 90% confidence that climate change made an extreme event at least twice as likely to occur.[44] Scientists are also constantly refining the techniques used to reduce uncertainty in their analyses, such as through additional and lengthened observational datasets, improvements to models, new analytical methods, and expert judgment.

The most robust attribution approaches combine good observations, physical understanding, rigorous statistical analysis, and detailed models to generate findings, along with clear communication and transparency with respect to research parameters, assumptions made, confidence in findings, and potential areas of uncertainty or bias. Studies that combine sound science with clear communication can generate findings that are sufficiently robust to support a wide variety of applications, but the confidence in and precision of those findings depends on the nature of the change, event, or impact being studied.

b. Special Considerations for Extreme Event and Impact Attribution

Attribution becomes increasingly complex and challenging as the focus of research moves away from long-term, broad-scale changes in the climate system and towards more localized, discrete extreme events and climate impacts. One key challenge is conducting the analysis at the appropriate *spatial and temporal scale*. Whereas climate change attribution as defined in Part II(A)(2)(a) above deals with change at a global or regional scale, typically over a long period of time, extreme event and impact attribution deal with more geographically and temporally distinct forms of change (e.g., how much has sea level risen in a particular city in the past twenty years). Natural variability, unrelated to changes in climate forcing, is larger at fine spatial and temporal scales, making it harder to

43. *Id.*

44. In this statement, the confidence level is 90% and the confidence interval starts at "twice as likely" and has no defined upper bound.

identify signals associated with anthropogenic or other forcings. Some climate forcings, such as aerosols, also differ both in concentration and forcing strength at subregional and subannual scales. Additionally, when models are used to assess extreme events that occur at finer spatial and temporal scales than the models themselves, some type of downscaling or bias correction is needed, which can introduce additional uncertainties.

Impact attribution studies must also account for *non-climate variables*—that is, characteristics of human and natural systems that are not part of the climate system. There are sometimes referred to as *exogenous variables* (i.e., phenomena that are not part of the climate system).[45] Consider a study examining the relationship between climate change, a heat wave, and public health impacts: the study would need to account for both climate variables (e.g., temperature and humidity) as well as non-climate variables (e.g., population risk factors for heat-related morbidity, access to air-conditioned facilities and emergency services) to ascertain the extent to which climate change caused or contributed to observed health outcomes. *Confounding variables*, which influence both dependent and independent variables in a study, are of special concern as they can lead to spurious associations between a driver and an event or impact.[46] The number of exogenous and confounding variables increases as attribution research moves towards an analysis of discrete impacts on humans, communities, and ecosystems.

Due to the difficulty of managing many exogenous variables, most attribution studies focus on just one "link" in the causal chain of anthropogenic climate change. This is often referred to as *single-step attribution*. Examples of single-step attribution include research linking increases in global average temperatures to changes in the atmospheric concentration of GHGs, and research linking increases in local sea level rise to increases in global average temperature. This focus on single-step attribution is apparent in IPCC WGII's approach to impact attribution (which, as noted

45. This may be somewhat of an oversimplification, as many variables which may appear to be "outside" of the climate system are still, to some extent, interdependent with that system.

46. In an impact or event attribution study, the dependent variable would be the impact or event under examination, and the independent variable would be the climate change-related driver of the impact or event (e.g., increases in GHG concentrations or, in some studies, increases in climate variables such as mean temperature).

above, examines how observed climate change is affecting natural and human systems, regardless of its cause).[47]

There is also a growing body of *multi-step attribution* studies. Such studies combine the two inquiries described above: scientists will first seek to identify how one or more core climate variables has changed in response to human activities, and then explore the implications of that change with respect to one or more specific impacts.[48] Multi-step attribution is useful for examining causal relationships in complex systems, but one potential drawback of this approach is that additional, "cascading" uncertainty and potential for error is introduced with each new "step" that is added to the analysis.

c. Source Attribution

Above, we note that source attribution is a distinct field of research that employs different methods and is subject to different constraints. There is some overlap in terms of the data collection and analytical techniques used for source attribution: scientists will use observational data to identify sources of GHGs, as well as physical understanding, statistical analysis, and models to ascertain the relative contribution of GHGs from a particular source or source category to anthropogenic climate change. But source attribution studies also rely on different types of evidence, particularly documentary evidence of GHG emissions and carbon sequestration impacts.[49]

Documentary evidence refers to information contained in documents and reports. For the purposes of source attribution, key sources of documentary evidence include national GHG emissions inventories, corporate GHG disclosures, securities disclosures, and other reports prepared by governments and private actors detailing GHG emissions or carbon sequestration impacts from a particular activity or source. Because such reports are prepared by humans, sometimes pursuant to a political or social agenda, they may

47. IPCC AR5 WGII, *supra* note 20, at 4 n.5.

48. IPCC AR5 WGI, *supra* note 25, at 867–952; Gabriele Hegerl et al., *Good Practice Guidance Paper on Detection and Attribution Related to Anthropogenic Climate Change, in* MEETING REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE EXPERT MEETING ON DETECTION AND ATTRIBUTION OF ANTHROPOGENIC CLIMATE CHANGE 3 (Thomas F. Stocker et al. eds., 2010).

49. For a more detailed discussion of the methods and techniques used in source attribution, see *infra* Part II(B)(4).

contain biases or errors of a different type than those found in raw data.

Source attribution also involves questions that cut across different social and scientific disciplines. Certainly, there is a physical science component to source attribution, as the ultimate goal is to ascertain the physical contribution of the source to anthropogenic climate change. But there are also social and normative questions that come into play when attributing emissions (or sequestration) to a particular source, particularly when trying to assign "responsibility" for emissions. Consider the many different ways that emissions can be "divvied up" across different lines—by stage of economic development, global region, country, sector, company, consumer, etc. Even within these categories, there are different ways of assigning emissions responsibility. For example, when assessing national responsibility for climate change, some have argued that we should not only look at emissions which are directly generated within the country ("territorial emissions") but also consider emissions embodied in products consumed within the country ("consumption-based emissions").[50] Similarly, when assessing corporate responsibility for climate change, there are important questions about the relative responsibility of upstream entities (e.g., fossil fuel producers) and downstream entities (e.g., manufacturers of carbon-intensive products and consumers of fossil fuels) in addition to the entities that directly generate emissions.

Granted, it is entirely possible to avoid such normative questions when publishing information about source attribution. For example, a study could simply provide a breakdown of emissions across different countries (perhaps both CO_2 exporters and CO_2 importers), sectors, etc., without reaching any conclusions about the *responsibility* of different actors or source categories. But in practice, when attribution science is related to law and policy, the question of responsibility is of paramount importance.

50. *See, e.g.*, C40 CITIES CLIMATE LEADERSHIP GROUP, CONSUMPTION-BASED GHG EMISSIONS OF C40 CITIES (2018), https://www.c40.org/researches/consumption-based-emissions [https://perma.cc/9XVC-MCRX]; Zeke Hausfather, *Mapped: The World's Largest CO2 Importers and Exporters*, CARBON BRIEF (May 7, 2017, 11:52 AM), https://www.carbonbrief.org/mapped-worlds-largest-co2-importers-exporters [https://perma.cc/3K2V-EFNE]; DANIEL MORAN ET AL., THE CARBON LOOPHOLE IN CLIMATE POLICY: QUANTIFYING THE EMBODIED CARBON IN TRADED PRODUCTS (2018), https://buyclean.org/media/2016/12/The-Carbon-Loophole-in-Climate-Policy-Final.pdf [https://perma.cc/FS95-N9W4].

B. Survey of Research to Date

1. Climate Change Detection and Attribution

Climate change detection and attribution research examines the effect of human activities on the global climate system, which is broadly defined to include the atmosphere, hydrosphere, cryosphere, lithosphere, biosphere, and the interactions between these components. The primary research question is: how do human-induced changes in the chemical composition of the atmosphere affect other essential climate variables such as temperature, precipitation, sea level, and sea ice? To answer this question, researchers must demonstrate that a detected change is "consistent with the estimated responses to the given combination of anthropogenic and natural forcing" and "not consistent with alternative, physically plausible explanations of recent climate change that exclude important elements of the given combinations of forcings."[51]

The existing body of research leaves little room for doubt that the global climate system is changing and human activities are at least partially responsible for that change; thus, there is no real question as to *whether* anthropogenic climate change is occurring. Scientists have also made considerable progress towards quantifying the effect of human activities on different components of the climate system. However, there is still some amount of uncertainty about the magnitude of the observed changes in the climate system that are due to different climate forcings—such as GHGs, aerosols, and solar radiation.[52] In this section, we

51. IPCC, WORKING GROUP I CONTRIBUTION TO THE THIRD ASSESSMENT REPORT OF THE IPCC, CLIMATE CHANGE 2001: THE SCIENCE OF CLIMATE CHANGE 56 (John T. Houghton et al eds., 2001). While in one sense attribution is easy to define, complex philosophical questions lurk in the background, including the question of how one defines causation. Deterministic causation is a simple binary framing ("A caused B") whereas probabilistic causation has a lower threshold of "A made B more likely than in otherwise would have been." Mike Hulme, *Attributing Weather Extremes to 'Climate Change': A Review*, 38 PROGRESS IN PHYSICAL GEOGRAPHY 499, 500 (2014). Even within the sub-branch of probabilistic causation, emphasized here, it should be noted that the way a problem is framed can influence the findings. See for example, the description of necessary vs. sufficient causality in Alexis Hannart et al., *Causal Counterfactual Theory for the Attribution of Weather and Climate-Related Events*, 97 BULL. AM. METEOROLOGICAL SOC'Y 99, 103–04 (2016).

52. These uncertainties primarily concern: 1) the magnitude of change in other possible drivers of climate changes (such as solar radiation changes); 2) the signature of change expected in the climate system due to human activities and '1' above; and 3) the magnitude of internal climate variability. IPCC AR5 WGI, *supra* note 25, at 867–952.

summarize the state of the terms of observed climate changes and the attribution of those changes to human activities. We focus here on mean changes in essential climate variables on a global and regional scale; changes in extremes and changes in local weather and climate are discussed in subsequent sections.[53]

a. Methods and Parameters

Scientists detect changes in the climate system through in situ measurements, such as the CO_2 readings from the Mauna Loa Observatory in Hawaii, and remote sensing from satellites and other platforms. Some of the key types of data collected through observations include measurements of GHG emissions and concentrations, atmospheric and surface temperature, water vapor (humidity), precipitation, sea ice, and sea levels. Scientists have also developed techniques to better understand past climatic conditions—for example, scientists can reconstruct paleoclimate conditions by studying the patterns in tree rings and gas bubbles trapped in ice cores.[54] This information offers important insights, including: 1) how sensitive different aspects of the climate system are to different climate forcings at various timescales, and 2) more robust estimates of natural variability than can be gleaned from the relatively short observational record.

Once change has been detected, the next step is attribution. Physical understanding of how the climate system reacts to different forcings is the foundation of climate change attribution. Examples of external forcings include GHGs, atmospheric aerosols, solar radiation, and reflectivity (albedo), all of which influence the balance of energy in the global climate system. Scientists must also have physical understanding of natural variability within the global climate system in order to ascertain whether an observed change in the system is the result of changes in forcings or natural variability.

Drawing on this physical understanding, scientists have developed global climate models that reproduce physical processes in the atmosphere, ocean, cryosphere, and land surface. One of

53. *See infra* Part II(B)(2) ("Extreme Event Attribution") and Part II(B)(3) ("Impact Attribution").

54. For more information on the development of observational techniques and datasets, see IPCC, WORKING GROUP I CONTRIBUTION TO THE FOURTH ASSESSMENT REPORT OF THE IPCC, Climate Change 2007: The Physical Science Basis 93–127 (Susan Solomon et al. eds., 2007).

the most important modeling initiatives is the Coupled Model Intercomparison Project (CMIP), which was launched by the World Climate Research Programme in 1995 to foster collaboration on and ongoing improvement of climate models and to provide a standard set of model simulations to facilitate comparison across models. Leveraging ongoing advances in physical understanding, observations, and computational power, climate models now operate at finer and finer spatial scales, include interactions across more and more components of the climate system, and generate thousands of years of model output under different forcings and initial conditions. As models have grown in sophistication, their utility for climate attribution has grown—models driven by historical greenhouse gas emissions and natural forcings (e.g., volcanoes and solar variability) can now "reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions."[55]

As noted above, there are challenges associated with "downscaling" from a global to a regional or local focus. These challenges are most prevalent in extreme event and impact attribution, but they also appear, to a lesser extent, in climate change attribution studies. This is because many of the observed changes in the global climate system vary on a regional basis—both due to differences in forcings and the higher natural variability at finer spatial scales.[56]

b. Status of Research

The observational record shows that significant changes in the global climate system are occurring. As noted in the IPCC's Fifth Assessment Report (AR5):

55. The IPCC issued this statement with *very high confidence*. IPCC AR5 WGI, Summary for Policymakers, *supra* note 25, at 15.

56. Above, we define "climate change attribution" as research aimed at determining "how human activities are affecting the *global* climate system." Thus, this section is concerned only with studies seeking to understand and attribute regional changes in essential climate variables in order to better understand changes in the global climate change. This section does not discuss studies that evaluate how climate and weather has changed in a region or locale in order to ascertain the effect on that region or locale (e.g., how much have sea levels risen in New York City?)—rather, those are discussed in the extreme event and impact attribution sections.

> Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.[57]

AR5 contained similarly conclusive findings about climate change attribution, particularly with respect to the link between human influence on climate and global warming:

> Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system.[58]

The report also found strong evidence that human activity had contributed to changes in other essential climate variables, such as sea level rise and the loss of sea ice, with different levels of confidence for different variables.[59]

Since AR5 was published in 2014, the observational record of changes in the global climate system has become even more robust, and the rate of observed change has accelerated for many essential climate variables. The body of research attributing these changes to anthropogenic influence on climate change has likewise become more robust, with more recent attribution studies further reinforcing some of the key messages from AR5. Below, we summarize the latest findings in terms of observed changes and attribution to human activity.[60]

i. Chemical Composition of Global Climate System

AR5 found, with *very high confidence*, that atmospheric concentrations of CO_2, methane (CH_4), and nitrous oxide (N_2O)

57. IPCC AR5 WGI, Summary for Policymakers, *supra* note 25, at 4.
58. *Id.* at 15.
59. *Id.*
60. There have been additional advances in the detection and attribution of long-term, time averaged climate variables that do not fit neatly into the five directly societally-relevant categories described here. Examples include fingerprinting of sea level pressure, Nathan P. Gillett, Francis W. Zwiers, Andrew J. Weaver & Peter A. Stott, *Detection of Human Influence on Sea-level Pressure*, 422 NATURE 292, 292–94 (2003), and water vapor, Benjamin D. Santer et al., *Incorporating Model Quality Information in Climate Change Detection and Attribution Studies*, 106 PROC. OF THE NAT'L ACAD. OF SCI. 14778, 14778–83 (2009).

are higher than they have been in 800,000 years, and that the rate of change in GHG concentrations over the past century is unprecedented in the past 22,000 years.[61] This was based on observations from 2011 (the latest data relied upon in AR5), showing that CO_2 concentrations had increased 40% to 391 parts per million (ppm), methane (CH_4) concentrations had increased 150% to 1803 parts per billion (ppb), and nitrous oxide (N_2O) concentrations had increased 20% to 324 ppb, as compared with pre-industrial levels.[62] This trend has continued since AR5 was published, with the latest in situ measurements putting CO_2 concentrations at 410.5 ppm, methane concentrations at 1862.8 ppb, and nitrous oxide concentrations at 332.4 ppb.[63]

Not all of these GHGs remain in the atmosphere, which is part of why it is necessary to look at multiple interconnected systems when detecting and attributing global climate change. AR5 found that the ocean had absorbed about 30% of the emitted anthropogenic CO_2, approximately 125–185 gigatons of carbon (GtC).[64] The uptake of carbon has caused ocean acidification: the pH of the ocean surface has decreased by 0.1 since the beginning of the industrial era, which corresponds with a 26% increase in hydrogen ion concentration (the measure of ocean acidity).[65] This acidification is relatively straightforward to attribute to anthropogenic carbon dioxide emissions specifically.[66] Terrestrial

61. IPCC AR5 WGI at 385. The IPCC also expressed medium confidence that the rate of GHG change was unprecedented in the past 800,000 years. These findings were based on paleoclimate observations from ice cores. *Id.* At the time AR5 was published, ice core records only extended back 800,000 years, so it was not possible to reach conclusions about GHG concentrations before this time. In 2017, scientists extracted a record-breaking 2.7-million-year-old ice core which indicated that CO_2 levels were also well below current levels during that time period. Paul Voosen, *2.7-million-year-old Ice Opens Window on Past*, 357 SCIENCE 630 (2017).

62. IPCC AR5 WGI at 678.

63. *Trends in Atmospheric Carbon Dioxide*, NOAA NAT'L CENTERS FOR ENVTL. INFO., https://www.esrl.noaa.gov/gmd/ccgg/trends/gl_trend.html [https://perma.cc/JKJ5-5GSV] (last visited Dec. 5, 2019); *Global CH_4 Monthly Means*, NOAA NAT'L CENTERS FOR ENVTL. INFO., https://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/ [https://perma.cc/8AE3-RWTJ] (last visited Dec. 5, 2019); *Nitrous Oxide (N2O)—Combined Data Set*, NOAA NAT'L CENTERS FOR ENVTL. INFO., https://www.esrl.noaa.gov/gmd/hats/combined/N2O.html [https://perma.cc/K483-DBHR] (last visited Dec. 5, 2019).

64. IPCC AR5 WGI, Summary for Policymakers, *supra* note 25, at 11–12.

65. *Id.* at 12.

66. *Id.* Bindoff describes it as 'very likely.' *Id.* at 870. In the same report, another ocean chemistry change, a global decrease in dissolved oxygen especially in near-coastal waters, was assessed with medium confidence to be attributable "in part to human influences." *Id.*

ecosystems are also absorbing CO_2, but there is significant uncertainty as to the actual quantity sequestered: research indicates that anywhere from 70–250 GtC have accumulated in terrestrial systems.[67] Accounting for these different absorption pathways is critical in all aspects of climate change detection and attribution (including extreme event and impact attribution) because the effect of GHGs is dependent on where those gases are stored. Uncertainties about historical storage, or sinks, leads to some uncertainty about the magnitude of total historical effect of anthropogenic sources on climate change. More importantly, a changing climate could weaken important sinks. For example, a warming ocean is able to absorb less CO_2, melting permafrost and hydrates could release ancient CO_2 and methane to the atmosphere, and changes in vegetation could increase or decrease the terrestrial carbon sink.

ii. Atmospheric and Surface Temperature

As noted above, AR5 found "unequivocal" evidence that the climate system is warming, concluding that it was "certain" that global mean surface temperature (GMST) had increased since the late 19th century, and "virtually certain" that the global troposphere had warmed since the mid-20th century.[68] With regards to attribution, AR5 noted that observed warming trends were consistent with physical understanding and models of how rising atmospheric GHG concentrations would affect the climate system, and that the trends could not be explained by other forcings or natural variability alone.[69] AR5 quantified the potential contribution of human influence as follows:

67. *Id.* at 12.

68. *Id.* at 4, 161–62. At that time, the observational record showed that: (i) each of the last three decades had been successively warmer, in terms of global surface temperatures, than any preceding decade since 1850, and the first decade of the 21st century was the warmest on record; and (ii) globally averaged combined land and ocean surface temperature had increased by 0.85 [0.65–1.06]°C from 1880 through 2012. *Id.* at 161–62.

69. *Id.* at 869. For example, in terms of natural variability, Atlantic Multidecadal Oscillation (AMO) variability can influence trends, but does not explain 1951–2010 warming. In terms of the magnitude of other possible forcings, only solar radiation changes have been in the direction that would be expected to lead to warming, but the magnitude of change over the period is too low to have contributed to much of the warming. Furthermore, the spatial pattern of the observed warming (e.g., lower tropospheric warming and stratospheric cooling) was also consistent with increases in GHG concentrations, but not other possible forcings. *Id.* at 867–952.

> GHGs contributed a global mean surface warming likely to be between 0.5°C and 1.3°C over the period 1951–2010, with the contributions from other anthropogenic forcings likely to be between –0.6°C and 0.1°C, from natural forcings likely to be between –0.1°C and 0.1°C, and from internal variability likely to be between –0.1°C and 0.1°C.[70]

Based on these estimates, AR5 concluded that "[i]t is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together."[71]

Since then, the warming trend has continued and a number of temperature-related records have been broken.[72] NCA4 found, with *very high confidence*, that: (i) global surface air temperature had increased by 1.8°F (~1°C) between 1901 and 2016, and (ii) "[m]any lines of evidence demonstrate that it is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century."[73] With regards to this attribution finding, USGCRP noted that there are "no convincing alternative explanations" for the observed warming in the past century.[74] USGCRP further found, with *high confidence*, that the likely range of human contribution to global mean temperature increase from 1951–2010 was 1.1° to 1.4°F (0.6° to 0.8°C) and that the likely contributions from natural forcing and internal variability to observed warming are minor.[75] There are a number of other recent studies which have reinforced and strengthened the evidentiary basis for human-induced warming. Analyses of global and regional warmth in 2014, 2015, 2016, and 2017 all found significant anthropogenic influence on record-breaking annual

70. *Id.* at 869.
71. *Id.* at 17.
72. Nineteen of the twenty hottest years on record have occurred since 2000 (with 1998 being the other hottest year), and 2016 was the hottest year on record with an average land and sea temperature that was 0.94°C above the 20th century average of 13.9°C. *See* NOAA, Climate Monitoring, https://www.ncdc.noaa.gov/climate-monitoring/global/globe/ytd/201911.
73. NCA4, *supra* note 7, at 13–14.
74. *Id.*
75. *Id.*

temperatures.[76] One noteworthy study compared observed temperatures in 2016 to annual global temperatures calculated in an ensemble of more than 24,000 years of CMIP5 simulations serving as a "control" for atmosphere (e.g., simulations in which greenhouse gases are kept at pre-industrial levels) and found that the observed 2016 temperatures were roughly 1.3°C higher than the historical average from 1881–1920, whereas the most extreme heat event in the control simulations was only 0.5°C above the historical average.[77] The scientists concluded that the record-breaking heat in 2016 could not have occurred in the absence of anthropogenic forcing on climate.[78]

iii. Oceans and Sea Level Rise

Just as the atmosphere has warmed, so too have the oceans. Two key detection findings in AR5 were that: (i) "[o]cean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*)";[79] and (ii) "[i]t is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010 . . . and it *likely* warmed between the 1870s and 1971."[80] With regards to attribution, AR5 found that "[i]t is *very likely* that anthropogenic forcings have made a substantial contribution to increases in global upper ocean heat content (0–700 m) observed since the 1970s."[81]

NCA4, which contained more recent measurements of ocean temperature, found that total ocean heat content has increased by approximately $33.5 \pm 7.0 \times 10^{22}$ joules since 1960 and that average sea surface temperature (SST) has increased by about 1.3°F ± 0.1°F (0.7°C ± 0.08°C) per century from 1900 through 2016.[82] USGCRP noted that the effect of anthropogenic forcing on this warming

76. *Explaining Extreme Events of 2017 from a Climate Perspective*, 100 BULL. AM. METROLOGICAL SOC'Y (SPECIAL SUPPLEMENT) S1 (2019) [hereinafter BAMS 2017]; *Explaining Extreme Events of 2016 from a Climate Perspective*, 99 BULL. AM. METROLOGICAL SOC'Y (SPECIAL SUPPLEMENT) S1 (2018) [hereinafter BAMS 2016]; *Explaining Extreme Events of 2015 from a Climate Perspective*, 97 BULL. AM. METROLOGICAL SOC'Y (SPECIAL SUPPLEMENT) S1 (2016) [hereinafter BAMS 2015]; *Explaining Extreme Events of 2014 from a Climate Perspective*, 96 BULL. AM. METROLOGICAL SOC'Y (SPECIAL SUPPLEMENT) S1 (2015) [hereinafter BAMS 2014].

77. BAMS 2016, *supra* note 76, at S11–14.

78. *Id.*

79. IPCC AR5 WGI, Summary for Policy Makers, supra note 25, at 8.

80. *Id.*

81. *Id.* at 17.

82. NCA4, *supra* note 7, at 364–65.

trend was clear but did not attempt to quantify that effect, possibly due to uncertainties about the actual magnitude of ocean warming stemming from a lack of long-term data (particularly with respect to deep ocean warming).[83] A recent study on heat content in the upper 2000 meters of the ocean found ocean warming approximately 40–50% faster than what was reported in the IPCC AR5 report.[84]

The increase in ocean heat content has been accompanied by observed increases in sea levels (and rates of sea level rise) since the 1800s. The observational record shows that, between 1901 and 2010, global mean sea level rose by approximately 0.19 meters (~7.5 inches).[85] AR5 found with *high confidence* that the rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia, and that sea level rise has been accelerating quite substantially during this time period (with the most rapid rate of rise occurring since 1993).[86] The primary drivers of rising sea levels to date are thermal expansion of the ocean (caused by increases in ocean heat content) and glacier mass loss. AR5 found *high confidence* in anthropogenic influence on these two drivers in the past half-century, which supported its conclusion that "[i]t is very likely that there is a substantial anthropogenic contribution to the global mean sea level rise since the 1970s."[87] NCA4 contained similar findings.[88]

iv. Cryosphere: Sea Ice, Glaciers, Permafrost, and Snowpack

The observational record has shown a substantial decline in northern hemisphere sea ice, terrestrial glaciers, and snowpack in the past century.[89] But there is considerable geographic variation in the magnitude and rate of the decline, as not all areas are warming at the same rate, and there has actually been a small

83. *Id.* at 366, 367, 381.

84. Lijing Cheng et al., *How Fast Are the Oceans Warming?*, 363 SCIENCE 128 (2019).

85. IPCC AR5 WGI, Summary for Policy Makers, *supra* note 25, at 11.

86. *Id.* For example, AR5 found that it is "*very likely* that the mean rate of global averaged sea level rise was 1.7 [1.5 to 1.9] mm yr^{-1} between 1901 and 2010, 2.0 [1.7 to 2.3] mm yr^{-1} between 1971 and 2010, and 3.2 [2.8 to 3.6] mm yr^{-1} between 1993 and 2010." *Id.*

87. *Id.* at 19.

88. NCA4, *supra* note 7, at 333 (finding that GMSL had risen by approximately 7–8 inches since 1900, and that human forcings had made a "substantial contribution" (*high confidence)* to observed sea level rise).

89. IPCC AR4 WGI, *supra* note 25, at 319–20; NCA4, *supra* note 7, at 303.

observed increase in Antarctic sea ice,[90] which is not fully understood.[91] Setting aside that uncertainty, one clear finding of AR5 was that there are "multiple lines of evidence [which] support very substantial Arctic warming since the mid-20th century."[92] There has also been a "considerable reduction in permafrost thickness and areal extent" in certain northern regions observed over the period 1975 to 2005.[93]

AR5 concluded that anthropogenic influences "very likely contributed to Arctic sea ice loss since 1979 . . . [,] likely contributed to the retreat of glaciers since the 1960s and the increased surface mass of the Greenland ice sheet since 1993 [,] . . . [and] likely [contributed] to observed reductions in Northern Hemisphere spring snow cover since 1970."[94] Similarly, NCA4 found with *high confidence* that it is very likely that human activities have contributed to sea ice loss, glacier mass loss, and northern hemisphere snow extent decline.[95] However, AR5 noted that there is *low confidence* in our scientific understanding of the extent to which anthropogenic influences have driven the aforementioned changes in the Antarctic, and both AR5 and NCA4 noted that there had actually been a small observed increase in Antarctic sea ice in the early 2000s, which would most likely be explained by localized natural variability.[96]

Research shows that these trends have continued and accelerated since AR5 was published. One recent study found that the

90. At least through approximately the middle of the 2010s, at which point a decline appears to have commenced. Claire L. Parkinson, *A 40-y Record Reveals Gradual Antarctic Sea Ice Increases Followed by Decreases at Rates Far Exceeding the Rates Seen in the Arctic*, 116 PROC. NAT'L ACAD. OF SCI. 14414, 14414–23 (2019).

91. Proposed explanations for the increase have included freshening of the waters near Antarctica (thereby facilitating sea ice formation) such as: Richard Bintanja et al., *The Effect of Increased Fresh Water from Antarctic Ice Shelves on Future Trends in Antarctic Sea Ice,* 56 ANNALS OF GLACIOLOGY 120 (2015); decreasing stratospheric ozone (inducing local cooling through changes in atmospheric circulation); and natural variability, John Turner et al., *Non-annular atmospheric circulation change induced by stratospheric ozone depletion and its role in the recent increase of Antarctic sea ice extent*, 36 GEOPHYSICAL RES. LETTERS 1 (2009).

92. IPCC AR5 WGI, Summary for Policy Makers, *supra* note 25, at 9.

93. *Id.*

94. *Id.* at 19.

95. NCA4, *supra* note 7, at 333. *See also* Noah Diffenbaugh et al., *Quantifying the Influence of Global Warming on Unprecendented Extreme Climate Events,* 114 PROC. NAT'L ACAD. OF SCI 4881 (2017), (finding "extremely high statistical confidence that anthropogenic forcing increased the probability of record-low Arctic sea ice extent").

96. IPCC AR5 WGI, Summary for Policy Makers, *supra* note 25, at 19; NCA4, *supra* note 7, at 39, ch. 11.

Greenland Ice Sheet is melting much faster than previously believed: the pace of ice melt has accelerated four-fold since 2003, with Greenland losing approximately 280 billion tons of ice per year between 2002 and 2016—enough to raise the worldwide sea level by 0.03 inches annually.[97]

v. Hydrologic Cycle and Precipitation

Ascertaining the effect of anthropogenic forcings on the hydrologic cycle and precipitation is one of the most challenging areas of climate change attribution. Part of the challenge is detecting change—in some regions spatial gradients of precipitation are large, while historical rainfall records are incomplete and contain mixed findings about the extent to which precipitation patterns have (or have not) changed since the early 1900s. Precipitation is also characterized by large natural variability across a range of timescales ranging from the intra-annual to the centennial. The detection findings in AR5 are therefore mixed: AR5 notes that there is high confidence that average precipitation in mid-latitude land areas has increased since 1951.[98] However, there is only medium confidence in precipitation change averaged over global land areas since 1951, and low confidence in precipitation change prior to 1951.[99]

With respect to attribution, AR5 found that anthropogenic forcings had likely accelerated the hydrologic cycle, primarily through increases in temperature which can induce more rapid evaporation and support heavier rain events. However, the effect on annual mean regional precipitation was unclear. Specifically, AR5 found that:

> It is *likely* that anthropogenic influences have affected the global water cycle since 1960. Anthropogenic influences have contributed to observed increases in atmospheric moisture content in the atmosphere (*medium confidence*), to global-scale changes in

97. Michael Bevis, *Accelerating Changes in Ice Mass Within Greenland, and the Ice Sheet's Sensitivity to Atmospheric Forcing,* 116 PROC. NAT'L ACAD. OF SCI 1934, 1934 (2019).

98. IPCC AR5 WGI, Summary for Policy Makers, *supra* note 25, at 4.

99. *Id.* at 5, 40. A recent paper that integrated climate models, observations, and reconstructions of climate over the past 1000 years detected an elevated risk of hydroclimatic drought (a blend of precipitation deficit and greater evaporation potential associated with warming) consistent with anthropogenic activities as early as the first half of the 20th century. Kate Marvel et al., *Twentieth-Century Hydroclimate Changes Consistent with Human Influence*, 569 NATURE 59 (2019).

> precipitation patterns over land (*medium confidence),* to intensification of heavy precipitation over land regions where data are sufficient (*medium confidence*), and to changes in surface and sub-surface ocean salinity (*very likely*).[100]

The changes in surface and subsurface ocean salinity are noted here due to the link between precipitation and salinity: the observational record shows that regions of high salinity (where evaporation is prevalent) have become more saline, whereas regions of low salinity (where precipitation is prevalent) have become fresher since the 1950s, and these regional trends provide "indirect evidence that evaporation and precipitation over the oceans have changed."[101]

NCA4 also contained mixed findings about the effect of rising GHG concentrations and temperatures on global precipitation patterns. NCA4 noted that there had been a modest rise in annual average precipitation across global land areas, but that this increase could not be deemed statistically significant due to a lack of data coverage in early rainfall records.[102] However, NCA4 did note that there had been an observed increase in arctic precipitation of approximately 5 percent since the 1950s, which had been detected and attributed to human activities.[103]

2. Extreme Event Attribution

Extreme event attribution is a branch of climate change attribution that seeks to understand how human-induced changes in the global climate system are affecting the frequency, severity, and other characteristics of extreme events, such as abnormally hot days, heat waves, tropical cyclones, abnormally heavy rainfall events, and meteorological droughts.[104] This can be contrasted with the

100. IPCC AR5 WGI, Summary for Policy Makers, *supra* note 25, at 17 (emphasis in original).

101. *Id.* at 8.

102. NCA4, *supra* note 7, at 46.

103. *Id.* at 47 (citing Seung-Ki Min et al., *Human-Induced Arctic Moistening*, 320 SCIENCE 518 (2008)).

104. Meteorological drought is defined based on climate variables, especially precipitation and temperature (and to a lesser extent solar radiation at the surface, wind, and atmospheric humidity). Hydrological drought, in contrast, is defined by shortages of available freshwater resources, such as reservoirs, groundwater, and rivers/streams. Hydrological drought, in contrast to meteorological drought, is thus linked more closely to freshwater usage and freshwater needs.

climate change attribution research described above, which focuses on changes in long-term mean variables rather than changes in extremes.

Since 2011, the Bulletin of the American Meteorological Society (BAMS) has been publishing annual reports on *Explaining Extreme Events from a Climate Perspective*.[105] The 2016 and 2017 BAMS reports both contained studies finding that certain extreme events could not have been possible in a pre-industrial climate, all of which were heat-related events.[106] Below, we summarize some of the methods used in this research and the confidence with which scientists have been able to attribute different types of extreme events to climate change.

a. Methods and Parameters

Extreme event attribution is rapidly advancing due to improved understanding of extreme events, improved modeling (including standardized sets of simulations that can be used by a broad research community), lengthening observational datasets and re-analyses (blends of observations and models), some of which now incorporate paleoclimate data like tree rings to develop pre-observational historical reconstructions,[107] more robust remote sensing data sets, and new analytical techniques.[108] Climate and weather models, in particular, are indispensable to most event attribution studies.[109] But statistical analysis can also be used in lieu of, or as a supplement to, models for locations with high quality observational records.[110]

105. *Explaining Extreme Events from a Climate Perspective,* BULL. AM. METEOROLOGICAL SOC'Y, https://www.ametsoc.org/ams/index.cfm/publications/bulletin-of-the-american-meteorological-society-bams/explaining-extreme-events-from-a-climate-perspective/ [https://perma.cc/7P25-68HT] (last visited Nov. 17, 2019).

106. *Id. See also* BAMS 2016, *supra* note 76; BAMS 2017, *supra* note 76.

107. *E.g.*, Marvel et al., *supra* note 99.

108. NAT'L ACAD. OF SCI., ENG'G AND MED., ATTRIBUTION OF EXTREME WEATHER EVENTS IN THE CONTEXT OF CLIMATE CHANGE 1 (2016) [hereinafter NAS 2016].

109. *Id.* at 44.

110. *See, e.g.*, IPCC AR5 WGI, *supra* note 25; Stefan Rahmstorf & Dim Coumou, *Increase of Extreme Events in a Warming World*, 108 PROC. NAT'L ACAD. OF SCI. 17905 (2011); Geert Jan van Oldenborgh, *How Unusual Was Autumn 2006 in Europe?*, 3 CLIMATE PAST 659 (2007); R. Vautard et al., *Extreme Fall 2014 Precipitation in the Cevenees Mountains, in* BAMS 2014, *supra* note 76, at S56; Geert Jan van Oldenborgh et al., *Climate Change Increases the Probability of Heavy Rains Like Those of Storm Desmond in the UK—An Event Attribution Study in Near-Real Time,* 12 HYDRO. EARTH SYST. SCI. DISCUSSIONS 13197 (2015).

Generally speaking, attribution of extremes is more challenging than attribution of means for a variety of reasons, including: 1) the local nature and short duration of many extremes (which makes them difficult to model given the coarse resolution of climate models); 2) the relative rarity of extreme events at a given location (which makes it difficult to detect and attribute a climate change "signal" amidst the large "noise" of natural variability); and 3) the cause-and-effect chains for extremes are often highly nonlinear and may include instantaneous and delayed effects.[111] There are also some modeling challenges that are particularly relevant for extreme event attribution. Christiansen (2015) notes models may be too Gaussian in their extreme events (that is, they don't produce enough of them). Furthermore, skewness—a statistical measure that is sensitive to the tails of the distribution—may vary by season. Scientists have devised statistical approaches to avoid the problems and limitations associated with climate models but all rely on simplifying assumptions.[112] Statistical approaches also tend to make the potentially faulty assumption that historical relationships will persist as the climate changes further.[113] Nonetheless, for many

111. Sebastian Sippel et al., *Warm Winter, Wet Spring, and an Extreme Response to Ecosystem Functioning in the Iberian Peninsula*, *in* BAMS 2016, *supra* note 76, at S80 (citing D.A. Frank et al., *Effects of Climate Extremes on the Terrestrial Carbon Cycle: Concepts, Processes, and Potential Future Impacts*, 21 GLOBAL CHANGE BIOLOGY 2861 (2015) and J.A. Arnone et al., *Prolonged Suppression of Ecosystem Carbon Dioxide Uptake After an Anomalously Warm Year*, 455 NATURE 383 (2008)).

112. For example, a study may assume that climate change can be represented by a polynomial trend and that any residual represents natural variability.

113. NAS 2016, *supra* note 108; Bo Christiansen, *The Role of the Selection Problem and Non-Guassianity in Attribution of Single Events to Climate Change*, 28 J. CLIMATE 9873 (2015). The above is one example of a much broader collection of approaches to addressing climate model limitations. Two other examples include: (1) Hannart proposed using (observed) data assimilation techniques to go beyond climate model ensembles (Hannart et al., *supra* note 51); (2) Numerous authors used optimal fingerprinting techniques (Gabriel Hegerl & Frank Zwiers, *Use of Models in Detection and Attribution of Climate Change*, 2 WIREs CLIMATE CHANGE 570 (2011); Nikolaos Christadis & Peter A. Stott, *Changes in the Geospatial Height at 500 hPa Under the Influence of External Climatic Forcings,* 42 GEOPHYSICAL RES. LETTERS 10798 (2015)) to develop approaches tailored to specific climate models. Based on some historical measure of skill by region and extreme event type, individual models can then be included or rejected in analyses (Andrew D. King et al., *The Timing of Anthropogenic Emergence in Simulated Climate Extremes*, 10 ENVTL. RES. LETTERS 1 (2015)). While such approaches offer advances relative to simple bias correction or using climate model output directly, there remains the possibility that (1) the "winning models" miss key processes/succeed for the wrong reasons, and (2) that they may miss emerging behavior as the planet warms. In both instances, prior strong performance by an individual model might not be indicative of skill in the emerging climate.

variables and locations, extreme event studies can generate reasonably reliable results.

The results of extreme event studies are sensitive to how the research question is framed,[114] and what methodological approaches and datasets are used. Studies may focus on a class of events, such as the 2017 Atlantic hurricane season, or an individual event. This second research area, sometimes called *single-event attribution*, is growing fast, and there are now hundreds of studies seeking to identify the "human fingerprint" on major storms, floods, heat waves, and other events.[115]

One critical framing question is how to define the "extreme event" (or event class) for the purposes of the study. This involves defining physical thresholds for what constitutes an "extreme" and determining the appropriate timeframe and spatial scale of the study, all of which have implications for the results of the study. For example, if in analyzing a heat extreme scientists select as their temperature threshold the maximum temperature achieved, and focus their analysis on the location that reached the highest temperatures during the heat event, the event may appear more exceptional, and the study less broadly relevant, than if the temperature threshold and spatial scale were selected in a more generic way. More fundamentally, there are often multiple metrics that could be used to define an extreme event. For example, a heat wave could be defined based on maximum temperature over the course of the heat wave, heat wave duration, a combination of temperature and moisture in the air, or atmospheric circulation associated with the event. Along similar lines, scientists may tend to study those events where attribution statements are easiest to make and/or where data availability and societal interest are high. These are just a few examples of how event framing can introduce selection bias into an attribution study, thus compromising the study results. Fortunately, selection bias is not an insurmountable obstacle: efforts are underway to standardize how extreme events are defined and selected for analysis, and this would have the

114. Framing includes how the event is defined, what conditioning is included, and how the results are presented (frequency vs. intensity, FAR vs. RR, etc.). NAS 2016, *supra* note 108, at 37.

115. *See, e.g.*, WORLD WEATHER ATTRIBUTION PROJECT, https://www.worldweatherattribution.org/ [https://perma.cc/5US8-M5ST] (last visited Dec. 29, 2019).

added benefit of facilitating more systematic comparison between extreme event studies.[116]

Scientists also have different options for how to go about analyzing the effect of anthropogenic climate change on the event. There are two approaches that dominate extreme event attribution studies.[117] The first is a "risk-based" approach, which focuses on the extent to which climate change has increased the probability (or risk) of an extreme event threshold (such as temperatures of 95°F) being crossed. The second is a "storyline" approach, which focuses on how a variety of factors, including climate change, have affected the characteristics and magnitude of an individual extreme event in its entirety. These approaches both have benefits and drawbacks, as described below.

The risk-based approach to extreme event attribution involves evaluating the extent to which human influence on climate has changed the probability of occurrence of an event at or below a particular threshold (e.g., a heavy rain event of five inches or less).[118] One key concept in such research is the "fraction of attributable risk" (FAR), which can be defined as the relative risk (or risk ratio)[119] of an extreme event or class of events occurring with and without anthropogenic climate change. The risk-based approach typically involves the use of two or more simulations from

116. NAS 2016, *supra* note 108, at 15.

117. The binary classification of risk-based vs. storyline approaches in the main text obscures some other approaches in the literature. As one example, Mann et al. suggested a modification to traditional frequentist statistical inference approach, that builds in prior physical understanding and updates based on experience. Michael E. Mann et al., *Assessing Climate Change Impacts on Extreme Weather Events: The Case for an Alternative (Bayesian) Approach*, 144 CLIMATIC CHANGE 131 (2017). Mann et al. equate it to the conditional storylines approach (for example: surface air temperature increase means more extreme temperatures, and means more moisture in the air), but goes on to propose something quite different. Mann et al. propose to use our full knowledge and expectations (through Bayesian statistics) rather than overweighting avoidance of type 1 errors (claiming a relationship where none exists). Mann et al. note that fear of type one error yields underestimates of risk and of human contributions to extremes (citing Stefan Rahmstorf et al., *Recent Climate Observations Compared to Projections*, 316 SCIENCE 709 (2007)). Mann et al. note that such a precautionary approach to risk is common in other fields where 'do no harm' prevails (citing Gerd Gigerenzer & Adrian Edwards, *Simple Tools for Understanding Risks: from Innumeracy to Insight*, 327 BRIT. MED. J. 741 (2003) (discussing this approach in the context of pharmaceuticals)). So, he says you get more accurate results and *additionally*, from a risk management and ethical perspective, more policy sound results.

118. Myles Allen, *Liability for Climate Change*, 421 NATURE 891, 891 (2003); Hannart et al., *supra* note 51.

119. Risk ratio/relative risk = the ratio of the probability of an outcome in an exposed group to the probability of an outcome in an unexposed group.

a climate model or models which differ in that 1) one simulation is meant to represent the "world that is"—that is with the greenhouse gas concentrations (and sometimes other forcings and changes in boundary conditions like a warming ocean as well) as they have evolved since an earlier reference period, and 2) the other simulation reflects a "counterfactual world" without anthropogenic forcing. Because climate models generally cannot reproduce the observed statistics of the extreme event in question, a corresponding percentile threshold is often used. For example, if a location experiences a five-inch rainfall event, and that is estimated based on observed data to be a once per year event, the precipitation threshold amount in the model that occurs once per year is used for the model comparisons. In mathematical terms:

$$FAR = 1 - P0/P1$$

Where P1 equals the probability of a climatic event (such as a heat wave) occurring in the presence of anthropogenic forcing of the climate system, and P0 equals the probability of the event occurring if the anthropogenic forcing were not present. If FAR equals zero, it means that anthropogenic climate change had no effect on the probability of the event occurring; if FAR equals one, it means that the event could not have happened in the absence of anthropogenic climate change; if FAR equals 0.5, it means that anthropogenic climate change doubled the probability of the event occurring. In multi-event studies, a FAR of 0.5 can be interpreted as meaning that half of the events would not have happened in a world without anthropogenic climate change.

This approach was pioneered by Myles Allen in a 2003 study in which he introduced the concept of FAR as a potential basis for liability for climate damages.[120] Many other studies have since replicated Allen's approach, estimating the FAR for a range of extreme events including heat waves, droughts, and floods. While the term FAR is almost exclusively used in extreme event attribution, probabilistic analysis is prevalent across all forms of attribution,[121] and the concept of "attributable risk" can in

120. Allen, *supra* note 118.

121. The prevalence of probabilistic analysis in both climate change and impact attribution is evident in the IPCC's frequent use of terms such as "likely" and "very likely" when describing human influence on observed changes and impacts.

principle be applied to both mean changes in climate[122] and a variety of climate change impacts. Indeed, the methodology derives from common approaches used in public health and other risk-focused research.[123] The advantages of this approach are that it is relatively well-established, understood, and accepted by the scientific community,[124] and it provides quantitative (probabilistic) findings similar to the sort of epistemological and environmental data that is often dealt with by policy-makers, planners, and courts. Drawbacks include: 1) overreliance on climate models, which as noted earlier, may not be able to simulate some types of extremes with fidelity in a baseline climate, and could have blind spots with respect to how climate change may be modifying key processes influencing the extreme event, and 2) susceptibility to Type II errors (i.e., false negatives) where the signal-to-noise ratio for an event is small due to large internal variability of the atmosphere, which is often the case for dynamically-driven events such as extreme precipitation and storms especially.[125] As such, it can

122. *See, e.g.*, Thomas Knutson et al., *CMIP5 Model-Based Assessment of Anthropogenic Influence on Record Global Warmth During 2016, in* BAMS 2016, *supra* note 76, at S13.

123. The concept of "attributable risk" actually originated in epidemiological studies (e.g., studies seeking to identify the extent to which smoking increases the risk of lung cancer) and is therefore well-suited for evaluating health-related risks. Some efforts have been made to quantify "attributable risk" for climate change-related health impacts, but most of these studies are forward-looking, and there is only a small body of research seeking to determine the attributable risk of observed public health impacts. There is still a strong need for more quantitative analysis on this topic. *See infra* Section II(B)(3); Kristie L. Ebi et al., *Monitoring and Evaluation Indicators for Climate Change-Related Health Impacts, Risks, Adaptation, and Resilience*, 15 INT'L. J. ENVTL. RES. PUB. HEALTH 1943 (2018) (discussing the need to develop quantitative indicators of climate change-related health risks); Wei W. Xun et al., *Climate Change Epidemiology: Methodological Challenges,* 55 INT'L. J. PUB. HEALTH 85 (2010) (discussing challenges in attributing epidemiological risks to climate change); Maud M.T.E. Huynen & Pim Martens, *Climate Change Effects on Heat- and Cold-Related Mortality in the Netherlands: A Scenario-Based Integrated Environmental Health Impact Assessment*, 12 INT'L. J. ENVTL. RES. PUB. HEALTH 13295 (2015) (quantifying the population attributable fractions (PAF) of mortality due to heat and cold, but projecting future impacts rather than attributing current impacts); S.J. Yoon et al., *Measuring the Burden of Disease Due to Climate Change and Developing a Forecast Model in South Korea*, 128 PUB. HEALTH 725 (2014) (quantifying influence of climate change on disease burden in South Korea).

124. *See* NAS 2016, *supra* note 108, at 3.

125. Kevin Trenberth et al., *Attribution of Extreme Climate Events*, 5 NATURE CLIMATE CHANGE 725 (2015).

underestimate the extent to which anthropogenic influence has increased the probability of an event.[126]

Some probabilistic approaches have adopted conditional risk-based analyses, both to simplify the modeling and to control for factors other than anthropogenic effects (such as natural variability, as discussed above).[127] Conditional analyses can in some respects be thought of as a logical outgrowth of the tension between risk based and storyline conceptualizations,[128] since they attempt to isolate the component of extreme events due to anthropogenic warming by treating other components as a control. For example, natural variability of the ocean surface could be treated as a control through a climate model experiment that used the same observed sea surface temperature *patterns* (on the assumption that patterns are due to natural variability) to drive both the counterfactual and anthropogenic forcing simulations, while universally increasing the SSTs by the amount assumed to correspond to anthropogenic forcing. By comparing the results, scientists can largely avoid the criticism that natural variability in ocean temperatures may have led to differences between the two sets of results. However, one price paid is that by simplifying the experiment, full probabilistic attribution is no longer possible, since the experiment was designed so as to ignore the question of how sea surface temperature patterns may be impacted by anthropogenic forcing. Also unaddressed is the possibility that the estimated magnitude of SST warming assumed with the anthropogenic forcing in the experimental design could be wrong. As models become more interactive and experimental designs grow more complex, the problem of what parts to condition become more and more vexing. Harrington summarized conditioning this way:

> More conditioning on the observations of the event will result in an attribution statement with higher confidence (as some possible sources of uncertainty will have been eliminated (Shepherd 2016)), but it will have less relevance to other extreme events which may occur in the future (Otto et al. 2016), and may only quantify the

126. FAR is not well defined when the baseline risk is very low; it also is not designed to be applied to situations with decreasing risk. NAS 2016 , *supra* note 108, at 28. Furthermore, when there are multiple causes, FAR can exceed 1.

127. *See supra* Section II(B)(1).

128. For further discussion of the storyline approach, see *infra* page 32.

> human influence on one part of a causal chain of physical phenomena contributing to the severity of a given event. From the perspective of an in-depth attribution study, multiple perspectives using varying levels of conditioning may therefore be complimentary.[129]

The "storyline" approach to extreme event attribution provides an alternative method for evaluating how climate change affected some or all of the components that come together to form an individual extreme event.[130] This approach is conditional in the sense that it takes the unique extreme event as given; rather than asking whether it could have happened without anthropogenic forcing, it asks how anthropogenic forcing may have modified the given event.[131]

The storyline approach was first introduced by Trenberth et al. (2015) as an alternative to the risk-based approach. The approach begins with the idea that some aspects of climate change are better understood than others, with warming temperature and thermodynamics emerging as first order aspects of climate change that are relatively straightforward to model and understand. Proponents of the approach have emphasized that, by contrast, changes in dynamics, or motion, with climate change are poorly understood and poorly simulated by models.[132] The storyline approach, focusing only on components that are well understood, like thermodynamics, allows for higher confidence statements about a portion of the event that science understands well, albeit it at the expense of having to forsake complete, quantitative statements.[133] A typical finding from a storyline approach might be

129. Luke James Harrington, *Novel Approaches to Quantify the Emergence of Anthropogenic Climate Change* (2017), (unpublished Ph.D. dissertation, Victoria University of Wellington) (on file with New Zealand Climate Change Research Institute School of Geography, Environment and Earth Sciences).

130. The storyline approach was first introduced by Kevin Trenberth. *See* Trenberth et al., *supra* note 125, at 726.

131. Theodore G. Shepherd, *A Common Framework for Approaches to Extreme Event Attribution*, 2 CURRENT CLIMATE CHANGE REP. 28, 28 (2016).

132. The National Academies explained: "Changes in atmospheric circulation and dynamics are generally less directly controlled by temperature, less robustly simulated by climate models, and less well understood." NAS 2016, *supra* note 108, at 6.

133. The reader may note similarities between conditional probabilistic attribution and the storylines approach. Conditional attribution starts by saying 'given this . . .'. The "given" in this context is often sea surface temperatures or sea ice extent, but it can also be a certain type of atmospheric circulation. The idea is to move part of the conditions, often the most vexing part, out of the attribution question. This approach still leaves the question open

"warming of the upper ocean and atmosphere associated with climate change enabled more rainfall during event Y than otherwise would have been experienced." In some studies, quantitative statements are included as well based on certain limited assumptions. In the above example, it might be stated that the warming of the upper ocean and atmosphere due to climate change—the thermodynamics—were responsible for an X percent increase in rainfall. Critically though, any quantitative statements, rather than being comprehensive, are linked to specific aspects of the climate system identified by the authors, such as water temperatures in the example above. Furthermore, most storyline approaches do not endeavor to assess what percentage of the driver—ocean temperature in the example above is due to human activity.

As with the probabilistic or risk based approach, several criticisms have been raised of the storyline approach.[134] First, focusing on a single event in its entirety (as opposed to the risk-based approach, in which events that are defined solely based on their exceedance of a threshold such as 95°F, or air pressure at a given height) and emphasizing changes across only a portion of the event drivers (e.g., focusing on thermodynamics rather than dynamics) limits the utility of the storylines approach for traditional policy and legal applications. Since each event is treated as unique, the applications for a class of events is unclear, and emphasis on a portion of the event's drivers, often in a qualitative way, immediately begs the question of how to address remaining drivers or summarize the event in toto. Second, the storyline approach has been criticized as oversimplistic due to the compartmentalization of an event into discrete components. More specifically the basic premise that within the context of climate change thermodynamics are well understood, and dynamics are not (or are unlikely to change in important ways for extreme events), has been challenged, with some arguing that there is a smooth gradient of understanding across system components such as thermodynamics

though of whether anthropogenic warming has impacted the part being taken as given. The storyline approach takes a full, specific event as the given; tries to initially identify all aspects and drivers; but then focuses on backing out how some of the better understood aspects of climate change—generally the thermodynamics, may have impacted the event magnitude.

134. Friederike E. Otto et al., *The Attribution Question*, 6 NATURE CLIMATE CHANGE 813 (2016).

and dynamics.[135] Furthermore, thermodynamics and dynamics interact. For example, a thermodynamic change, such as warming of the upper ocean, induces changes in the dynamics of atmospheric circulation such as rising air, which can feed back on thermodynamics, for example by changing cloud cover and thus solar radiation received at the surface. Neglecting dynamics thus inevitably misses ways that thermodynamics can be impacted by dynamics, thus rendering the thermodynamics analysis incomplete.[136] Another potential drawback of this approach is that it generates more qualitative findings that may be less useful for certain applications than the quantitative findings of the risk-based approach.[137]

While there is some debate about the relative merits of these two approaches, the reality is that they are complementary—they each provide different insights on the effect of anthropogenic climate change on event characteristics, and one approach can be used to fill gaps where the other is unsuitable. For example, the probabilistic/risk-based approach may be more justifiable for analyzing all events below a threshold, for a class of events that are

135. For example, Mann et al. (2017) notes that dynamical changes with warming are starting to come into focus: more specifically, a growing body of work based on observations and simple models supports the idea that the latitudinal pattern of mean temperature changes (including Arctic amplification) may support changes in atmospheric dynamics that supports wave resonance and 'stuck' weather, which enhances the magnitude and duration of extremes. It should be noted that global climate models generally do not reproduce this pattern of wave resonance and 'stuck' weather with warming. Michael E. Mann et al., *Influence of Anthropogenic Climate Change on Planetary Wave Resonance and Extreme Weather Events*, 7 SCI. REPORTS 45242 (2017).

136. Otto shows how the dynamics and thermodynamics counteracted each other in 2013 German floods. *See* Otto et al., *supra* note 134, at 815. Similarly, a study in Western Australia found dynamics/circulation changes that favor less rain, but thermodynamic (specifically sea surface temperature) changes that favor increase in rain. Thomas L. Delworth & Fanrong Zeng, *Regional Rainfall Decline in Australia Attributed to Anthropogenic Greenhouse Gases and Ozone Levels*, 7 NATURE GEOSCIENCE 583 (2014).

137. For example, the quantitative findings from risk-based studies may be more suitable to answering questions about apportioning liability for climate change. A related criticism is that individual extreme events are complicated, and the storyline approach, through its lack of a clear methodology, opens doors to claims of cherrypicking. For example, Trenberth et al. note that during the "Snowmaggendon event" unusually high sea surface temperatures led to more moisture being available. Trenberth et al., *supra* note 125, at 727. The authors are silent on other drivers of snowfall amount, such as storm location and availability of cold air. In this instance, the approach is arguably justified given the "thermodynamic" links between sea surface temperature and warming, but especially in the hands of less knowledgeable researchers, the lack of a clear, replicable methodology may open the door to perceptions of cherrypicking of event components.

relatively well simulated by climate models (e.g., 99% temperature extremes), whereas the storylines approach may be more appropriate for complex, iconic, multivariate events such as Hurricane Sandy, which combine everything from extreme storm surge and snowfall to high winds.[138] Granted, even with both approaches there is still a fair amount of uncertainty about the human fingerprint on certain events and certain event classes.[139] This is evident from the fact that the risk-based and storyline approaches can produce very different findings about the magnitude of the human influence on certain events, as highlighted in our discussion of specific event studies below.[140]

A recent development in this field is the emergence of and growing focus on "rapid" and "advance" (or "predictive") event attribution. The World Weather Attribution (WWA) project, founded in 2014, is at the forefront of these efforts: it conducts "real-time" (i.e., rapid) attribution analysis of extreme weather events that happen around the world.[141] To accomplish this, WWA and other like entities use seasonal forecasts rather than observations to simulate extreme weather events under current climate conditions before the events actually occur. The goals of this approach are twofold: first, to demonstrate the feasibility of using forecast for reliable attribution findings, and second, to make it possible to issue attribution findings for extreme weather events as they occur.[142] This second function can help facilitate engagement with the media, policy-makers, and the public while events are still fresh in everyone's mind. However, some scientific rigor may be lost when research is conducted with such alacrity. For example, there may be less opportunity to test the model's ability to simulate the actual event, and there may be little or no time for traditional peer-review. Nevertheless, as attribution research continues to mature, and standardization of experiments

138. Elisabeth Lloyd & Naomi Oreskes, *Climate Change Attribution: When Is It Appropriate to Accept New Methods?*, 6 EARTH'S FUTURE 311 (2018).

139. To help address uncertainty, the National Academies has noted a need for more research on: (i) the role of natural variability in extreme events; (ii) the characterization of uncertainty; (iii) why it is that different approaches have yielded very different findings; (iv) what methods are used for event section; and (v) how the counterfactual (no anthropogenic climate change) world is framed. NAS 2016, *supra* note 108, at 12.

140. *See infra* section II(B)(2)(b).

141. WORLD WEATHER ATTRIBUTION PROJECT, *supra* note 115.

142. About World Weather Attribution, https://www.worldweatherattribution.org/about/ (last visited Jan. 14, 2020).

enables more multi-model evaluations, rapid—and even predictive—event attribution will grow in prominence and robustness.

b. Status of Research

IPCC AR5 summarized the status of observations on extreme events as follows:

> Changes in many extreme weather and climate events have been observed since about 1950. It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased. The frequency or intensity of heavy precipitation events has likely increased in North America and Europe. In other continents, confidence in changes in heavy precipitation events is at most medium.[143]

NCA4 contained similar findings.[144] With respect to attribution, both AR5 and NCA4 recognized that the evidence of human influence on extreme events varies depending on the event and, in many cases, is difficult to ascertain. Generally speaking, the confidence with which scientists have been able to attribute extreme events to climate change has been highest for events that are directly related to temperature.[145] Extreme events that are the result of more complex interactions between variables (e.g., drought) are more difficult to attribute. There is moderate confidence about extreme precipitation increases. While there is relatively low confidence about precipitation deficits alone in the context of drought, there is higher confidence in the combined impacts of higher temperature and precipitation on drought risk. For other classes of severe weather, such as tropical cyclones, mid-latitude storms, and smaller scale convective events and tornadoes, confidence is generally lower. However, these generalizations mask substantial nuance across space and time; for example, high temperature extremes at individual highly continental locations in

143. IPCC AR5 WGI, Summary for Policymakers, *supra* note 25, at 5.
144. NCA4, *supra* note 7, at 207–76.
145. NAS 2016, *supra* note 108, at 2.

the mid and high latitudes (where internal variability is large) may be difficult to attribute, and high water level extremes may be difficult to attribute in places where large storm surges are relatively frequent, rendering the sea level rise signature on coastal high water levels relatively less prominent.

Since AR5 was published in 2013, the world has seen a growing number of record-breaking extreme events and hundreds of new event attribution studies have been published. The majority of these studies deal with heat, precipitation, and storm-related impacts, but a growing number of studies are assessing more novel types of extremes—as one example, a recent study looked at "extreme winter sunshine" in the United Kingdom.[146] Notably, of the 146 studies published in the BAMS reports since 2011, approximately 70% have found that anthropogenic climate change was a significant driver of the event studied.[147] The 2016 and 2017 BAMS reports also contained several studies in which the authors concluded that the event *could not have happened* in the absence of anthropogenic climate change. Another meta-analysis of extreme event attribution studies, published in 2018, found that forty-one of fifty-nine papers published in 2016 and 2017 found a positive signal of climate change, and that thirty-two of forty-three papers published in 2018 found that climate change had increased the event's likelihood or intensity.[148] That meta-study also noted that the only four studies published in 2018 which found that climate change decreased the likelihood or intensity of the event all dealt with snow and/or cold temperatures.[149] With all this new research, the evidentiary basis for attributing extreme events to climate change is growing rapidly.

i. Extreme Heat

The core characteristics of extreme heat events (magnitude, frequency, and duration) are all highly sensitive to changes in mean temperatures at a global scale.[150] Thus, an increase in the

146. Nikolaos Christidis et al., *Human Contribution to the Record Sunshine of Winter 2014/15 in the United Kingdom*, *in* BAMS 2015, *supra* note 76, at 47.

147. *See* Stephanie C. Herring et al., *Abstract*, *in* BAMS 2016, *supra* note 76, at Sii.

148. RICHARD BLACK & RUSSEL BAUM, ENERGY & CLIMATE INTELLIGENCE UNIT, EVEN HEAVIER WEATHER 6 (2018).

149. *Id.*

150. Radley M. Horton et al., *A Review of Recent Advances in Research on Extreme Heat Events*, 2 CURRENT CLIMATE CHANGE REP. 242, 242 (2016).

magnitude, frequency, and duration of extreme temperature events is a direct and foreseeable consequence of a warming climate. Not surprisingly, confidence in attribution findings is generally greatest for extreme heat events, as compared with other types of extreme events.[151] NCA4 found, with *very high confidence*, that the frequency and intensity of extreme heat events are increasing in most continental regions around the world, consistent with the expected physical responses to a warming climate.[152]

One of the earliest extreme event attribution studies dealt with the European heat wave of 2003. Applying the risk-based approach, Stott et al. (2004) found that it was very likely (confidence level >90%) that human influence had at least doubled the risk of a heat wave of the sort experienced that summer.[153] Since then, scientists have developed a robust body of research linking unusually warm temperatures and heat waves to anthropogenic climate change.[154] One meta-analysis of unprecedented extremes on a global level found that:

> [H]istorical warming has increased the severity and probability of the hottest month and hottest day of the year at >80% of the available observational area. For the most protracted hot and dry events, the strongest and most widespread contributions of anthropogenic climate forcing occur in the tropics, including increases in probability of at least a factor of 4 for the hottest month and at least a factor of 2 for the driest year.[155]

The studies contained in recent BAMS reports further reinforce this conclusion. The BAMS reports covering 2014 through 2017

151. NAS 2016, *supra* note 108, at 7; *see* Stephanie C. Herring et al., *Introduction to Explaining Extreme Events of 2016 From a Climate Perspective*, *in* BAMS 2016, *supra* note 76, at S2.

152. NCA4, *supra* note 7, at 19.

153. Peter Stott et al., *Human Contribution to the European Heatwave of 2003,* 432 NATURE 610, 610 (2004).

154. IPCC AR5 WGI, Summary for Policymakers, *supra* note 25, at 19 ("There has been further strengthening of the evidence for human influence on temperature extremes since the SREX. It is now very likely that human influence has contributed to observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century, and likely that human influence has more than doubled the probability of occurrence of heat waves in some locations.").

155. Diffenbaugh et al., *supra* note 95, at 4881. The researchers noted that the framework they used in this study was capable of systematically evaluating the role of dynamic and thermodynamic factors such as atmospheric circulation patterns and atmospheric water vapor, lending much greater statistical confidence their findings.

contained a total of thirty-five studies examining anthropogenic influence on extreme heat (including terrestrial and marine heat), and thirty-three of those studies (91%) found that anthropogenic climate change had increased either the likelihood or the severity of the heat event.[156] Notably, there were several studies in the two most recent reports (from 2016 and 2017) which concluded that heat-related events would have been "virtually impossible" in the absence of anthropogenic influence on climate. One of these studies focused on record-breaking global annual *mean* surface temperatures in 2016,[157] while others focused on phenomena that more closely fit the definition of an "extreme" event, specifically: extreme heat in Asia,[158] and marine heat waves off the coast of Alaska[159] and Australia.[160] All three studies employed the risk-based approach and found that FAR equals one, meaning the event could not have happened without anthropogenic influence. The BAMS editors noted these findings were novel and significant for two reasons: (i) they show that the influence of anthropogenic climate change can, at some point, become sufficiently strong to cause an extreme event which is beyond the bounds of natural variability alone; and (ii) because of the small sample size of events shown in the report, it is possible that many other temperature-related extreme events from recent years also could not have occurred in the absence of anthropogenic climate change.[161]

Dozens of other studies have found that climate change very likely influenced the probability and/or magnitude of heat-related events around the world. One study focused on two heat waves in India and Pakistan in 2015 which are estimated to have caused approximately 3,200 deaths.[162] Looking at both heat and humidity (such compound assessments of multiple variables are becoming

156. BAMS 2014, *supra* note 76; BAMS 2015, *supra* note 76; BAMS 2016, *supra* note 76; BAMS 2017, *supra* note 76.

157. Thomas Knutson et al., *CMIP5 Model-Based Assessment of Anthropogenic Influence on Record Global Warmth During 2016, in* BAMS 2016, *supra* note 76, at S11.

158. Yukiko Imada et al., *Climate Change Increased the Likelihood of the 2016 Heat Extremes in Asia, in* BAMS 2016, *supra* note 76, at S97.

159. John Walsh et al., *The High Latitude Marine Heat Wave of 2016 and Its Impacts on Alaska, in* BAMS 2016, *supra* note 76, at S39.

160. S.E. Perkins-Kirkpatrick et al., *The Role of Natural Variability and Anthropogenic Climate Change in the 2017/18 Tasman Sea Marine Heatwave, in* BAMS 2017, *supra* note 76, at S105.

161. Herring et al., *supra* note 151, at S1.

162. Michael Wehner et al., *The Deadly Combination of Heat and Humidity in India and Pakistan in Summer 2015, in* BAMS 2015, *supra* note 76, at S81.

more common), the researchers found that anthropogenic forcing had substantially increased the likelihood of the observed heat indices (by approximately 800–100,000%).[163]

Another compound extremes study focused on heat and drought in Thailand, specifically examining the causal forcings behind a severe drought, which affected forty-one Thai provinces and caused an agricultural loss of approximately $500 million, and a corresponding heat wave which resulted in an estimated six-fold increase in heat stroke cases as well as extensive forest fires throughout the country.[164] There, researchers found that record temperatures could not have occurred without the influence of anthropogenic influence on climate, and that this increased the likelihood of low rainfall in the region.[165] A third study looking at anomalous Arctic warmth in the winter of 2016 concluded that it "most likely" would not have been possible without anthropogenic forcing (the FAR ranged from 0.96-0.99 across five observational datasets).[166]

While the above studies provide compelling evidence of human influence on extreme heat events, it is important to recognize that quantitative estimates of risk ratios can differ considerably depending on the method used in the research. This was one key finding from a study examining the role of anthropogenic warming in the 2015 central and eastern European heat waves.[167] There, researchers used a combination of statistical analysis of observational data and model simulations for attribution purposes. They found that both approaches provided "consistent evidence that human-induced climate change has contributed to the increase in the frequency and intensity of short-term heat waves and heat stress" in the region, but that risk ratio (or FAR) estimates at local scales differ considerably depending on the exact methodology applied.[168] It should be noted that the fact that more heat attribution studies rely on models than rely on observations

163. *Id.* at S85.

164. Nikolaos Christidis et al., *The Hot and Dry April of 2016 in Thailand*, *in* BAMS 2016, *supra* note 76, at S128.

165. *Id.*

166. Jonghun Kam et al., *CMIP5 Model-based Assessment of Anthropogenic Influence on Highly Anomalous Arctic Warmth During November–December 2016*, *in* BAMS 2016, *supra* note 76, at S34, S36.

167. Sebastian Sippel et al., *The Role of Anthropogenic Warming in 2015 Central European Heat Waves*, *in* BAMS 2015, *supra* note 76, at S51.

168. *Id.* at S55.

does not indicate that models overestimate anthropogenic influence relative to observations. For example, Sippel and Otto, using a high resolution climate model simulation, found that observed upward trends in heat extremes were three times larger between 1901–2015 than the trend in the climate model driven by historical forcings, suggesting that using observations would have produced a change in relative risk that was three times larger than the model yielded.[169] Another study relying exclusively on statistical analysis of observations to examine the 2010 Russian heat wave found that the warming in the region observed since the 1960s had increased the risk of a heat wave of the magnitude observed in 2010 by a factor of approximately five, corresponding to a FAR of 0.8.[170]

ii. Drought

While drought is closely connected to increases in temperature, it is typically more challenging to isolate the effect of anthropogenic climate change on dryness and drought conditions because droughts are such highly complex meteorological events (with many factors affecting their probability, severity, and duration) and because large internal variability in precipitation makes it more difficult to identify a climate change signal.[171] Nonetheless, researchers have made significant advances in drought attribution in recent years. Of the twelve studies on drought and dryness that were included in the 2015, 2016, and 2017 BAMS reports, eleven (92%) found clear evidence of anthropogenic influence on the severity or probability of the observed event.[172]

One persistent finding is that it is easier to attribute the heat-related aspects of drought to anthropogenic activities than it is to attribute reductions in rainfall, due to the dynamic nature of the hydrologic cycle.[173] For example, a study of the 2014 drought in

169. *See id.* at S53–S55. As noted earlier, however, use of observations without models is somewhat fraught, for reasons including the difficultly of isolating natural variability in models and (in some cases) data limitations.

170. Rahmstorf & Coumou, supra note 110, at 17905.

171. In this section, we use the term "drought" to refer to meteorological drought—that is, drought brought about by dry weather patterns. Studies examining hydrologic drought—that is, drought brought about by low water levels—would more properly be classified as "impact attribution studies."

172. BAMS 2015, *supra* note 76; BAMS 2016, *supra* note 76; BAMS 2017, *supra* note 76.

173. *See, e.g.*, NCA4, *supra* note 7, at 22: "The human effect on recent major U.S. droughts is complicated. Little evidence is found for a human influence on observed

the Horn of Africa found no evidence of anthropogenic influence on the likelihood of low rainfall, but "clear signals in other drivers of drought" (namely, higher temperatures and increased net incoming radiation).[174] One assessment of observed "flash droughts"[175] in southern Africa found that these events had increased by 220% from 1961–2016, and that there had also been a decreasing trend in precipitation from 1948–2016, but also recognized that "simulations of surface air temperature change are much more reliable than those for soil moisture and precipitation."[176] A model based study which also focused on drought in southern Africa found that climate change likely increased the intensity of the 2015–2016 El Niño which in turn contributed to decreases in precipitation in the region.[177]

The numerous studies on the 2011–2017 California drought also reflect the complexity and dependency of results on methodological choices. Swain 2014 focused on geopotential heights (the heights of pressure surfaces above mean sea level) because droughts are associated with high atmospheric pressure and blockage of moisture-laden storms, and found that high heights were attributable to anthropogenic warming.[178] Funk 2014, focusing on warming of ocean temperatures off a portion of the US West coast, found that the ocean warming did not contribute to drought risk.[179] And Wang and Schubert found conflicting results: circulation anomalies associated with anthropogenic forcing did increase drought risk, but humidity increases associated with

precipitation deficits, but much evidence is found for a human influence on surface soil moisture deficits due to increased evapotranspiration caused by higher temperatures. (*High confidence*)".

174. T. R. Marthews et al., *The 2014 Drought in the Horn of Africa: Attribution of Meteorological Drivers*, *in* BAMS 2014, *supra* note 76, at S83; *see also* Eduardo S. P. R. Martins et al., *A Multimethod Attribution Analysis of the Prolonged Northeast Brazil Hydrometeorological Drought (2012–16)*, *in* BAMS 2016, *supra* note 76, at S65.

175. The term "flash drought" refers to a rapid-onset drought, typically caused by very dry and hot weather conditions.

176. Xing Yuan et al., *Anthropogenic Intensification of Southern African Flash Droughts as Exemplified by the 2015/16 Season*, *in* BAMS 2016, *supra* note 76, at S86.

177. Chris Funk et al., *Anthropogenic Enhancement of Moderate-to-Strong El Niño Events Likely Contributed to Drought and Poor Harvests in Southern Africa During 2016*, *in* BAMS 2016, *supra* note 76, at S91.

178. Daniel L. Swain et al., *The Extraordinary California Drought of 2013-2014: Character, Context, and the Role of Climate Change*, 95 BULL. AM. METEOROLOGICAL SOC'Y (SPECIAL SUPPLEMENT) S3, S7 (2014) [hereinafter BAMS 2013].

179. Chris Funk et al., *Examining the Contribution of the Observed Global Warming Trend to the California Droughts of 2012/13 and 2013/14*, *in* BAMS 2013, *supra* note 178, at S11.

anthropogenic warming reduced drought risk.[180] However, a more recent study found that anthropogenic warming *had* increased drought risk in California—specifically, that the precipitation deficits in California were more than twice as likely to yield drought years if they occurred when conditions were warm.[181]

iii. Heavy Precipitation

Both AR5 and NCA4 found clear evidence that extreme rainfall events are increasing around the world, and this is generally consistent with expected physical responses to a warming climate.[182] However, as noted above, the dynamic nature of extreme precipitation events—which can be very local and brief in nature, and thus characterized by large variability and difficult to model—can make it more difficult to attribute specific precipitation events to anthropogenic climate change than temperature extremes, particularly where scientists use the risk-based approach to attribution. In the BAMS reports published for 2014 through 2017, ten out of eighteen studies on heavy precipitation (56%) identified an anthropogenic influence on event frequency or magnitude.[183] But to the extent that studies have found a link to anthropogenic activities, some of the results have been quite striking.

One study of extreme rainfall in China in 2016 found that anthropogenic forcings, combined with the 2015–2016 strong El Niño cycle, had increased the risk of the rainfall event tenfold.[184] Other studies looking at extreme rainfall events in China have similarly found evidence of anthropogenic forcing on extreme

180. Hailan Wang & Siegfried Schubert, *Causes of the Extreme Dry Conditions Over California During Early 2013*, *in* BAMS 2013, *supra* note 178, at S7.

181. Noah Diffenbaugh et al., *Anthropogenic Warming Has Increased Drought Risk in California,* 112 PROC. NAT'L ACAD. SCI. 3931, 3931 (2015).

182. NCA4, *supra* note 7, at 19 ("The frequency and intensity of . . . heavy precipitation events are increasing in most continental regions of the world (*very high confidence*)"); IPCC AR5 WGI, Summary for Policymakers, *supra* note 25, at 7. With each additional degree Celsius of warming, the atmosphere is capable of holding an additional 7% more water vapor. Dim Coumou & Stefan Rahmstorf, *A Decade of Weather Extremes,* 2 NATURE CLIMATE CHANGE 491 (2012).

183. BAMS 2014, *supra* note 76; BAMS 2015, *supra* note 76; BAMS 2016, *supra* note 76; BAMS 2017, *supra* note 76.

184. Qiaohong Sun & Chiyuan Miao, *Extreme Rainfall (R20mm, RX5day) in Yangtze–Huai, China, in June–July 2016: The Role of ENSO and Anthropogenic Climate Change*, *in* BAMS 2016, *supra* note 76, at S102.

rainfall and flood events in that region.[185] Meredith et al. (2015) used a high-resolution regional climate model to assess how water temperature increases in the Black Sea affected a highly-local "convective" precipitation event.[186] They found a 300% increase in extreme precipitation associated with a non-linear transition in the stability of the atmosphere.[187] A lower resolution model would not be able to resolve this non-linear precipitation change associated with higher sea surface temperatures.[188]

As noted above, the "storyline" approach to attribution was developed in part to improve attribution for difficult to model events like extreme precipitation. Researchers used this approach to examine the effect of anthropogenic climate change on the 2013 floods in Boulder, Colorado, and found that anthropogenic drivers increased the magnitude of the rainfall for that week by approximately 30%.[189] The scientists also conducted a probabilistic analysis of potential impacts on flooding and found that this 30% increase in rainfall approximately doubled the likelihood of flood-inducing rainfall occurring during that event.[190] In contrast, researchers evaluating the Boulder floods under the risk-based framework found no evidence that anthropogenic climate change had increased the probability of the event occurring.[191] This underscores the sensitivity of results to methodological choices made in extreme event attribution.

185. Claire Burke et al., *Attribution of Extreme Rainfall in Southeast China During May 2015*, *in* BAMS 2015, *supra* note 76, at S92; Chunlüe Zhou et al., *Attribution of the July 2016 Extreme Precipitation Event Over China's Wuhang*, *in* BAMS 2016, *supra* note 76, at S107.

186. Edmund P. Meredith et al., *Evidence for Added Value of Convection-Permitting Models for Studying Changes in Extreme Precipitation*, 120 J. GEOPHYSICAL RES. ATMOSPHERE 12500, 12500 (2015).

187. *See* Edmund P. Meredith et al., *Crucial Role of Black Sea Warming in Amplifying the 2012 Krymsk Precipitation Extreme*, 8 NATURE GEOSCIENCE 615, 615 (2015). This increase was related to the change in temperature with height; warming water warmed the lower atmosphere above it, making the lower atmosphere less dense and thereby facilitating rainfall-conducive rising of air. *Id.* at 618.

188. *See id.* at 616. Note that the paper itself did not directly attribute the increasing sea surface temperatures to anthropogenic forcing.

189. Pardeep Pall et al., *Diagnosing Conditional Anthropogenic Contributions to Heavy Colorado Rainfall in September 2013,* 17 WEATHER AND CLIMATE EXTREMES 1, 1 (2017).

190. *Id.* at 5.

191. *See* Martin Hoerling et al., *Northeast Colorado Extreme Rains Interpreted in a Climate Change Context*, in BAMS 2013, *supra* note 178, at S17.

iv. Tropical and Extratropical Cyclones

Climate change can fuel tropical cyclones in several ways. Although key uncertainties remain with respect to how anthropogenic forcing has influenced some tropical cyclone determinants (e.g., wind shear and atmospheric aerosols), other drivers are quite clear. First, sea surface temperatures have warmed in most places, which—all things being equal—allows the most intense storms to strengthen, leading to non-linear increase in storm impacts. Second, a warmer atmosphere can hold more moisture and thus can lead to heavier rainfall and flooding. Finally, higher sea levels exacerbate coastal flooding and high-water levels during storms.

Attribution studies on tropical and extratropical cyclones have generated mixed results. Many early studies performed using the risk-based approach found no clear evidence that anthropogenic forcings altered the probability or severity of the cyclones examined therein.[192] But more recently, there have been numerous studies in which researchers have identified a fairly large anthropogenic "fingerprint" on select storm characteristics. One such study examined 2015 tropical cyclone activity in the western North Pacific Ocean—looking specifically at the level of accumulated cyclone energy (ACE)—and found that anthropogenic forcing largely increased the odds of the ACE values that were observed (FAR = 0.81).[193]

There have also been a number of studies on individual tropical cyclones. Unsurprisingly, for Hurricane Harvey there have been several studies focused on the storm's prodigious rainfall totals, which reached approximately sixty inches. Risser and Wehner, using a statistical approach known as extreme value analysis, found anthropogenic forcing led to 37% more precipitation over land;[194] van Oldenborgh et al. 2017 found a 15% increase using a model

192. *See, e.g.*, Frauke Feser et al., *Hurricane Gonzalo and Its Extratropical Transition to a Strong European Storm*, *in* BAMS 2014, *supra* note 76, at S54; Lei Yang et al., *Anomalous Tropical Cyclone Activity in the Western North Pacific in August 2014*, *in* BAMS 2014, *supra* note 76, at S124.

193. Zhang et al., *Influences of Natural Variability and Anthropogenic Forcing on the Extreme 2015 Accumulated Cyclone Energy in the Western North Pacific, in* BAMS 2015, *supra* note 76 at S133.

194. Mark Risser & Michael Wehner, *Attributable Human-Induced Changes in the Likelihood and Magnitude of the Observed Extreme Precipitation During Hurricane Harvey*, 44 GEOPHYSICAL RES. LETTERS 12457, 12457 (2017).

and without considering possible changes in atmospheric dynamics.[195] Allowing for dynamical changes in addition to thermodynamics, Wang et al. 2018 found a ~25% increase.[196] A recent Trenberth 2018 paper showed large positive upper ocean heat content anomalies in advance of Harvey. Upper ocean heat content anomalies are straightforward to link to anthropogenic warming, in so far as the authors note that ~92% of anthropogenically induced warming has gone towards heating the ocean. The authors go on to note that Hurricane Harvey was able to tap the anomalous heat in the nearby upper ocean, ultimately converting the energy into extreme rainfall.[197] While this last paper is not focused on attribution per se, it is emblematic of how broader science advances, past and present, help inform attribution studies—much as attribution studies can advance broader physical understanding. The Trenberth (2018) paper also makes a critical point about non-linearity and threshold crossing of impacts; the authors note that even if precipitation increase with climate change in a storm like Harvey is only 5–15%, that incremental increase could conceivably generate the bulk of all costs. Impacts of hurricane winds have also been shown to increase non-linearly with stronger winds. In the case of the three major landfalling 2017 Atlantic hurricanes, costs were hundreds of billions of dollars.[198]

In contrast to tropical cyclone findings, few attribution studies to date have found an anthropogenic signal in extra-tropical cyclones. One example, Feser et al. (2014), relied on sixty-seven years of observed data and found a recent storm experiencing extra-tropical transition was unexceptional in the context of the long-term observational dataset.[199]

195. Geert Jan van Oldenborgh, *Attribution of Extreme Rainfall from Hurricane Harvey, August 2017,* 12 ENVTL. RES. LETTERS 1, 1 (2017).

196. S. Wang et al., *Quantitative Attribution of Climate Effects on Hurricane Harvey's Extreme Rainfall in Texas*, 13 ENVTL. RES. LETTERS 1, 1(2018).

197. Kevin Trenberth et al., *Hurricane Harvey Links to Ocean Heat Content and Climate Change Adaptation*, 6 EARTH'S FUTURE 730, 730 (2018).

198. Willie Drye, *2017 Hurricane Season Was Most Expensive in U.S. History,* NAT'L GEO. (Nov. 30, 2017).

199. Feser et al., *supra* note 192, at S54.

3. Impact Attribution

Impact attribution focuses on the consequences and outcomes of climate change. Many of the phenomena discussed above (e.g., loss of sea ice, increases in sea levels, and changes in precipitation) can certainly be described as "impacts" of a changing climate[200]—but, as noted at the outset of this section, for the purposes of this paper, we use the IPCC AR5 definition of "impacts":

> In this report, the term impacts is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts and sea level rise, are a subset of impacts called physical impacts.[201]

Impact attribution gets closer to what people really care about in the liability and policy context, and, in particular, the question of who will be harmed by climate change and to what extent. But because impact attribution deals with consequences that are farther along the causal chain, it is harder to issue robust findings about the connection between anthropogenic influence on climate and specific on-the-ground impacts.

a. Methods and Parameters

Impact attribution, like climate change attribution, relies on physical understanding, observational data, statistical analysis, and models. However, impact attribution also involves unique challenges that can make the attribution of impacts more difficult than the attribution of climate change and extreme weather events.

The most fundamental challenge is that, as research moves further down the causal chain from human influence on climate change to discrete impacts on human and natural systems,

200. For example, an "impact" of climate change can be defined as "any change in a physical, biological, or human system that is driven by a long-term climate trend." Cynthia Rosenzweig & Peter Neofotis, *Detection and Attribution of Anthropogenic Climate Change Impacts*, 4 WIREs CLIMATE CHANGE 121, 121 (2013).

201. IPCC AR5 SYR, *supra* note 33, at 124.

researchers must account for an increasing number of non-climate and exogenous variables which complicate the attribution analysis (sometimes referred to as "confounding factors"). For example, in a study seeking to link public health impacts from a heat wave to anthropogenic forcing, researchers would need to account for land use decisions, access to cooling, and other adaptations affecting public health, as well as baseline vulnerability of subsets of the population to heat impacts (based on factors such as age, pre-existing health conditions, and outdoor activity) in order to ascertain the extent to which anthropogenic climate change was responsible for those impacts.

The relationship between two variables can also be complex and non-linear. For example, while the relationship between increasing mortality and each additional degree of warming may be well understood at moderately high temperatures, there may be limited knowledge, or observational basis, of just how steeply mortality may rise with temperature once extreme temperatures occur.[202] Furthermore, there is typically not a linear cause-and-effect relationship, but rather there is an interconnected web of variables where a change in any one variable can create cascading effects and feedback loops. As one example, it has been argued that anthropogenically-enhanced droughts in agricultural breadbaskets, such as Russia in 2010,[203] had cascading impacts on grain prices that disproportionately affected food insecure populations around the globe, ultimately contributing both to malnutrition and civil unrest in regions far away from the original extreme climate event.[204]

Researchers must also account for internal system dynamics in impact attribution studies. For example, a study of how a species' population was impacted by anthropogenic forcing might need to consider the amplitude of long-term population variability due to natural cycles of predator-prey interactions that could in principle be independent of climate. For many systems, and places, standardized long term data sets simply are not available. Furthermore, establishing causation, as opposed to simply observing correlation, can present another challenge, especially for

202. Ebi et al., *supra* note 123, at 085004-3.

203. Rahmstorf & Coumou, *supra* note 110.

204. *See* Troy Sternberg, *Chinese Drought, Bread and the Arab Spring*, 34 APPLIED GEOGRAPHY 519 (2012).

impacts systems where robust models do not exist that allow for simulation of counterfactual worlds, i.e. realizations other than the single realization actually experienced in the real world. In the absence of long-term impact datasets and strong impact models, attribution impact researchers have had to make assumptions. For example, across many impact sectors, short-term weather fluctuations that happened to align with the time period when impacts data were available have been used to estimate sensitivity to climate change,[205] or impacts of earlier events for which data was not available.[206,207] This may be problematic, either because long-term responses inherently differ from short-term responses, or because of changes in the various state variables over time (e.g., long term changes in confounding factors like technological innovation or population change).[208]

Treatment of antecedent climate conditions not being included in the formal attribution analysis requires care as well. For example, a study of flooding damages along a river due to a specific heavy rain event might have to consider how prior meteorological/climate conditions impacted soil moisture, water levels, and even vegetation, as these prior conditions would affect flood extent and damage.

Finally, some of the challenges discussed in the extreme events section apply here as well. For example, the spatial and temporal scale of an impact—and the driving extreme event—may be too fine to capture with existing models. In these instances, large natural variability relative to any anthropogenic signal, absence of

205. *See Oliver* Deschênes & Michael Greenstone, *The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather*, 102 AM. ECON. REV. 3761 (2012); Oliver Deschênes & Michael Greenstone, *Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US*, 3 AM. ECON. J.: APPLIED ECON. 152 (2011).

206. Maximilian Auffhammer et al., *Integrated Model Shows that Atmospheric Brown Clouds and Greenhouse Gases Have Reduced Rice Harvests in India*, 103 PROC. NAT'L ACAD. SCI. 19668, 19670 (2006).

207. To be sure, there are some examples of studies where long-term impact data enabled assessment of long-term changes in impacts. *See* Kristie L. Ebi et al., *Detecting and Attributing Health Burdens to Climate Change*, 125. ENVTL. HEALTH PERSP. 085004-1, 085004-2 (2017) (noting a 2014 study by Bennett et al. on temperature-related mortality in Australia from 1968 to 2007. Charmian Bennett et al. *Shifts in the Seasonal Distribution of Deaths in Australia, 1968–2007*, 58 INT'L J. BIOMETEOROLOGY 835 (2014)).

208. Ebi 2017 provide a strong example: "on a time scale of decades, local food production may shift successfully to new heat-tolerant technologies or be abandoned altogether." Ebi et al, *supra* note 207, at 085004-2 (internal citations omitted).

representative local data, and the aforementioned modeling challenges may hinder impact attribution.

There are a variety of approaches taken in impact attribution studies. Roughly speaking, most impact attribution studies can be characterized as either "single-step" or "multi-step" studies (also known as "direct" and "joint" attribution, respectively). The single-step studies focus on the relationship between impacts and observed changes in mean climate variables or extremes, without going so far as to draw a complete causal connection from the impact to anthropogenic influence on climate. This is similar to the approach taken in the IPCC reports: impacts are discussed in the WGII report but are generally not explicitly linked to human forcings. One key idea underpinning this approach is that human influence is a primary driver of climate change, so we can infer that many of the impacts where attribution is well advanced are ultimately caused by anthropogenic climate change—especially those linked to climate variable, like mean temperature at a continental scale. This approach has the advantage of simplicity, but can only generate robust, quantitative findings where the impact attribution study can be linked to one or more external studies of an appropriate scale and scope, which establish the role of human influence in the change in climate variable giving rise to the impact. In the absence of such studies, scientists may be able to infer that an impact was "caused" by climate change, but they will not be able to isolate the proportional contribution of human influence on that impact. Due to this limitation, many single-step attribution studies tend to communicate results in a conservative fashion, focusing on whether there is *any* human influence on a particular impact rather than quantifying the magnitude of the influence.[209]

The multi-step or "joint" impact attribution studies, which are less common, involve at least two attribution steps: first, linking a change in a mean climate variable or extreme to anthropogenic influence and second, linking impacts to that change.[210] For example, a study could link mortality to temperature increases, and then link temperature increases to greenhouse gas emissions. This

209. IPCC AR5 WGI, *supra* note 25, at 878.

210. For a more detailed explanation of these two approaches, *see* Dáithi Stone et al., *The Challenge to Detect and Attribute Effects of Climate Change on Human and Natural Systems,* 121 CLIMATIC CHANGE 381, 390–91 (2013).

second approach is sometimes referred to as "end-to-end" attribution.[211] The multi-step approach is preferable in principle, but in practice the complexity of multi-step attribution analysis, with its potential for cascading uncertainty, can lead to weak and/or heavily-caveated attribution statements.

A distinction can also be drawn between impact attribution studies that contain quantitative analysis of impacts, and impact attribution studies which only contain a qualitative description of impacts. In quantitative studies, the analysis often mirrors that of extreme event studies—the emphasis being on determining the extent to which climate change increased the risk of certain impacts. Quantitative impact assessments do not always rely on models—sometimes they rely on more simple methods, like extrapolation of observations or historical statistical relationships to estimate impacts such as changes in crop yield. In the qualitative studies, scientists will look at a change like increases in surface temperature, attribute those changes to anthropogenic influence, and then simply describe how the change in the climate variable affected other variables.[212] The advantage of the qualitative approach is that it can provide useful insights into the nature of possible climate change impacts that have not received a great deal of scientific or public attention to date.[213] But the qualitative approach would not be as effective at supporting certain applications, such as liability claims, precisely because it does not generate quantitative data.

b. Status of Research

The WGII report for AR5 found strong evidence that "changes in climate have caused impacts on natural and human systems on all continents and across all oceans" in recent decades.[214] However, it also found that evidence of climate-change impacts was "strongest

211. *See, e.g.*, Cynthia Rosenzweig et al., *Attributing Physical and Biological Impacts to Anthropogenic Climate Change* 453 NATURE 353, 354 (2008).

212. *See, e.g.*, Michael Jacox et al., *Forcing of Multiyear Extreme Ocean Temperatures that Impacted California Current Living Marine Resources in 2016*, *in* BAMS 2016, *supra* note 76, at S27.

213. BAMS annual extreme event attribution reports, for example, are increasingly weighing in on impacts *after* assessing whether the extreme event can be linked to anthropogenic forcing. The majority of the papers address the link between the impact and the extreme event in a qualitative way, with a few exceptions.

214. IPCC AR5 WGII, Summary for Policymakers, *supra* note 20, at 4.

and most comprehensive" for natural systems, whereas evidence linking impacts on human systems to climate change was more limited.[215] Most of the attribution findings in the WGII report are the product of "single-step attribution" although the report does cite to some studies that have conducted multi-step attribution. In recent years, the BAMS reports have also been expanded to encompass impacts attribution in addition to extreme event attribution, and most of the studies in those reports employ single-step attribution.[216] Two key areas of focus in impact attribution studies include the Arctic and the oceans, where changes are occurring more rapidly and impacts are therefore more apparent. Impacts from extreme events, particularly heat waves, are also a major focus of impact attribution studies.

i. Ecosystems, Species, and Ecological Indicators

Much of the existing impact attribution research focuses on ecological impacts, seeking to understand how climate change is affecting individual species, ecosystems, and ecological functioning. The focus of such studies is on natural systems, but there are clear implications for human systems, insofar as we rely on natural systems, such as fisheries, for food as well as other ecosystem services, such as water and air filtration. There is robust evidence of impacts in this category. In particular, IPCC AR5 found with *high confidence* that "[m]any terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, and abundances, and species interactions in response to ongoing climate change."[217] IPCC AR5 also expressed *high confidence* in findings that several recent species extinctions can be attributed to climate change,[218] and *very high confidence* that climate-related extremes such as heat waves, droughts, floods, and cyclones were altering ecosystems.[219] IPCC AR5 expressed *high* and *medium confidence* about a number of other region-specific impacts,

215. *Id.*

216. Herring et al., *supra* note 151, at S3. As noted earlier, in the BAMS reports, the single-step tends to be the link between anthropogenic warming and climate or extreme events, with the link to impacts treated less rigorously.

217. IPCC AR5 WGII, Summary for Policymakers, *supra* note 18, at 4. Note the absence, though, of direct attribution of the climate change to anthropogenic forcing, rather than other possible factors, like natural variability.

218. *Id.*

219. *Id.* at 6.

such as changes in the timing of critical biological events, increased tree mortality, pest outbreaks, and other ecosystem disturbances.[220]

There are many examples of both single-step and multi-step attribution of ecological impacts. Most of the multi-step studies focus on the impact of increasing temperatures on biological systems.[221] In one of the earliest and most comprehensive meta-analyses, Rosenzweig et al. 2008 conducted a broad assessment of observed changes in natural systems.[222] The researchers demonstrated that: (i) regional climate changes were caused by human forcing, and (ii) observed changes in natural systems were consistent with the estimated responses of physical and biological systems to regional climate change and not consistent with alternative explanations that exclude regional climate change. Specifically, they found that approximately 95% of 829 documented physical changes (e.g., glacier reduction and earlier spring peak of river discharge) and that 90% of 28,800 documented changes in biological systems (e.g., earlier blooming) were in directions consistent with warming.[223] The researchers endeavored to explicitly account for confounding variables such as land use change, management practices, pollution and human demography shifts.

Many other impact studies have been conducted since 2008 to improve understanding of exactly how climate change is affecting biological systems. The 2016 BAMS report contained several examples of such studies, including three studies finding that increases in sea surface and ocean temperatures were harming ocean ecosystems through impacts such as coral reef bleaching and reduced fish stocks,[224] and a study on terrestrial impacts which found that anthropogenic influence on climate change was actually driving higher ecosystem productivity on the Iberian Peninsula

220. IPCC AR5 WGII, Technical Summary, *supra* note 18, at 44–46.

221. *See, e.g.*, Terry Root et al., *Human-Modified Temperatures Induce Species Changes: Joint Attribution*, 102 PROC. NAT'L ACAD. SCI. 7465 (2005); Ebi et al., *supra* note 207.

222. Cynthia Rosenzweig et al., *Attributing Physical and Biological Impacts to Anthropogenic Climate Change*, 453 NATURE 353, 354 (2008).

223. *Id.* While those key findings were presented in quantitative terms, each documented change was handled in a qualitative way (looking at direction of change and not amount changed).

224. Sophie C. Lewis & Jennie Mallela, *A Multifactor Risk Analysis of the Record 2016 Great Barrier Reef Bleaching*, *in* BAMS 2016, *supra* note 76, at S144; Jacox et al., *supra* note 212; Russel E. Brainard et al., *Ecological Impacts of the 2015/16 El Niño in the Central Equatorial Pacific*, *in* BAMS 2016, *supra* note 76, at S21.

through warmer winters coupled with wet springs and increases in CO_2 availability.[225] These studies exemplified the diversity of approaches in impact attribution: one of the marine studies focused on the role of anthropogenic forcing in causing ocean temperatures that had resulted in certain ecological impacts without taking a detailed look at the impacts themselves;[226] another focused on the extent to which coral reef and seabird communities were disrupted by record-setting sea surface temperatures and made an "indirect two-step link to human-induced climate change" by referencing findings from a companion paper attributing the record-setting temperatures to anthropogenic forcing;[227] and the third was a multi-step attribution study in which scientists attributed abnormally warm SST to anthropogenic forcing and then qualitatively examined the respective role of the abnormally warm SST on coral bleaching.[228] The multi-step attribution study of the Iberian Peninsula was noteworthy for the complexity of the model design, which included counterfactual simulations for both the climate model and the ecosystem model. The experimental design supported attribution of ecosystem impacts not only to observed changes in climate associated with anthropogenic forcing, but also to direct impacts of higher CO_2 concentrations on vegetation.[229]

As evident from these and other studies, impacts on marine ecosystems are a key topic in impact attribution. One reason for this is ocean temperatures are rising quickly in many regions relative to natural variability (indicating a high signal to noise ratio).[230] Not coincidentally, the impacts on marine resources are more evident, in some cases, than terrestrial impacts, as more and more species and ecosystems approach climate thresholds that may not have occurred during their evolutionary history. The effect of climate change on fishery productivity is also a major concern throughout the world and a key focus of many studies.[231]

225. Sippel et al., *supra* note 111, at S80.

226. Jacox et al., *supra* note 212.

227. Stott et al., *Future Changes in Event Attribution Methodologies, in* BAMS 2016, *supra* note 76, at S156 (referencing Brainard et al., *supra* note 224).

228. Lewis & Mallela, *supra* note 224.

229. Sippel et al., *supra* note 111.

230. Thomas Frölicher, et al., *Marine Heatwaves Under Global Warming*, 560 NATURE 360, 360 (2018).

231. *See, e.g.,* NAT'L OCEANIC AND ATMOSPHERIC ADMIN., WHAT CAUSED THE SACRAMENTO RIVER FALL CHINOOK STOCK COLLAPSE? (2009); Jonathan A. Hare et al., *Cusk (Brosme brosme) and Climate Change: Assessing the Threat to a Candidate Marine Fish Species Under the US*

ii. Inland Flooding and Hydrologic Impacts

A fair amount of research has also been conducted on the impacts of climate change on inland or riverine floods, hydrologic droughts, and changes in streamflow. Above, we discuss meteorological droughts as a type of extreme climate event—hydrologic droughts are more properly classified as "impacts" of climate change because there are so many confounding factors that affect their characteristics. The same can be said for floods. While these are often discussed as "extreme events" in common parlance, they are more properly classified as impacts of climate change due to the number of non-climate related confounding factors that affect flood characteristics.[232] It is also worth bearing in mind that floods and other hydrologic impacts can be affected by slow-onset changes such as temperature increases as well as extreme events. IPCC AR5 found, with *medium confidence,* that changes in precipitation, snow melt, and ice are altering hydrological systems and affecting water resources (both in terms of quality and quantity).[233] However, IPCC AR5 did not find evidence that, on a global scale, surface water and groundwater drought frequency had changed in the last few decades,[234] but did discuss research linking regional drought conditions to climate change.[235] IPCC AR5 also found with *very high confidence* that climate-related extremes were disrupting water supply.[236]

Flood attribution studies follow the same pattern as other impact attribution studies—single-step attribution, as well as storyline approaches dominate existing studies to date.[237] The climate variables that are most relevant to inland flood impact analysis include precipitation, storms, and temperature (which can cause flooding through, e.g., snowmelt and permafrost thawing). Some multi-step analyses have also been performed for hydrologic

Endangered Species Act, 69 ICES J. MARINE SCI. 1753 (2012); Kyle Meng et al., *New England Cod Collapse and the Climate*, PLOS ONE, July 27, 2016.

232. These include, for example, geography, topography, hydrology, water infrastructure, land use decisions, and building design. Note though that precipitation associated with a flood would be treated as an "extreme event" under our nomenclature.

233. IPCC AR5 WGII, *supra* note 18, at 44.

234. *Id.*

235. *See, e.g.*, *id.* (expressing *medium confidence* that climate change had increased soil moisture drought in the Sahel since 1970).

236. *Id.* at 6.

237. *See, e.g.*, Trenberth et al., *supra* note 125.

droughts and other hydrologic impacts.[238] For example, a 2008 study of human-induced changes in the hydrology of the western United States found that up to 60% of the climate-related trends in river flow, winter air temperature, and snow pack between 1950 and 1999 were human-induced.[239]

iii. Coastal Impacts

Climate change is affecting coastlines through sea level rise, changes in the severity and frequency of storms and extreme rainfall events, temperature changes (particularly marine temperatures), and ocean acidification. IPCC AR5 found that many coastal areas are already experiencing adverse impacts such as submergence, coastal flooding, coastal erosion, and saltwater intrusion, all of which are exacerbated by sea level rise, but found also that the impacts of anthropogenic climate change on coastlines are difficult to tease apart from human-related drivers such as land use change and in situ adaptations such as sea walls.[240] Studies attributing coastal impacts to anthropogenic influence on climate may focus exclusively on physical impacts or may seek to link physical impacts to economic or public health outcomes.

Findings from recent coastal impact studies suggest that some coastal areas are already undergoing dramatic transformations driven primarily by sea level rise. For example, one single-step study of flooding in Southeast Florida focused on the role of sea level rise in monthly high tides and found that the probability of a 0.57-meter tidal flood within the Miami region had increased by more than 500% since 1994 due to a 10.9-centimeter increase in sea levels.[241] The findings from this study are compelling—indeed both the link between 1) anthropogenic warming and sea level rise and 2) sea level rise and the frequency of coastal flooding are two

238. *See, e.g.*, Sebastian Sippel & Friederike E. L. Otto, *Beyond Climatological Extremes—Assessing how the Odds of Hydrometeorological Extreme Events in South-East Europe Change in a Warming Climate*, 125 CLIMATIC CHANGE 381 (2014); Pardeep Pall et al., *Anthropogenic Greenhouse Gas Contribution to Flood Risk in England and Wales in Autumn 2000*, 470 NATURE 382 (2011); Geert Jan van Oldenborgh et al., *The Absence of a Role of Climate Change in the 2011 Thailand Floods, in* EXPLAINING EXTREME EVENTS OF 2011 FROM A CLIMATE PERSPECTIVE 1047 [hereinafter BAMS 2011] (2012).

239. Tim Barnett et al., *Human-Induced Changes in the Hydrology of the Western United States*, 319 SCIENCE 1080, 1080 (2008).

240. IPCC AR5 WGII, *supra* note 18, at 364.

241. William V. Sweet et al., *In Tide's Way: Southeast Florida's September 2015 Sunny-day Flood, in* BAMS 2015, *supra* note 76, at S25.

of the most robust aspects of climate change. Nevertheless, this and similar studies are limited insofar as they do not quantify the anthropogenic influence on the observed changes in sea level rise and corresponding impact on floods, nor do they speak to specific impacts on human systems (e.g., economic damages or public health outcomes).

iv. Wildfires

Climate change primarily exacerbates wildfire risk through hotter and drier conditions. Perhaps counterintuitively, in water-limited regions, an unusually wet growing season, during which time more vegetation grows which can later become fuel, can set the stage for a large fire season once the vegetation dries out. Winds, atmospheric humidity, solar radiation, and lightning strikes also influence fire risk. While wildfires are sometimes characterized as "extreme events" related to climate change, they are far from purely meteorological events; rather, they are a product of both climatological and terrestrial conditions. For example, the expansion of human development and electrical systems into previously-remote forest zones leads to an increase in ignition, and forest management and fire suppression decisions affect fire frequency and intensity.[242] As such, the link between climate change and wildfires is less direct than the link between climate change and events such as heat waves. IPCC AR5 expressed *medium* and *low confidence* in various studies linking increases in the severity or frequency of wildfires to climate change,[243] with the higher confidence for wildfires in data-rich North America. Research performed since then has generated more robust evidence of a link between *anthropogenic* climate change and wildfires in North America and Australia.[244]

242. A. Park Williams et al., *Observed Impacts of Anthropogenic Climate Change on Wildfire in California*, 7 EARTH'S FUTURE 892, 892 (2019) (recognizing that the effects of climate change on wildfire can vary greatly across space and time due to confounding factors such as fire suppression and ignitions from humans).

243. *See, e.g.*, IPCC AR5 WGII, *supra* note 18, at 44 (*low confidence* that climate change had increased wildfires on Mt. Kilamanjaro); *id.* at 45 (*medium confidence* that climate change increased wildfire frequency in subarctic conifer forests and tundra, and *medium confidence* that climate change increased wildfire activity, fire frequency, and duration in forests of Western U.S. and boreal forests in Canada).

244. NCA4, *supra* note 7, at 242-245.

One of the earliest studies on this topic, published in 2004, found that human-induced climate change had a detectable influence on Canadian forest fires in recent decades[245] A 2016 end-to-end study on wildfires in the western United States found that, while there were numerous factors that aided the recent rise in fire activity, observed warming and drying had significantly increased fuel aridity during the fire season, fostering a more favorable environment for wildfires.[246] They found that anthropogenic climate change caused over half of the documented increases in fuel aridity since the 1970s and doubled the cumulative forest fire area since 1984.[247] The same researchers published a subsequent study focused on California which found that human-induced warming had already significantly enhanced wildfire activity in the state, particularly in the forests of the Sierra Nevada and North Coast.[248] Another end-to-end study focusing on the role of extreme vapor pressure deficits (VPD) in wildfire risk found that anthropogenic influences quintupled the risk of extreme VPD for western North America and had doubled the risk of extreme VPD in extratropical Australia.[249]

Again, the findings from these studies are compelling, but like many impact studies, they rely on proxies for wildfire risk such as fuel aridity in order to attribute impacts. Further studies can help continue to provide answers to help quantify the extent to which anthropogenic climate change has caused an increase in wildfires as compared with other confounding factors such as fire suppression and development in wildfire-prone areas.

245. N.P. Gillett et al., *Detecting the Effect of Climate Change on Canadian Forest Fires*, 31 GEOPHYSICAL RES. LETTERS 1, 1 (2004).

246. John Abatxoglou & A. Park Williams, *Impact of Anthropogenic Climate Change on Wildfire Across Western US Forests,* 113 PROC. NAT'L ACAD. SCI. 11770, 11770 (2016).

247. *Id.*

248. A. Park Williams et al., *supra* note 242, at 892 (more specifically, the authors found that anthropogenic climate change had contributed to an eightfold increase in summertime forest-fire area, which in turn had contributed to a fivefold increase in California's annual wildfire extent).

249. Simon F.B. Tett et al., *Anthropogenic Forcings and Associated Changes in Fire Risk in Western North America and Australia During 2015/16, in* BAMS 2016, *supra* note 76, at S60–64.

v. Air pollution

There have been relatively few attribution studies of air pollution. Vautard 2018 looked indirectly at air pollution in Europe.[250] Rather than modeling actual air pollution, they modeled changes in the occurrence of "flow analogues" (i.e. wind and air pressure patterns associated with observed historical pollution events), finding that anthropogenic forcing had produced a 10% increase in the frequency of such events. As climate models become more able to model air pollution directly, and as awareness grows of how harmful fire and directly anthropogenic sources of air pollution (e.g., factories and vehicle emissions) are, we may see more attribution work on air pollution. Such studies will have to address the correlation between climate and air pollution, which differs by region, season, and type of pollutant.

vi. Public Health

Public health impacts are another important topic in attribution research. Here, again, many studies focus on how extreme heat affects health because the link between climate change and extreme heat is relatively direct. There has been much discussion of how other climate-related events and impacts, such as floods and wildfires, can affect public health, but there is little research linking anthropogenic forcings to health impacts from those types of events in a robust, quantitative fashion. As noted in IPCC AR5, evidence of impacts on public health is not as robust as evidence of other impacts, and "[a]t present the worldwide burden of human ill-health from climate change is relatively small compared with effects of other stressors and is not well quantified."[251] However, IPCC AR5 did find more robust evidence of specific types of health impacts, expressing *medium confidence* in findings of increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming, *medium confidence* that local changes in temperature and rainfall have altered the distribution of some water-borne illnesses and disease vectors,[252] and *very high confidence*

250. *See* Robert Vautard et al., *Attribution of wintertime anticyclonic stagnation contributing to air pollution in Western Europe, in* BAMS 2016, *supra* note 76, at S70–75.
251. IPCC AR5 WGII, Summary for Policymakers, *supra* note 18, at 6.
252. *Id.*

that climate-related extremes were affecting morbidity, mortality, mental health, and human well-being.[253]

Attribution of public health impacts, like other impacts, is challenging due to data requirements and the complexity of isolating causal factors that contribute to health outcomes. As noted by Ebi et al. 2017, robust detection and attribution of health impacts requires reliable long-term datasets, in-depth knowledge of the many drivers and confounding factors that affect public health outcomes, and refinement of analytic techniques to better capture the effect of anthropogenic forcing on health outcomes.[254] Two key challenges are the fact that high-quality, long-term public health data is not available for many parts of the world, and there are many confounding factors that influence public health outcomes in any given region.

Despite the limitations, Ebi et al. 2017 found that "advances are possible in the absence of complete data and statistical certainty: there is a place for well-informed judgments, based on understanding of underlying processes and matching of patterns of health, climate, and other determinants of human well-being."[255] To illustrate this point, the researchers discuss several contexts in which it is possible to show that a "proportion of the current burden of climate-sensitive health outcomes can be attributed to climate change": (i) heat waves, (ii) the emergence of tick vectors of Lyme disease in Canada, and (iii) the emergence of *Vibrio* in northern Europe. For heat waves, the researchers described several approaches for estimating the number of heat wave deaths attributable to anthropogenic climate change. These included two variants on multi-step attribution that would combine either the risk-based or storyline approach to extreme event attribution with an assessment of how changes in exposure to heat waves affect mortality, as well as a single-step attribution approach which would combine observations of the changes in the incidence and severity of heat waves with the exposure analysis. For *Vibrio*, the researchers found that it was possible to attribute increases in the incidence of *Vibrio* to incremental increases in sea surface temperatures, which could then be attributed to climate change. For tick vectors and Lyme disease, the researchers found that there was indirect

253. *Id.*
254. Ebi et al., *supra* note 207, at 085004-1.
255. *Id.*

evidence that higher temperatures were one of the forces leading to the expansion of these vectors, but that more detailed analyses of longer-term surveillance data was needed to actually quantify the relationship between climate change and tick vectors. One key takeaway from the authors of that study was that there are many different approaches to health impact attribution but no standard practice at this time.

Single-step attribution is still routinely used in health impact assessments. One such study looked at heat-related mortality in Sweden and found that mortality from heat extremes in 1980–2009 was double what would have occurred without climate change.[256] As noted, the key limitation to these studies is that they do not answer the question of how *anthropogenic* climate change is affecting public health.

The first fully quantitative end-to-end attribution analysis of heat-related morality from climate change was published in 2016.[257] This study combined a climate model with a health impact assessment model to attribute deaths from the 2003 European heat wave and found that anthropogenic climate change increased the risk of heat-related mortality by approximately 70% in Central Paris and 20% in London, and that approximately 506 (± 51) deaths were attributable to climate change in Paris, and 64 (± 3) deaths were attributable in London.[258]

Where data on public health outcomes is lacking, researchers may use changes in climate variables as proxies for health impacts. For example, a study on public health impacts from extreme temperatures in California's Central Valley used a temperature threshold of 40°C as a proxy for heat stress, and found that anthropogenic forcing had more than doubled the probability of a prolonged period (13+ days) during which temperatures exceeded that threshold).[259] Another study took a similar approach to examining health impacts from the 2015 Egyptian heat wave, using

256. Daniel Oudin Åström et al., *Attributing Mortality from Extreme Temperatures to Climate Change in Stockholm, Sweden*, 3 NATURE CLIMATE CHANGE 1050, 1051. (2013). The researchers accounted for confounding variables such as urbanization and the urban heat island effect, but did not attempt to quantify human influence on observed increases in extreme heat events.

257. Daniel Mitchell et al., *Attributing Human Mortality During Extreme Heat Waves to Anthropogenic Climate Change* 11 ENVTL. RES. LETTERS 1, 1 (2016).

258. *Id.*

259. Roberto Mera et al., *Climate Justice and the Application of Probabilistic Event Attribution to Summer Heat Extremes in the California Central Valley*, 133 CLIMATIC CHANGE 427, 435 (2015).

wet bulb globe temperature as a proxy for human discomfort caused by high heat and humidity, and found that the wet bulb temperatures observed during the heat wave were 69% more likely due to anthropogenic climate change.[260] This indirect approach to impact attribution is essentially the same as extreme event attribution but with a greater focus on implications for health outcomes. By construction, such studies assume a fixed relationship between the climate or climate extreme metric being calculated (e.g., a wet bulb temperature threshold) and the societal impact (additional mortality). This fixed approach may limit the applicability of the findings across places, subpopulations, and adaptation/policy contexts.

vii. Agriculture

Agricultural impacts, like public health impacts, are challenging to attribute to anthropogenic climate change due to gaps in data and the number of confounding factors that influence agricultural productivity.[261] One important finding from the research thus far is that climate change is having both positive and negative effects on agriculture depending on the region examined. Based on multiple studies covering a wide range of regions and crops, IPCC AR5 found with *high confidence* that "negative impacts of climate change on crop yields have been more common than positive impacts."[262] IPCC AR5 also found with *very high confidence* that climate-related extremes were disrupting the food supply.[263]

Attribution studies on agricultural impacts focus on linking observed changes in crop productivity to observed changes in temperature, rainfall, atmospheric greenhouse gas concentrations,

260. Daniel Mitchell, *Human Influences on Heat-Related Health Indicators During the 2015 Egyptian Heat Wave, in* BAMS 2015, *supra* note 76, at S72.

261. Agriculture and ecosystems are directly impacted by CO_2 concentrations. There is also growing research on how other pollutants associated with anthropogenic emissions (or byproducts of those emissions), like low-level ozone, may impact crops, ecosystems, and human health. For example, one recent study found a 10% decrease in soy production associated with and elevated ozone concentrations linked to anthropogenic ozone precursors. The fact that these chemical reactions are highly sensitive to temperature and other climate factors points at the challenges of quantifying results. Wolfgang Cramer et al., *Detection and Attribution of Observed Impacts*, in CLIMATE CHANGE 2014: IMPACTS, ADAPTATION 979-1037 (Christopher B. Fields et al eds., 2014).
and Vulnerability

262. IPCC AR5 WGII, Summary for Policymakers, *supra* note 18, at 4.

263. *Id.* at 6.

and extreme events. Some of the earliest studies on this topic demonstrated that declining crop yields co-occurred with anthropogenic summer warming at regional scales.[264] A more recent end-to-end study on how anthropogenic climate change affected drought and poor harvests in South Africa during 2016 found that anthropogenic forcings had likely contributed to a decrease in rainfall corresponding with a decrease in production, but did not go so far as to quantify precise impacts on crop productivity or economic damages.[265]

viii. Economics and Development

All of the changes in weather, extreme events, and impacts caused by climate change have implications for the economic health, stability, and social development of communities and nations. The primary drivers of these economic and development impacts include: 1) physical impacts on infrastructure and human settlements (e.g., from sea level rise and storms); 2) impacts on public health and human productivity; and 3) impacts on food production.[266] Quantifying these impacts is particularly challenging, as this requires quantification of all the different types of impacts discussed above, and more. But some initial efforts have been made to do so. IPCC AR5 highlighted several examples of studies drawing a qualitative link between observed climate changes and/or impacts and the corresponding effect on regional or national economic outcomes. For example, IPCC expressed *high confidence* in the fact that "extreme weather events currently have significant impacts in multiple economic sectors" in Europe.[267]

264. *See* David B. Lobell & Christopher B. Field, *Global Scale Climate-Crop Yield Relationships and the Impacts of Recent Warming*, 2 ENVTL. RES. LETTERS 1, 1 (2007); Lianzhi You et al., *Impact of Growing Season Temperature on Wheat Productivity in China*, 149 AGRIC. FOREST METEOROLOGY 1009, 1009 (2007); David B. Lobell et al., *Climate Trends and Global Crop Production Since 1980*, 333 SCIENCE 616, 616 (2011).

265. Chris Funk et al., *supra* note 177, at S91.

266. For example, the 2017 and 2018 wildfires in California caused billions of dollars of damage. Facing the prospect of liability for many of those fires, Pacific Gas and Electric (PG&E), one of the largest utilities in the United States, has filed for bankruptcy. While there has not yet been a formal attribution study establishing the causal link between anthropogenic climate change and those fires, initial analyses suggest that unusually warm temperatures did play a role. Kurtis Alexander, *Scientists See Fingerprints of Climate Change All Over California's Wildfires*, S.F. CHRON. (Aug. 3, 2018), https://www.sfchronicle.com/science/article/Scientists-see-fingerprints-of-climate-change-all-13128585.php. [https://perma.cc/TUK4-TMW6].

267. IPCC AR5 WGII, *supra* note 18, at 42.

IPCC AR5 also cited some specific examples of economic and social impacts from climate-related events, such as the 2008 Zambezi River flooding in Mozambique which displaced 90,000 people.[268] IPCC also highlighted research linking higher temperatures to declines in economic growth and per capita income in low-income countries,[269] and linking declining rainfall to the slower growth of Sub-Saharan economies,[270] but this research did not address the extent to which anthropogenic influence was responsible for observed impacts.

4. Source Attribution

We use the term "source attribution" in this paper to describe efforts to identify and attribute climate change to specific sources. A "source" could be a particular actor (e.g., a country or a company), a sector, or an activity. As one step in the longer chain to source attribution, we include efforts to unpack the relative contributions of different sources to greenhouse gas emissions and concentrations. As noted above, source attribution has been, and remains, a distinct discipline from what is commonly labeled "detection and attribution" in the climate science community.[271] However, the distinction is beginning to blur, as recent studies have endeavored to apply climate change and extreme event attribution to individual sources. This research is thus a critically important data point for societal questions about how we should allocate *responsibility* for climate change and its impacts among different actors—and these questions are at the heart of many policy, planning, and legal debates.

a. Methods and Parameters

As discussed above, the key sources of data used in source attribution come from direct measurements of emissions, which can be performed *in situ* or remotely from satellites, as well as documentary evidence of emissions contained in corporate reports,[272] government inventories, and other sources. Where

268. *Id.*
269. *Id.* at 997.
270. *Id.*
271. *See supra* Section II(A)(1).
272. These are most often emissions reports, although some historical emissions have been estimated based on production reports.

direct emissions data is lacking, scientists can use indirect methods, such as models, to estimate emissions from sources and activities. Indirect methods are particularly important for estimating emissions from land use changes and non-point sources such as agricultural operations.

As with other areas of attribution, it is challenging to establish a complete causal chain linking a source's contribution to climate change to specific changes in the global climate system and corresponding impacts on natural and human systems. Establishing such a causal chain involves going beyond merely quantifying the emissions contribution of the source and ascertaining the proportional contribution of those emissions to: (i) concentrations of greenhouse gases and other forcings, and (ii) ultimately how those changes in concentrations impact for example sea level rise, extreme weather events, and the resultant impacts on ecosystems and/or communities. There are some recent studies linking specific sources to certain changes in the global climate system but most of the existing research on "source attribution" focuses on quantifying emissions from sources and determining the proportional contribution to increases in atmospheric greenhouse gases.[273]

One complicating factor is that climate change is not a product of a single pollutant or polluting activity, and different GHGs and other forcing agents have different effects on climate in terms of magnitude, duration, location, and type of effect.[274] For example, aerosols typically reflect sunlight, and to generalize due to this and other aerosol properties, aerosols tend to offset some of the heat-trapping effects of greenhouse gases. Data gaps are a major issue here: there are no known industry-aerosol databases, although there have been efforts to estimate national aerosol contributions.[275] This is important because large uncertainty about the emissions or climate effects of a single important forcing agent (like aerosols) affects our estimates for other forcing agents.

There is also a good deal of uncertainty about the extent and timing of historical land use changes and their impact on atmospheric concentrations of greenhouse gases. Some of these

273. *See infra* Section II(B)(4)(b)(ii).

274. *See supra* Section II(B)(1).

275. *E.g.*, Ragnhild B. Skeie et al., *Perspective Has a Strong Effect on the Calculation of Historical Contributions to Global Warming*, 12 ENVTL. RES. LETTERS 1 (2017).

land use changes, like deforestation, also impact climate in other ways. For example, land use decisions which change the amount of sunlight absorbed at the surface can have an important or negligible effect on climate, depending on factors such as the latitude at which the deforestation occurs, and the reflective properties of the surface underneath the previously-forested area. Another complicating factor is that climate change itself directly impacts the magnitude of sources and sinks for greenhouse gases. For example, a warmer ocean is less able to uptake carbon dioxide, and changes in vegetation with climate change could switch some natural systems from net sources to net sinks, and vice versa.

Nonetheless, scientists can and have endeavored to calculate the relative contributions of emissions and land use change, and, within the category of emissions, of different pollutants. In climate change attribution studies, scientists can bolster emissions data with actual measurements of atmospheric greenhouse gases (such as those taken at Mauna Loa) to determine the overall effect of human activity on climate, with the aforementioned caveats. In source attribution, an estimate of total anthropogenic emissions is the denominator against which a specific source's emissions contribution can be compared. Consider the following equation as an illustration of this concept:

$$Cs = Gs/Gg$$

Here, *Cs* equals the source's proportional contribution to climate change, *Gs* equals greenhouse gases generated by the source (including any releases or loss in carbon sequestration caused by the source), and *Gg* equals total global greenhouse gases from all anthropogenic sources. The measurements of atmospheric greenhouse gases help scientists quantify *Cs*, but they do not provide much if any insight on the magnitude of the source's emissions.

Another complicating factor is how to account for historical emissions when ascertaining the proportional contribution of a source to climate change. Given that greenhouse gases accumulate over time, stay in the atmosphere, and can even have lasting climate effects that extend beyond the time that the added gas is in the atmosphere, it makes sense to include historical emissions in source attribution studies. But data about historical emissions is much more limited, given the absence of satellite-based observations and other data sources, less rigorous reporting requirements, and disappearance over time of some emitting entities and documents.

The steps from 1) emissions estimates to concentration estimates, and from 2) concentration estimates to climate effects like warming surface temperature and sea level rise, require the use of models. Although full climate models are beginning to be applied to attribution based on individual source estimates, most of the research described below relies on simplified climate models that can conduct rapid simulations based on differing source emissions. These simplified models enable sundry experiments for example based on individual country emissions, but some fidelity is sacrificed for the greater speed and simplicity. These models include assumptions about certain climate parameters (e.g., *equilibrium climate sensitivity*—which can be loosely defined as the final global warming associated with a certain amount of additional forcing, often defined as a doubling above preindustrial CO_2 equivalent; and *transient response*, a measure of more rapid climate system response).

This question of how to account for historical emissions brings us back to an earlier point about the role of social science in source attribution. As explained above, physical sciences alone cannot fully answer the question of who is "responsible" for emissions because responsibility can be apportioned in many different ways. There are presently two primary approaches—assigning responsibility to national governments and assigning responsibility to private actors—but there are also questions about how to apportion responsibility under each approach.[276]

International climate negotiations have historically focused on using national responsibility as the basis for allocating emission reduction burdens.[277] This focus is evident in the United Nations

276. *See supra* Section II(A)(2)(c) (national emissions contributions could be calculated based on emissions generated within national boundaries or emissions embedded within consumed products; private sector emissions from fossil fuel consumption could be apportioned to fossil fuel production companies, power plants, or consumers).

277. A Brazilian proposal taken up by the UNFCCC Subsidiary Body for Scientific and Technical Advice (SBSTA) said national historical emissions impacts on temperature should determine the burden of addressing climate change. A rationale provided was that these countries had benefitted economically and geopolitically from their emissions. For more information about the Brazilian proposal and the underlying rationale for this approach, *see* Emilio L. La Rovere et al., *The Brazilian Proposal on Relative Responsibility for Global Warming, in*

Framework Convention on Climate Change (UNFCCC), which places the responsibility for reporting on and reducing emissions on national governments;[278] the so-called "Brazilian Proposal" which emerged from UNFCCC negotiations in the mid-1990s and holds that greenhouse gas emission reduction targets should be set according to each country's historical contribution to climate change;[279] and the Paris Agreement which relies on nationally determined contributions (NDCs) as the primary basis for mitigating emissions.[280] The UNFCCC reporting framework has also historically focused on territorial emissions rather than consumption-based emissions as the metric for gauging national responsibility.

That said, in recent years there has been a strong push both in international and domestic fora to: (i) account for consumption-based emissions as well as territorial emissions at the national level,

BUILDING ON THE KYOTO PROTOCOL: OPTIONS FOR PROTECTING THE CLIMATE (Kevin A. Baumert et al. eds., 2002); BENITO MULLER ET AL., DIFFERENTIATING (HISTORIC) RESPONSIBILITIES FOR CLIMATE CHANGE (2007); M.G.J. DEN ELZEN ET AL., DUTCH MINISTRY OF ENV'T, RESPONSIBILITY FOR PAST AND FUTURE GLOBAL WARMING: TIME HORIZON AND NON-LINEARITIES IN THE CLIMATE SYSTEM (2002); Nathan Rive et al., *Climate Agreements Based on Responsibility for Global Warming: Periodic Updating, Policy Choices, and Regional Costs,* 16 GLOBAL ENVTL. CHANGE 182 (2006); Kevin A. Baumert & Nancy Kete, *Introduction: An Architecture for Climate Protection,* in BUILDING ON THE KYOTO PROTOCOL: OPTIONS FOR PROTECTING THE CLIMATE (Kevin A. Baumert et al. eds., 2002); Stephen Gardiner, *Ethics and Global Climate Change*, 114 ETHICS 555 (2004). More recently, Underdal and Wei reference "accumulated competitive advantages" via technological innovation and economic growth as the source of Annex 1 higher wealth today. Arild Underdal & Taoyuan Wei, *Distributive Fairness: A Mutual Recognition Approach*, 51 ENVTL. SCI. POL'Y 35, 37 (2015). The Annex 1 countries have argued against apportionment of responsibility based on historical emissions, on the grounds that, they were not aware of the effects of greenhouse gas emissions until ~1990, when the IPCC described these effects in detail. *See* JYOTI PARIKH & KIRIT PARIKH, CLIMATE CHANGE: A PARKING PLACE MODEL FOR A JUST GLOBAL COMPACT (2009). Others have countered that there were many earlier warnings about the perils of greenhouse gas emissions. *See, e.g.*, PRESIDENT'S SCI. ADVISORY COMM., RESTORING THE QUALITY OF OUR ENVIRONMENT (1965); Wallace S. Broeker, *Climatic Change: Are We on the Brink of a Pronounced Global Warming?,* 189 SCIENCE 460–64; WORLD METEOROLOGICAL ORGANIZATION, PROCEEDINGS OF THE WMO/IAMAP SYMPOSIUM ON LONG-TERM CLIMATIC FLUCTUATIONS, WMO Doc. 421 (Aug. 1975); NAT'L ACAD. OF SCI., CARBON DIOXIDE AND CLIMATE: A SCIENTIFIC ASSESSMENT (1979). Based on this record, Mattoo and Subramanian (2012) argued for 1970 as the start year. Aaditya Mattoo & Arvind Subramanian, *Equity in Climate Change: An Analytical Review*, 40 WORLD DEV. 1083 (2012).

278. United Nations Framework Convention on Climate Change, May 9, 1992, S. Treaty Doc No. 102-38, 1771 U.N.T.S. 107 [hereinafter UNFCC].

279. La Rovere et al., *supra* note 277.

280. Paris Agreement to the United Nations Framework Convention on Climate Change, Dec. 12, 2015, T.I.A.S. No. 16-1104 [hereinafter Paris Agreement].

and (ii) impose direct responsibility on private actors for emissions and to impose corresponding obligations on those actors.[281] Much of the focus has been on imposing regulatory requirements or liability for climate change on fossil fuel producers and electric generating companies. This brings us to another question about divvying up responsibility for emissions, which is whether it is appropriate to assign responsibility for emissions to entities that extract and sell fossil fuels. Erickson and Lazarous 2013 illustrate how extraction-based emissions accounting can be contrasted to "territorial" and "consumption-based" accounting methods in the following figure:[282]

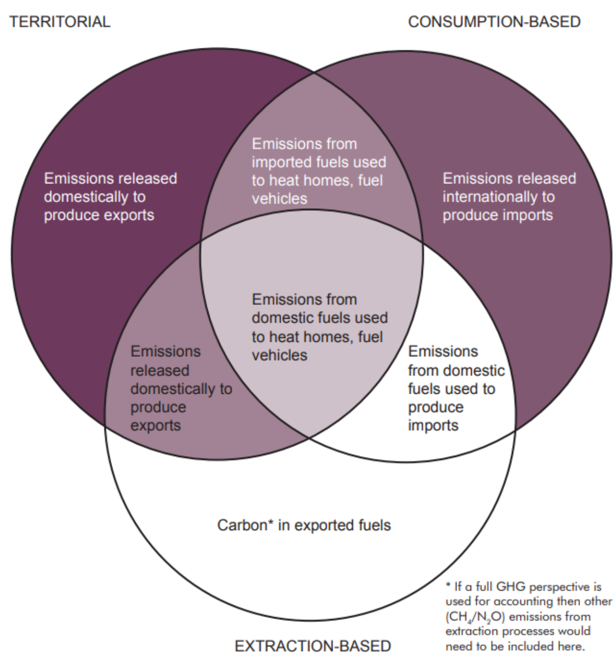

Figure 1: Comparison of territorial, consumption, and extraction-based GHG accounting

One might argue that imposing responsibly on upstream producers, or even midstream electric generators, is unfair because it lets consumers off the hook, but there are pragmatic and ethical

281. *See infra* Section III(C)(5) for an overview of cases filed against private actors for their contribution to climate change.

282. PETER ERICKSON & MICHAEL LAZARUS, STOCKLHOLM ENV'T INST., ACCOUNTING FOR GREENHOUSE GAS EMISSIONS ASSOCIATED WITH THE SUPPLY OF FOSSIL FUELS (2013).

reasons for focusing on upstream producers and electric generators. As a practical matter, it is easier to regulate a smaller group of well-informed companies than a very large group of poorly informed consumers, and some of the costs imposed on upstream and midstream entities will flow down to consumers, thus sending the appropriate price signals.[283] As an ethical matter, fossil fuel producers and energy companies have long known about the climate risks posed by use of their products, have lobbied against regulation, and ultimately profit most from the consumption of fossil fuels.

While most national emissions inventories currently focus on territorial emissions, researchers have found that it would be relatively easy for countries to produce extraction-based and consumption-based inventories based on readily available data.[284] In other words, pursuing these alternative accounting methodologies would not be significantly more expensive or technically challenging than the territorial approach. These alternative accounting methodologies also provide valuable insights that are not captured in the territorial approach—for example, the consumption-based approach accounts for "leakage" of GHG emissions to other countries via trade and helps countries understand the importance of developing policies aimed at reducing consumption of carbon-intensive products. Ultimately, though they may carry different legal weight, all three methodologies are useful in addressing the question of who is "responsible" for climate change.

283. *See, e.g.*, JONATHAN RAMSEUR & JANE LEGGETT, CONG. RES. SERV., R45625, ATTACHING A PRICE TO GREENHOUSE GAS EMISSIONS WITH A CARBON TAX OR EMISSIONS FEE: CONSIDERATIONS AND POTENTIAL IMPACTS (Mar. 22, 2019).

284. Glen P. Peters, *From Production-Based to Consumption-Based National Emissions Inventories*, 65 ECOLOGICAL ECONOMICS 13 (2008); Steven J. Davis & Ken Caldeira, *Consumption-Based Accounting of CO2 Emissions*, 107 PROC. NAT'L ACAD. SCI. 5687 (2010); Manfred Lenzen et al., *Building EORA: A Global Multi-Region Input–Output Database at High Country and Sector Resolution*, 25 ECON. SYS. RES. 20 (2013); Stavros Afionis et al., *Consumption-Based Carbon Accounting: Does It Have a Future?,* 8 WIREs CLIMATE CHANGE 1 (2017); Glen P. Peters, et al., *A Synthesis of Carbon in International Trade,* 9 BIOGEOSCIENCES 3247 (2012); Kirsten S. Wiebe & Norihiko Yamano, *Estimating CO2 Emissions Embodied in Final Demand and Trade Using the OECD ICIO 2015,* (OECD Sci., Tech. Indus., Working Paper 2016/05); Steven J. Davis et al., *The Supply Chain of CO2 Emissions*, 108 PROC. NAT'L ACAD. SCI. 18554 (2011); THOMAS MICHAEL POWER & DONOVAN S. POWER, THE ENERGY FOUNDATION, THE IMPACT OF POWDER RIVER BASIN COAL EXPORTS ON GLOBAL GREENHOUSE GAS EMISSIONS (2013).).

b. Status of Research

i. National Emissions Estimates

Countries have been developing and refining national greenhouse gas emission inventories since the early 1990s, pursuant to emission reporting requirements laid out in the United Nations Framework Convention on Climate Change (UNFCCC). The original agreement called upon developed countries (the "Annex I" parties) to prepare and periodically update national emission inventories listing all emissions and removals of direct GHGs from five sectors—energy; industrial processes and product use; agriculture; land use, land-use change, and forestry (LULUCF); and waste—in a standardized format.[285] The parties to the UNFCCC eventually introduced emission reporting requirements for non-Annex I countries as well, accompanied by programs aimed at addressing capacity and resource constraints in those countries.[286] The UNFCCC secretariat compiles all emissions inventory data in an online database,[287] and many other organizations use that data to analyze emissions trends.[288]

Due to this international emissions reporting system, there is a good deal of data on national emissions dating back to the 1990s, and the dataset has become more comprehensive through the 2000s as developed country parties have also begun reporting emissions. However, there are still significant gaps in the UNFCCC data, particularly with respect to historical emissions and developing country emissions through the mid-aughts. Governmental agencies, scientific organizations, and researchers have helped to fill gaps in UNFCCC data through independent

285. UNFCCC, Reporting Requirements, https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/reporting-requirements [perma.cc/66SQ-5LNT] (last visited Sep. 11, 2019).

286. UNFCCC, *National Reports from Non-Annex I Parties*, UNITED NATIONS CLIMATE CHANGE, https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-convention/national-communications-non-annex-i-parties/national-reports-from-non-annex-i-parties [https://perma.cc/P7E4-ZXAS] (last visited Sep. 11, 2019).

287. UNFCCC, *GHG Data from UNFCCC*, UNITED NATIONS CLIMATE CHANGE, https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/ghg-data-unfccc [https://perma.cc/Q7FD-EKQY] (last visited Sep. 11, 2019).

288. *See, e.g.*, *CAIT Climate Data Explorer*, WORLD RES. INST. http://cait.wri.org/ [https://perma.cc/K784-6M28] (last visited Dec. 30, 2019).

research on topics such as historical fossil fuel use by country,[289] but there is still a fair amount of uncertainty on national emissions estimates, especially prior to the 1990s.

The UNFCCC reporting approach focuses on emissions produced within a country. As noted above, another way to apportion emissions among countries is to focus on embedded emissions—that is, the emissions embedded within products consumed in the country. This more downstream approach to calculating national emissions has gained considerable traction in recent years. In 2010, researchers constructed a global database of CO_2 imports and exports.[290] The Global Carbon Project has since developed a similar database that looks at both domestically produced emissions ("CO_2 Production") and emissions once CO_2 embodied in both imports and exports have been included ("CO_2 Consumption").[291] Other research institutions have since published their own analyses of emissions embedded in trade products.[292] Some efforts have also been made to evaluate consumption-based emissions at sub-national levels.[293] Indeed, new approaches continue to emerge. For example, Matthews 2016 proposed and applied the notion of national carbon debts and credits, based on per capita cumulative emissions, relative to a benchmark.[294]

Several efforts have been made to link these national emissions to specific changes in climate and corresponding impacts. Li et al. 2016 focused on Chinese emissions and found that China

289. *See, e.g.*, *Carbon Dioxide Information Analysis Centre (CDIAC)*, U.S. DEPT. OF ENERGY, https://cdiac.ess-dive.lbl.gov/ [https://perma.cc/2W7H-HYZ7] (last visited Dec. 30, 2019); *ESS Dive*, U.S. DEP'T OF ENERGY, https://ess-dive.lbl.gov/ [https://perma.cc/5Y72-QV8L] (last visited Dec. 30, 2019); CAIT Climate Data Explorer, *supra* note 288; KEVIN A. BAUMERT ET AL., NAVIGATING THE NUMBERS: GREENHOUSE GAS DATA AND INTERNATIONAL CLIMATE CHANGE POLICY 3139 (2005); CLIMATE EQUITY REFERENCE CALCULATOR, https://calculator.climateequityreference.org/ [https://perma.cc/T5XU-89HM] (last visited Dec. 31, 2019).

290. Steven J. Davis et al., *The Supply Chain of CO2 Emissions*, 108 PROC. NAT'L ACAD. SCI. 18554 (2011).

291. *Global Carbon Budget,* GLOBAL CARBON PROJECT, https://www.globalcarbonproject.org/carbonbudget/ [https://perma.cc/Q8LU-92FE] (last visited Dec. 31, 2019). *See also* Glen Peters et al., *Growth in Emission Transfers Via International Trade from 1990 to 2008*, 108 PROC. NAT'L ACAD. SCI. 8903 (2011); Hausfather, *supra* note 50.

292. *See, e.g.*, Moran et al., *supra* note 50.

293. *See, e.g.*, C40 Cities, *supra* note 50.

294. H. Damon Matthews, *Quantifying Historical Carbon and Climate Debts Among Nations*, 6 NATURE CLIMATE CHANGE 60 (2016).

contributes 10 ± 4% of the current global radiative forcing, and that the relative contribution to global mean surface temperature (GMST) increase was 12 ± 2%.[295] Skeie et al. 2017 used a climate model to link the relative emissions contribution from multiple countries to GMST change, taking into account historical emissions and focusing on the largest emitters, and found that China was responsible for 6–13% and the United States was responsible for 15%–26% of the observed GMST increase.[296] Skeie et al. noted, however, that these findings were very sensitive to the parameters of the study, including technical decisions such as the timeframe for the analysis, as well as more normative decisions about the basis for attributing emissions (e.g., place of extraction vs. place of burning vs. place of final consumption) and about whether to look at per capita or total emissions. They also emphasized that, in non-linear systems, the proportional contribution to emissions will differ from the proportional contribution to impacts.

Otto et al. 2017 was the first study to apply the nation-based emissions framework to individual extreme event attribution, focusing on an Argentina heat wave.[297] A motivation was to quantify the proportional contribution of nation states to a phenomenon—specifically a damaging extreme event—that is closer to impacts and "losses" than phenomena to which source emission approaches had previously been applied, such as changes in global mean surface temperature.

The approach makes the simplifying assumption that each country's contributions to GMST can be linearly transferred to the Argentine heat wave. GMST is used as a responsibility indicator partly on the grounds that it is used in climate policy. Otto et al. uses two alternate methods to extract the relative contributions to GMST reported in Skeie et al., each of which has large uncertainties.[298] One major finding is that the sequence in which nations are summed in the cumulative approach is hugely important. It also means that when focusing on one entity's

295. Bengang Li et al., *The Contribution of China's Emissions to Global Climate Forcing*, 531 NATURE 357, 357 (2016).

296. Skeie et al., *supra* note 275.

297. Friederike E.L. Otto et al., *Assigning Historic Responsibility for Extreme Weather Events*, 7 NATURE CLIMATE CHANGE 757 (2017).

298. The distribution method assessed the US contribution as 34% (with a 20–54% uncertainty range), whereas the second approach, known as the gradient method, assessed the US at 28% (19–45% uncertainty range). *Id.* at 758.

emissions, results may be quite different if you remove the entity of interest from a full account, as opposed to adding that entity only to a counterfactual experiment. That is: the "How would the likelihood of the event change if only the region in question has emitted?" versus "How would the likelihood of the event change if the region of interest had not emitted?" questions yield very different results.

Finally, building on efforts to develop national emissions inventories and link these to climate change impacts, a fair amount of work has gone into developing "carbon budgets" both on a global level and for individual countries. Such budgets provide one possible foundation for holding governments accountable for mitigating their impact to climate change. The IPCC assessments and UNFCC targets (limiting warming to 2°C or 1.5°C) are, in turn, often used as the foundation for establishing budgets. Starting in the mid-aughts, the UNFCCC COP issued several decisions based on IPCC findings which recognize that industrialized countries must reduce emissions 25–40% below 1990 levels by 2020 to limit global warming to 2°C.[299] Academic researchers and organizations like the Global Carbon Project have since put a significant amount of work into developing more specific national budgets that correspond with the UNFCCC targets.[300] This work on carbon budgets is complemented by research examining the adequacy of national pledges under the Paris Agreement in light of temperature goals.[301]

299. *See, e.g.*, Bali Action Plan, U.N. DOC. FCCC/CP/2007/6/ Add.1; UNFCCC, Draft Resolution, Outcome of the Work of the Ad Hoc Working Group on Long-Term Cooperative Action under the Convention, Cancun, Mex. Nov. 29–Dec.10, 2010, U.N. DOC. FCCC/AWGLGA/2010/6.7 (Dec. 10, 2010); Report of the Conference of the Parties on its Eighteenth Session, held in Doha from 26 November to 8 December 2012, 2013; UNFCCC; FCCC/CP/2012/8, February 28, 2013.

300. *See, e.g.*, GLOBAL CARBON PROJECT, *supra* note 291.

301. *See, e.g.*, Yann Robiou de Pont & Malte Meinshausen, *Warming Assessment of the Bottom-Up Paris Agreement Emissions Pledges*, 9 NATURE COMMUNICATIONS 4810 (2018). Scholars from legal, policy, and social sciences disciplines have also written on the topic of how carbon budgets should be allocated to reflect normative considerations such as justice and equity, reflecting the fact that this is one area where the law and science interact in significant ways. *See, e.g.*, Cass Sunstein & Eric Posner, *Climate Change Justice* (John M. Olin Program in Law and Economics Working Paper No. 354, 2007); Catriona McKinnon, *Climate Justice in a Carbon Budget*, 133 CLIMATIC CHANGE 375 (2015).

ii. Corporate Emissions Estimates

There have been a number of efforts to attribute emissions to corporate actors and business sectors in recent years. Many of these efforts have focused on tracing emissions to the companies producing fossil fuels and other carbon-intensive products. Heede 2013 looked at historic production records from ninety producers of oil, natural gas, coal, and cement found that the emissions from these sources totaled 914 $GtCO_2e$, equivalent to 64% of cumulative worldwide emissions of industrial CO_2 and methane from 1751–2010.[302] Heede dubbed these producers the "carbon majors" based on their disproportionately large contribution to global emissions. He also found that approximately half of the emissions were generated since 1986—a piece of data which could be used to contradict claims about unforeseeability (since it is difficult to argue that companies were unaware of the risks of climate change by that time). Another noteworthy finding was that substantial emissions had come from fossil fuels sourced from non-Annex I countries such as China, India, Saudi Arabia, South Africa, Iran, Brazil, Mexico, Nigeria, Venezuela, Kuwait, Angola, Malaysia, and Libya, and that this called into question the UNFCCC's differential treatment of such countries at that time.[303] Heede's research eventually became the basis of the well-known *Carbon Majors* report, first published in 2014 and updated in 2017, and an accompanying online database.[304] Notably, the 2017 update found that one hundred fossil fuel producers were linked to 71% of industrial greenhouse gas emissions since 1988.[305]

Researchers from the Union of Concerned Scientists (UCS) have continued research on the carbon majors. Ekwurzel et al. 2017 took Heede's work a step further, applying his emission findings to a simplified climate model to assess the impacts of those emission contributions on global temperature change and sea level rise.[306]

302. Heede, *supra* note 31. These included fifty investor-owned, thirty-one state-owned, and nine nation-state producers of fossil fuels and cement. *Id.*

303. Heede, *supra* note 31, at 231.

304. RICHARD HEEDE, CARBON MAJORS: ACCOUNTING FOR CARBON AND METHANE EMISSIONS 1854–2010: METHODS & RESULTS REPORT (2014); PAUL GRIFFIN ET AL., THE CARBON MAJORS DATABASE: CDP CARBON MAJORS REPORT 2017 (2017); PAUL GRIFFIN ET AL., THE CARBON MAJORS DATABASE: METHODOLOGY REPORT 2017 (2017).

305. GRIFFIN ET AL., CDP CARBON MAJORS REPORT, *supra* note 304, at 8.

306. Ekwurzel et al., *supra* note 13. This approach was similar to that applied by Otto et al., *supra* note 297, insofar as the researchers went beyond merely estimating the

They found that emissions from the ninety carbon majors were responsible for approximately 57% of the observed rise in atmospheric CO_2, approximately 42–50% of the rise in global mean surface temperature (GMST), and 26–32% of the global sea level rise over the historical period from 1880–2010.[307] Taking a closer look at the past few decades, they find that the carbon majors were responsible for approximately 43% of the rise in atmospheric CO_2, 29–35% of the rise in GMST, and 11–14% of the global sea level rise from 1980–2010.[308]

These efforts have been complemented by initiatives such as the Climate Disclosure Project (CDP), a voluntary system whereby companies report on emissions in exchange for reputational credit,[309] as well as new legal mandates calling for companies to report emissions to national and in some cases sub-national governments.[310] The IPCC also compiles emissions data for specific sectors (energy, transport, buildings, industry, forestry, agriculture, and waste) and uses this data to help frame discussions on effective mitigation approaches.[311]

III. LEGAL AND POLICY APPLICATIONS

The ability to detect and attribute environmental changes to anthropogenic greenhouse gas emissions is useful for a variety of different law and policy applications. In the broadest sense, detection and attribution are the scientific tools that policy-makers and lawyers can use to show the existence, causes, and effects of

contribution of sources to global emissions and also looked at the effect on temperature change and sea level rise (whereas Otto et al. focused on an extreme event).

307. Ekwurzel et al., *supra* note 13, at 579.

308. *Id.* The authors note that the calculations are incomplete at this moment in time since the CO_2 already emitted will continue to impact the dependent climate variables in the future. Along similar lines, growing abatement of aerosol emissions associated with fossil fuel combustion leads to more warming and sea level rise per unit of fossil fuel combustion.

309. CLIMATE DISCLOSURE PROJECT (CDP), https://www.cdp.net [https://perma.cc/RA5A-K6VX] (last visited Sep. 11, 2019).

310. *See, e.g.*, *GHG Reporting Program,* EPA, https://www.epa.gov/ghgreporting [https://perma.cc/U42K-ZMAZ] (last visited Sep. 11, 2019); *Mandatory GHG Emissions Reporting*, CAL. AIR RES. BOARD, https://ww2.arb.ca.gov/our-work/programs/mandatory-greenhouse-gas-emissions-reporting [https://perma.cc/V32L-GG4H] (last visited Sep. 11, 2019).

311. *See* IPCC, WORKING GROUP III CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE IPCC, CLIMATE CHANGE 2014: MITIGATION OF CLIMATE CHANGE 351–413 (Ottmar Edenhofer et al. eds., 2014) (drawing most emissions data from the Emissions Database for Global Atmospheric Research (EDGAR) project).

climate change. This information can help inform critical policy decisions, such as the appropriate level for an emissions cap or a carbon tax. It can also help plaintiffs pursue certain types of legal actions, such as cases against government actors for failure to act on climate change. However, attribution science is not a panacea—the evidence generated by this field is not always effective at persuading or compelling policy-makers, courts, or the public to take action on climate change.[312] This is in part due to the complexity of and limitations in the science, but there are also barriers to policy and legal action on climate change that inhere in the nature of political decision-making and legal doctrine, unrelated to the quality of detection and attribution data.[313] This section addresses the salience of attribution science to policy-making at various scales of governance, its role in planning and environmental impact assessment, and the critical role it has played and will play in climate change litigation.

A. Policy-Making

Attribution science plays a critical role in policy-making. It helps to build support for actions to address the causes and impacts of climate change by: (i) demonstrating that anthropogenic climate change is already underway and resulting in adverse impacts, and (ii) lending confidence to model projections of how the climate will change in response to greenhouse gas emissions and how these changes will affect people and the environment in the decades to come.[314] Indeed, as the body of detection and attribution evidence has grown, an increasing number of jurisdictions have adopted greenhouse gas reduction targets and have commenced adaptation

312. *See, e.g.*, COMMUNICATING CLIMATE CHANGE INFORMATION FOR DECISION-MAKING (Silvio Serrao Neumann et al. eds, 2018); Ishani Mukherjee & Michael Howlett, *Communicating about Climate Change with Policymakers*, *in* OXFORD RESEARCH ENCYCLOPEDIA OF CLIMATE SCIENCE (2016); Sabrina McCormick et al., *Science in Litigation, the Third Branch of U.S. Climate Policy*, 357 SCIENCE 979, 979–980 (2017).

313. These include political, social, and economic barriers to policies and programs aimed at addressing climate change, as well as judicial doctrines that prevent courts from adjudicating climate change-related disputes. *See, e.g.*, Susanne C. Moser, *Communicating Climate Change: History, Challenges, Process and Future Directions*, 1 WIRES CLIMATE CHANGE 31 (2010); Richard J. Lazarus, *Super Wicked Problems and Climate Change: Restraining the Present to Liberate the Future*, 94 CORNELL L. REV. 1153 (2009).

314. Easterling et al., *supra* note 22.

planning activities.[315] The greater this body of evidence, the greater the justification for imposing stringent greenhouse gas reduction requirements, incentivizing the transition away from fossil fuels, and making large expenditures to prepare for the effects of climate change. Having a clear justification is important both for political reasons and for the purpose of defending mitigation and adaptation programs in court.

Attribution science can also contribute to more effective mitigation and adaptation policies. Information about source attribution is particularly helpful for informing mitigation policy, as it can be used to determine which actors, activities, or sectors should be targeted for regulation or to determine the appropriate level of regulation for any given source category. Meanwhile, information about impact attribution can help policy-makers identify the most significant climate change-related risks and make prudent decisions about how to allocate resources for adaptation.[316] For example, the IPCC, the USGCRP, and other authoritative bodies rely on quantitative detection and attribution studies to develop and refine their impact assessments, and this information feeds directly into national and sub-national adaptation planning efforts.[317] Regional modeling, downscaled analyses, and the use of local impact, adaptation, and vulnerability ("IAV") studies is particularly important in this context.

A related function of attribution science is that it can help decision-makers better understand the cost of unabated climate change, thus informing decisions about the appropriate level of regulation (e.g., the right price of a carbon tax) and also aiding in the justification of regulations. Consider the greenhouse gas emission and energy efficiency standards promulgated in the United States by the Obama Administration: for many of these

315. *See* Michal Nachmany & Joana Setzer, *Global Trends in Climate Change Legislation and Litigation: 2018 Snapshot,* GRANTHAM RES. INST. ON CLIMATE CHANGE & ENV'T, http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2018/04/Global-trends-in-climate-change-legislation-and-litigation-2018-snapshot-3.pdf [https://perma.cc/B672-822Q]; *Climate Change Laws of the World Database,* GRANTHAM RES. INST. ON CLIMATE CHANGE & ENV'T, http://www.lse.ac.uk/GranthamInstitute/climate-change-laws-of-the-world/ [https://perma.cc/HJ26-3U7A] (last visited Dec. 31, 2019).

316. *See* Easterling et al., *supra* note 22; Sebastian Sippel et al., *Stakeholder Perspectives on the Attribution of Extreme Weather Events: An Explorative Enquiry,* 7 WEATHER, CLIMATE, SOC'Y 224, 229 (2015).

317. *See* NCA4, *supra* note 7, at 114–32; IPCC AR5 WGI, *supra* note 25, at 867–952; IPCC AR5 WGII, *supra* note 18, at 979–1038.

rules, the U.S. Environmental Protection Agency ("EPA") conducted a cost-benefit analysis in which it monetized the effects of greenhouse gas emission reductions using the federal Social Cost of Carbon ("SC-CO_2")—a metric developed by the U.S. government that reflects the potential damages that can be attributed to the addition of one ton of CO_2 into the atmosphere in a particular year, expressed as a range of possible costs.[318] Using this metric, the Administration concluded that the total monetized benefits of the economic, environmental, and public health impacts from these standards significantly outweighed the costs.[319] This finding served as a key justification for issuing the standards.[320] While the SC-CO_2 and similar metrics for other gases are primarily based on predictions of future impacts, detection and attribution studies provide information about present impacts which can help to improve predictive models and also lend confidence to impact projections.

Finally, attribution science provides a framing mechanism for international negotiations, including those conducted under the United Nations Framework Convention on Climate Change ("UNFCCC") and the Paris Agreement. There are several ways in which attribution science is useful in this context. First, the growing body of evidence linking emissions and land use changes to harmful impacts helps build political support for ambitious action on climate change, and also provides a basis for critiquing countries that do not go far enough with their emission reduction pledges (referred to in the Paris Agreement as "nationally determined contributions").[321] Second, attribution science can

318. *See, e.g.*, EPA, EPA-452-R-15-003, REGULATORY IMPACT ANALYSIS FOR THE CLEAN POWER PLAN FINAL RULE (Aug. 2015); EPA, EPA-420-R-12-016, REGULATORY IMPACT ANALYSIS: FINAL RULEMAKING FOR 2017–2025 LIGHT-DUTY VEHICLE GREENHOUSE GAS EMISSION STANDARDS AND CORPORATE AVERAGE FUEL ECONOMY STANDARDS (Aug. 2012); Energy Conservation Program: Energy Conservation Standards for Commercial Refrigeration Equipment Final Rule, 79 Fed. Reg. 17,726 (Mar. 28, 2014) (codified at 10 C.F.R. pt. 431(c)).

319. Energy Conservation Program: Energy Conservation Standards for Commercial Refrigeration Equipment Final Rule, 79 Fed. Reg. at 17,730.

320. Zero Zone Inc. v. Dep't of Energy, 832 F.3d 654, 678–79 (7th Cir. 2016) (upholding use of the SC-CO_2 in rulemaking establishing energy conservation standards for commercial refrigeration equipment).

321. Paris Agreement, *supra* note 280, at art. 14, ¶ 1 (establishing a "global stocktake" whereby the parties to the agreement "shall periodically take stock of the implementation of this Agreement to assess the collective progress towards achieving the purpose of this Agreement and its long-term goals."). For information about how emission budgets would

help improve decision-making about how to allocate funds for adaptation insofar as it provides insight into which countries, regions, sectors, and population groups have the greatest risk of harm due to anthropogenic climate change. Third, attribution science can help countries reach agreement on the highly contentious "loss and damage" framework whereby the countries that are least responsible for climate change are compensated by more responsible countries for harmful impacts caused by climate change.[322]

This third area—loss and damage—is where attribution science could potentially play the biggest role. To develop a functional loss and damage framework, countries would need to answer two types of questions that can only be answered through a combination of attribution science and predictive modeling: first, which countries have already suffered harmful impacts as a result of climate change and are most certain to do so in the future, and second, to what extent are other countries responsible for those impacts.[323] As discussed above, one complicating factor is that there are often multiple drivers behind harmful impacts linked to climate change—for example, construction and development practices within a coastal community can increase the vulnerability of people and structures in that area to the effects of storms and sea level rise, and numerous factors, including degree of community cohesion and economic development, can decrease resilience to them. In

serve as benchmarks in the global stocktake, *see generally* Christian Holz & Xolisa Ngwadla, *The Global Stocktake Under the Paris Agreement: Opportunities and Challenge*, EUROPEAN CAPACITY BUILDING INITIATIVE (Anju Sharma ed., 2016), http://www.eurocapacity.org/downloads/GST_2016%5B1%5D.pdf [https://perma.cc/ER2Y-DGKE]; *see also* IPCC, SPECIAL REPORT: GLOBAL WARMING OF 1.5°C (Valerie Masson-Delmotte et al. eds., 2018), https://www.ipcc.ch/sr15/ [https://perma.cc/9959-GSRB] (providing a recent example of how information about climate change impacts can build considerable political support for climate action).

322. For more on this topic, see Christian Huggel et al., Commentary, *Loss and Damage Attribution*, 3 NATURE CLIMATE CHANGE 694 (2013); Rachel James et al., *Characterizing Loss and Damage From Climate Change*, 4 NATURE CLIMATE CHANGE 938 (2014); Daniel Farber, *The Case for Climate Compensation: Justice for Climate Change Victims in a Complex World*, 2008 UTAH L. REV. 377 (2008).

323. For a more detailed discussion of how attribution science can inform the development of a loss and damage framework, *see* Christian Huggel et al., *Reconciling Justice and Attribution Research to Advance Climate Policy,* 6 NATURE CLIMATE CHANGE 901 (2016); Roda Verheyen, *Loss and Damage Due to Climate Change: Attribution and Causation—Where Climate Science and Law Meet*, 8 INT'L J. GLOBAL WARMING 158 (2015); Christian Huggel et al., *Potential and Limitations of the Attribution of Climate Change Impacts For Informing Loss and Damage Discussions and Policies,* CLIMATIC CHANGE (SPECIAL ISSUE) 10.1007 (2015).

most cases, even the most sophisticated attribution studies cannot fully resolve the question of how much of the harm incurred by a community is due to anthropogenic climate change as opposed to confounding risk factors. The complex and multi-causal nature of harms related to climate change may therefore make it difficult to reach consensus on loss and damage issues. As discussed in further detail below, it may also prove to be an obstacle to lawsuits seeking compensation from emitters for climate-related damages.

B. Planning and Environmental Impact Assessment

Attribution science also facilitates on-the-ground planning for the effects of climate change by providing more robust data about how climate change is already affecting landscapes, ecosystems, and human systems such as cities, infrastructure, and food production. This information can feed into scenario planning, informing the likely and possible ranges of outcomes under different greenhouse gas emission trajectories.[324] Finally, attribution studies that focus on regional or localized impacts can be used to develop and refine downscaled projections of climate change impacts within a particular geographic region, and to improve the accuracy and precision of the models that are used to develop those projections.[325] All of this can feed into a more robust analysis of how climate change is affecting and will affect proposed and planned actions.

We see this type of analysis being performed in regional resource management planning, state and local planning, environmental reviews, and corporate disclosures. For example, during the Obama Administration, the federal agencies that manage public lands and natural resources began using detection and attribution science to better understand how climate change is affecting water

324. Easterling et al., *supra* note 22. *See generally Observed and Projected (Longer-term) Changes in Weather and Climate Extremes,* 11 WEATHER CLIMATE EXTREMES (SPECIAL ISSUE) A1 (2016).

325. *See, e.g.*, Mohammad Reza Najafi et al., *Attribution of the Observed Spring Snowpack Decline in British Columbia to Anthropogenic Climate Change,* 30 J. CLIMATE 4113 1 (2017); Beena Balan Sarojini et al., *Detection and Attribution of Human Influence on Regional Precipitation,* 6 NATURE CLIMATE CHANGE 669 (2016); Peihua Qin & Zhenghui Xie, *Detecting Changes in Future Precipitation Extremes Over Eight River Basins in China Using RegCM4 Downscaling,* 121 J. GEOPHYSICAL RES. ATMOSPHERES 6802 (2016); Chunzhen Liu & Jun Xia, *Detection and Attribution of Observed Changes in the Hydrological Cycle under Global Warming,* 2 ADVANCES IN CLIMATE CHANGE RES. 31 (2011); Tim P. Barnett et al., *supra* note 239, at 1080.

resources, ecosystems, and biodiversity in the United States and to develop appropriate response strategies.[326] Federal, state, and local agencies are also now using data on observed impacts such as sea level rise, melting permafrost, and extreme heat events to better understand natural hazards and to inform planning decisions.[327]

Attribution science can also help decision-makers better understand a proposed or planned action's contribution to global climate change. Currently, environmental impact assessments ("EIAs") and other planning documents express this contribution by quantifying the anticipated greenhouse gas emissions that will be generated as a result of the action, and then providing a brief qualitative description of the types of impacts which can be expected as a result of climate change. Because the overall contribution of the action to global greenhouse gases is typically quite small, no attempt is made to draw a direct link between the action's greenhouse gas emissions and specific on-the-ground impacts of climate change. Improvements in detection and attribution could facilitate the development and refinement of metrics that could be used to better explain how a project will contribute to global climate change. The SC-CO_2 and cost metrics for nitrous oxide ("SC-N_2O") and methane ("SC-CH_4") are good examples: EIA documents can use these metrics to translate greenhouse gas emissions into a specific dollar value which serves as a proxy for on-the-ground impacts (and as discussed above,

326. *See, e.g.*, PETER BACKLUND ET AL., U.S. CLIMATE CHANGE SCI. PROGRAM, THE EFFECTS OF CLIMATE CHANGE ON AGRICULTURE, LAND RESOURCES, WATER RESOURCES, WATER RESOURCES, AND BIODIVERSITY IN THE UNITED STATES (Margaret Walsh et al. eds., 2008); LEVI D. BREKKE, U.S. GEOLOGICAL SUR., CLIMATE CHANGE AND WATER RESOURCES MANAGEMENT: A FEDERAL PERSPECTIVE, CIRCULAR 1331 (2009); JESSICA WENTZ, SABIN CTR. FOR CLIMATE CHANGE L., CONSIDERING THE EFFECTS OF CLIMATE CHANGE ON NATURAL RESOURCES IN ENVIRONMENTAL REVIEW AND PLANNING DOCUMENTS: GUIDANCE FOR AGENCIES AND PRACTITIONERS (2016).

327. *See, e.g.*, *Sea Level Rise,* CAL. ADAPT., https://cal-adapt.org/tools/slr-calflod-3d/ [https://perma.cc/5BQD-2EJL] (last visited Sep. 11, 2019); Press Release, NYS Dep't of Envt'l Conservation, DEC Announces New Sea Level Rise Projection Regulation for New York (Feb. 6, 2017), http://www.dec.ny.gov/press/109195.html [https://perma.cc/7XAY-BZWJ]; *Sea Level Rise Viewer,* NOAA, https://coast.noaa.gov/slr/ [https://perma.cc/X48G-QFBT] (last visited Nov. 21, 2019); *Flood Map Revision Process,* FEMA, https://www.fema.gov/flood-map-revision-processes [https://perma.cc/YZQ5-CU5A] (last visited Nov. 21, 2019). *See also* ADITI KAPOOR, CLIMATE DEVELOPMENT KNOWLEDGE NETWORK AND WORLD WEATHER, POLICY BRIEF: CLIMATE ATTRIBUTION SCIENCE: A USEFUL TOOL TO PLAN FOR EXTREME HEAT EVENTS (2017).

improved attribution data can be used to justify and refine these metrics).

C. Litigation

Evidence linking human influence on climate to the harmful impacts of climate change plays an important role in lawsuits seeking to compel action on climate change as well as the legal defense of programs and regulations aimed at reducing greenhouse gas emissions or advancing adaptation objectives. The manner in which such evidence is utilized and the extent to which it influences case outcomes will depend on the type of case and the stage of litigation. Below, we present a detailed breakdown of legal issues and cases involving climate change-related claims and how attribution science is used in different contexts: 1) establishing standing to sue; 2) introducing expert scientific testimony and reports as evidence; 3) challenges to government failures to regulate GHG emissions; 4) the legal defense of existing GHG emission standards; 5) lawsuits seeking to hold emitters liable for damages from climate change impacts; and 6) lawsuits involving climate change adaptation, impact assessment, and disclosures.[328]

1. Establishing Standing to Sue Sources of GHG Emissions for Climate-Related Harms

Standing doctrines address the question of who should have access to courts to adjudicate a particular claim.[329] Whether a plaintiff has standing is a jurisdictional question that is addressed at

328. There are certain legal doctrines that may control the outcome of these cases but more indirectly implicate questions of attribution, such as the political question doctrine, the foreign affairs preemption doctrine, and the doctrine of legislative displacement. *See* discussion *infra* Section III(C)(5).

329. There is large body of scholarship on the question of standing for climate change-related damages. *See, e.g.*, Bradford C. Mank, *Standing and Future Generations: Does* Massachusetts v. EPA *Open Standing for Generations to Come?*, 34 COLUM. J. ENVTL. L. 1 (2009); Bradford C. Mank, *Standing and Global Warming: Is Injury to All Injury to None?*, 35 ENVTL. L. 1 (2005); Blake R. Bertagna, Comment, *"Standing" Up for the Environment: The Ability of Plaintiffs to Establish Legal Standing to Redress Injuries Caused by Global Warming*, 2006 BYU L. REV. 415 (2006); Christopher L. Muehlberger, Comment, *One Man's Conjecture is Another Man's Concrete: Applying the "Injury-in-Fact" Standing Requirement to Global Warming*, 76 UMKC L. REV. 177 (2007); Joseph M. Stancati, Note, *Victims of Climate Change and Their Standing to Sue: Why the Northern District of California Got it Right*, 38 CASE W. RES. J. INT'L L. 687 (2006–2007); Nigel Cooney, Note, *Without a Leg to Stand on: The Merger of Article III Standing and Merits in Environmental Cases*, 23 WASH. U. J. L. & POL'Y 175 (2007).

the outset of litigation before the merits are adjudicated.[330] Standing requirements vary considerably by jurisdiction. Here, we will focus on the standing jurisprudence of U.S. federal courts—since this is the context where attribution science has played the most significant role—recognizing that these federal standards are among the most restrictive in the world.[331]

Federal standing doctrine arises from the Supreme Court's determination that Article III of the Constitution limits the jurisdiction of the federal courts to cases or controversies where the plaintiff has a concrete and personal stake in the outcome of the litigation.[332] Based on this understanding, the Supreme Court has held that Plaintiffs must establish that (i) they have suffered an injury-in-fact—that is, "an invasion of a legally protected interest which is (a) concrete and particularized and (b) actual or imminent, not conjectural or hypothetical;"[333] (ii) the injury-in-fact is fairly traceable to the defendants' allegedly unlawful actions;[334] and (iii) the injury could be redressed by a favorable court decision.[335] Attribution science is central to standing contests over each of these prongs.

a. Standing Elements

i. Injury-in-Fact

The types of harms giving rise to standing include injuries to economic, physical, spiritual, aesthetic, and recreational interests.[336] There is no threshold requirement for the size of the

330. While standing is a jurisdictional issue, the issues implicated in the standing analysis may go directly to the merits of the case, which may lead a court to defer its standing analysis under the case has been fully briefed and all evidence reviewed.

331. *See* John Dimanno, *Beyond Taxpayers' Suits: Public Interest Standing in the States*, 41 CONN. L. REV. 639 (2008); Christopher S. Elmendorf, *State Courts, Citizen Suits, and the Enforcement of Federal Environmental Law by Non-Article III Plaintiffs*, 110 YALE L.J. 1003 (2001); J. Michael Angstadt, *Securing Access to Justice Through Environmental Courts and Tribunals: A Case in Diversity,* 17 VT. J. ENVTL. L. 345 (2016); Matt Handley, *Why Crocodiles, Elephants, and American Citizens Should Prefer Foreign Courts: A Comparative Analysis of Standing to Sue*, 21 REV. LITIG. 97, 117 (2002); Niran Somasundaram, *State Court Solutions: Finding Standing for Private Climate Change Plaintiffs in the Wake of* Washington Environmental Council v. Bellon, 42 ECOLOGY L.Q. 491 (2015).

332. Lujan v. Defs. of Wildlife, 504 U.S. 555, 556 (1992).

333. *Id.* at 560 (internal citations and quotations omitted).

334. *Id.*

335. *Id.* at 561.

336. Ass'n of Data Processing Serv. Orgs. Inc. v. Camp, 397 U.S. 150, 152, 154 (1970).

injury—any "identifiable trifle" is sufficient to establish standing.[337] However, injury must be "particularized," meaning that it is not a "generalized grievance" shared by the public at large.[338] The requirement of particularized injury has been viewed as a potential barrier for plaintiffs seeking standing based on injuries caused by climate change, since such injuries are often shared by the public. However, some plaintiffs have successfully used impact attribution research to persuade the courts that their injuries are sufficiently particularized for standing purposes.[339]

It is more difficult to establish an injury-in-fact based on the risk of future harm. The general rule is that the future harm must be "imminent, not conjectural or hypothetical."[340] The term can be interpreted as entailing a temporal element, a probabilistic element, or both.[341] The Supreme Court has conceded that this is an "elastic concept"[342] and has defined it differently in different cases. Most recently, the Court has held that the imminence requirement is met where the harm is "certainly impending" or where there is a "substantial risk" of the harm occurring.[343] To establish standing based on the prospect of future environmental damage, plaintiffs must demonstrate either: (i) a substantial risk of direct harm (e.g., physical health impacts), or (ii) that they visit the affected area or use the affected resources for recreational, spiritual, or aesthetic purposes and/or have concrete plans to do so in the future.[344]

337. United States v. Students Challenging Regulatory Agency Procedures (SCRAP), 412 U.S. 669, 689 n.14 (1973).

338. United States v. Richardson, 418 U.S. 166, 171 (1974); Schlesinger v. Reservists Comm. To Stop the War, 418 U.S. 208, 217 (1974).

339. *See* Massachusetts v. EPA, 549 U.S. 497, 525 (2007) (finding state had standing due to loss of land resulting from sea level rise), Connecticut v. Am. Elec. Power Co., 582 F.3d 309 (2d Cir. 2009*), rev'd*, 564 U.S. 410 (2011) (finding state had standing due to loss of snow pack, the corresponding effect on water supplies and flooding, and the effect of sea level rise and coastal erosion on coastal property).

340. *Lujan*, 504 U.S. at 560.

341. Evan Tsen Lee & Josephine Mason Ellis, *The Standing Doctrine's Dirty Little Secret*, 107 NW. U.L. REV.169, 179–80 (2012) (noting cases where courts have found a lack of imminence because the alleged injury would not happen immediately, and cases where courts have found a lack of imminence because the injury was too "conjectural" and there was insufficient probability that it would ever occur).

342. *Lujan,* 504 U.S. at 565 n.2.

343. Clapper v. Amnesty Int'l USA, 568 U.S. 398, 414 n.5 (2013); Susan B. Anthony List v. Driehaus, 573 U.S. 149, 158 (2014).

344. *Lujan*, 504 U.S. 555; Summers v. Earth Island Inst., 555 U.S. 488 (2009).

ii. Causation and Redressability

The second and third elements of standing (causation and redressability) are closely related, sometimes referred to as "two sides of the same coin."[345] These requirements have proven to be the most difficult to prove in cases involving climate-related harms. For causation, the plaintiff must establish that the injury is "fairly traceable" to the challenged action "and not the result of the independent action of some third party not before the court."[346] Courts often look for factual causation, typically expressed as a "but for" test: would the plaintiff not have been injured but for the defendant's action.[347] In cases brought against governments and private actors for failure to regulate or abate emissions, the Supreme Court has found sufficient causation where the emissions represent a "meaningful contribution" to global climate change.[348] What constitutes a "meaningful contribution" to global climate change is a question that at this point will be determined on a case-by-case basis.[349]

Finally, the redressability prong requires that it is likely and not "merely speculative" that the injury would be redressed by a favorable decision.[350] The prospect of even partial redress may be sufficient.[351]

345. Ctr. For Biological Diversity v. EPA, 90 F. Supp. 3d 1177, 1190 (W.D. Wash. 2015). *See also* Gonzales v. Gorsuch, 688 F.2d 1263, 1267 (9th Cir. 1982); Duke Power Co. v. Carolina Envtl. Study Grp., 438 U.S. 59, 74 (1978).

346. *Lujan*, 504 U.S.at 560 (internal citations and quotation marks omitted).

347. *See, e.g., Duke Power Co*, 438 U.S. at 74–75; Allen v. Wright, 468 U.S. 737, 758 (1984).

348. *See Massachusetts*, 549 U.S. at 525 (emissions from all U.S. motor vehicles made a "meaningful contribution" to global climate change).

349. *See, e.g.*, Wash. Envtl. Council v. Bellon, 732 F.3d 1131, 1135 (9th Cir. 2013) (emissions from Washington power plants amounting to 6% of state's total GHG emissions not a "meaningful contribution" to climate change), *reh'g en banc denied*, 741 F.3d 1075 (9th Cir. 2014); Amigos Bravos v. U.S. Bureau of Land Mgmt., 816 F. Supp. 2d 1118, 1136 (D.N.M. 2011) (254,730 metric tons of GHGs per year that might result from the approval of 92 oil and gas leases were not a "meaningful contribution" to global climate change); Juliana v. United States, 217 F. Supp. 3d 1224 (D. Or. 2016) (Motion to Dismiss denied because U.S. agencies had regulatory authority over at least 14% of global GHGs and this was sufficient for standing).

350. *Lujan*, 504 U.S. at 561.

351. *See Massachusetts*, 549 U.S. 497; *Am. Elec. Power Co.*, 582 F.3d 309 (2d Cir. 2009), *rev'd*, 564 U.S. 410 (2011).

iii. Procedural Injury

Standing requirements are somewhat relaxed for cases that involve "procedural injuries."[352] Such injuries occur when agencies undertake actions without adhering to legally mandated procedures, such as when a federal agency undertakes a major action without preparing an environmental impact statement ("EIS"), promulgates a final rule without adhering to the Administrative Procedure Act ("APA")'s notice and comment requirements, or otherwise fails to implement a process that is required by statute.[353] Courts will sometimes refer to these cases as involving "procedural rights."[354]

iv. Standing for States and Associations

Adding an additional layer to the standing analysis is the fact that states have special standing to sue, both by virtue of their sovereign status and the breadth of their interests, which encompass the state's direct interests, e.g., state property, as well as the interests of their residents.[355] Large associations may also have an easier time establishing standing than private individuals due to the number of members in those associations. This holds true in cases involving the risk of future harm: an association with many members may be able to establish that, in aggregate, its members face a "substantial

352. *Lujan*, 504 U.S. at 571–72.

353. Christopher T. Burt, Comment, *Procedural Injury Standing After* Lujan v. Defenders of Wildlife, 62 U. CHI. L. REV. 275, 276 (1994); F. Andrew Hessick, *Probabilistic Standing*, 106 NW. U. L. REV. 55, 69 (2012) (citing *Summers*, 555 U.S. at 496–97).

354. *Lujan*, 504 U.S. at 572 n.7; *Massachusetts*, 549 U.S. at 498 (citing APA § 7607(b)(1)) (noting that that the "right to challenge agency action unlawfully withheld" is a procedural right created by the APA). In *Lujan*, the Supreme Court affirmed that procedural rights are "special" and that "[t]he person who has been accorded a procedural right to protect his concrete interests can assert that right without meeting all the normal standards for redressability and immediacy." 504 U.S. at 572 n.7. The Court further explained, "Thus, under our case law, one living adjacent to the site for proposed construction of a federally licensed dam has standing to challenge the licensing agency's failure to prepare an environmental impact statement, even though he cannot establish with any certainty that the statement will cause the license to be withheld or altered, and even though the dam will not be completed for many years." *Id.* Notably, the plaintiff must still show that they will suffer a concrete injury-in-fact that is linked to the procedural injury. *Summers*, 555 U.S. at 496 (citing *Lujan*, 504 U.S. at 572 n. 7); *Massachusetts*, 549 U.S. at 518 (noting that the plaintiff needs to show that the "procedural step was connected to the substantive result" and that there is "some possibility that the requested relief will prompt the injury-causing party to reconsider the decision that allegedly harmed the litigant."). For more on this topic, see Burt, *supra* note 353, at 280–81.

355. *Massachusetts*, 549 U.S. 497; Georgia v. Tenn. Copper Co., 237 U.S. 474 (1915).

risk" of harm, where an individual plaintiff would not be able to make this showing.

Consider the case of *Natural Resources Defense Council v. EPA*, a case involving a challenge to the adequacy of an ozone pollution standard decided by the D.C. Circuit Court of Appeals in 2007. The ozone standard was expected to result in a very small increase in the risk of cancer—one in 200,000, according to NRDC's experts. This might not have sufficed as an "imminent" threat to an individual plaintiff's interest, but NRDC was able to establish standing by presenting evidence of the aggregated risk across all of its 490,000 members.[356] The D.C. Circuit Court of Appeals explained:

> The lifetime risk that an individual will develop nonfatal skin cancer as a result of EPA's rule is about 1 in 200,000 by the intervenor's lights. Even if a quantitative approach is appropriate—an issue on which we express no opinion—this risk is sufficient to support standing. One may infer from the statistical analysis that two to four of NRDC's nearly half a million members will develop cancer as a result of the rule.[357]

However, in *Summers v. Earth Island Inst.*, five Supreme Court justices rejected a similar argument in the public lands context. There, the Sierra Club sought standing to challenge U.S. Forest Service regulations based on potential injury to its members' use and enjoyment of national forests. The majority denied standing because the Sierra Club had failed to establish that any member had concrete plans to visit a site where the regulations would be applied.[358] The dissent argued that, because the Sierra Club had 700,000 members, there was a statistical probability that one of their members would be adversely affected by the regulations,[359] but the majority held that "such speculation does not suffice" for standing purposes.[360]

356. Nat. Res. Def. Council v. EPA, 464 F.3d 1, 7 (D.C. Cir. 2006).

357. *Id.*

358. *Summers*, 555 U.S. at 496.

359. *Id.* at 505–07.

360. *Id.* at 499. *Summers* does not totally foreclose the possibility of standing based on a probabilistic injury. The probabilistic inquiry in *Summers* was whether one of the association members might visit a forest that was affected by the regulation in the near future—this question is much easier to answer through affidavits than through statistical analysis, since it depends on the members' intent. In contrast, the probabilistic inquiry in *Nat. Res. Def.*

v. Concluding Notes on Standing

As may be evident from the above discussion, standing jurisprudence is viewed by many as "incoherent"[361] and inevitably subjective.[362] The lack of a coherent approach is particularly apparent in cases involving the risk of future harm, where courts typically conduct a qualitative rather than quantitative assessment of the risk to determine whether it rises to a level of imminence.[363] Hessick notes that as a likely consequence of their qualitative analyses, courts have "[g]enerally proven themselves incapable of applying [this standard] in a rigorous way,"[364] and explains that "[u]ncertainty about probability forces courts to forego precise calculations of probabilities and instead to evaluate probability on a gestalt feeling of the likelihood of a harm occurring. Assessments of this sort, however, are vulnerable to biases."[365] As a result of these factors, it is very difficult to predict whether or how federal courts will grant standing in climate change cases, particularly where plaintiffs allege an increased risk of future harm rather than a present injury. One way or the other, the state of attribution science is and will be central.

b. Case Law on Standing to Sue for Climate Change-Related Harms

The role of attribution science in establishing standing, then, is to determine whether plaintiffs have suffered an injury, or risk of an injury, that can be linked to anthropogenic climate change, and therefore linked to emissions that were generated by a private entity or inadequately regulated by a government entity. Attribution data is a valuable complement to impact projections as it can be used to establish an existing injury while also lending

Council v. EPA was whether one of the association members might be harmed by involuntary exposure to pollution—statistical analysis is both necessary and well-suited to making such predictions. Faced with a situation more analogous to *Nat. Res. Def. Council v. EPA,* the Court may have reached a different conclusion about the statistical probability of injury.

361. Lee & Ellis, *supra* note 341, at 169, 200; William A. Fletcher, *The Structure of Standing,* 98 YALE L. J. 221, 231 (1988).

362. Cass Sunstein, *What's Standing After Lujan? Of Citizen Suits, "Injuries," and Article III,* 91 MICH. L. REV. 163, 188–89 (1992); Albert Lin, *The Unifying Role of Harm in Environmental Law,* 3 WIS. L. REV. 897, 938 (2006); Lee & Ellis, *supra* note 341, at 200; Hessick, *supra* note 353, at 73.

363. Hessick *supra* note 353, at 73.

364. *Id.*

365. *Id.* at 75.

credibility to projections of future harm. This section reviews key decisions which illustrate how attribution of impacts to anthropogenic climate change factors into standing analysis.

i. *Massachusetts v. EPA*

The Supreme Court first addressed the issue of standing to bring climate change-related claims in *Massachusetts v. EPA*. There, a group of states, cities, and environmental organizations brought a lawsuit challenging the EPA's decision not to regulate greenhouse gas emissions from motor vehicles under the Clean Air Act. One of the key questions in the case was whether EPA could decline to exercise its regulatory authority because there was too much uncertainty about the causes and effects of climate change.[366] The question of uncertainty was also relevant to the question of standing—the issue being whether plaintiffs could establish a sufficiently certain causal link between the failure to regulate and harms that they had incurred and would incur as a result of climate change. Because this case involved a procedural right—specifically, the right to challenge agency action unlawfully withheld—the immediacy and redressability requirements were relaxed.[367]

In their briefs, the plaintiffs supported their standing and merits claims by describing the many harms that they would incur as a result of climate change—for example, the states were experiencing and would continue to experience a "loss of state-owned property to rising sea levels. . . added costs to deal with emergency response measures caused by more frequent intense storm surge flooding events . . . damage to state-owned historic, archeological, and natural resources including state forests . . . [and] damage to state-owned facilities and infrastructure along the coast."[368] These assertions were supported by numerous

366. *Massachusetts*, 549 U.S. at 497, 513–14 (citing EPA, Control of Emissions from New Highway Vehicles and Engines: Notice of Denial of Petition for Rulemaking, 68 Fed. Reg. 52922, 52929–31 (Sept. 8, 2003)).

367. *Id.* at 518.

368. Petitioners' Reply Brief in Support of Petition for Mandamus at 2, Massachusetts v. EPA, 549 U.S. 497 (2007) (No. 05-1120).

expert declarations[369] as well as an amicus brief filed by climate scientists in support of the plaintiffs.[370]

In its initial review of the case, the U.S. Court of Appeals for the D.C. Circuit proceeded directly to the merits without resolving the standing issues separately, noting that this was a case where the standing inquiry and the merits inquiry clearly overlapped and that it would be "exceedingly artificial to draw a distinction between the two."[371] One concurring judge commented on standing, asserting that he would have dismissed the case because the plaintiffs only alleged what he viewed as a "generalized grievance" shared by all U.S. residents rather than the sort of "particularized grievance" required under standing law.[372]

On review, a five justice majority held that at least one of the plaintiffs—the state of Massachusetts—had presented sufficient evidence of actual and imminent harms to establish standing in the case, specifically the fact that it would suffer serious loss of coastal property as a result of sea level rise.[373] The Court noted that Massachusetts had a "special position and interest" in the case, in part because "it actually owns a great deal of the territory alleged to be affected" by climate change, and in part because of its status as a sovereign state.[374] The Court referred to data in the petitioners' affidavits showing that "global sea levels rose between 10 and 20 centimeters over the 20th century as a result of global warming and have already begun to swallow Massachusetts' coastal land" and that "[r]emediation costs alone . . . could reach hundreds of millions of dollars."[375] It held that this was a sufficiently particularized injury. Responding to EPA's assertion that Massachusetts' injury was "conjectural because the land loss that the state expected could not be quantified," the Court said that it was unnecessary to determine "the precise metes and bounds of [the state's] soon-to-be-flooded

369. *See, e.g.*, Final Brief for the Petitioners at 2–3, Massachusetts v. EPA, 415 F.3d 50 (D.C. Cir. 2005) (Nos. 03-1361, consolidated with Nos. 03-1362 through 03-1368).

370. Brief of Amici Curiae Climate Scientists David Battisti, et. al. in Support of Petitioners at 10–18, Massachusetts v. EPA, 549 U.S. 497 (2007) (No. 05-1120).

371. Massachusetts v. EPA, 415 F.3d 50, 56 (D.C. Cir. 2005), *rev'd*, 549 U.S. 497 (2007). Interestingly, on the merits the court held that there was sufficient uncertainty about the causes and effects of climate change such that EPA had reasonably declined to exercise its authority. *Massachusetts*, 415 F.3d at 58.

372. *Id.* at 60–61 (Sentelle, J., concurring).

373. *Massachusetts*, 549 U.S. at 517.

374. *Id.* at 523.

375. *Id.* at 521–23.

land" because the general trend was clear: Massachusetts was losing land and would continue to lose land to sea level rise.[376]

Turning to the causation and redressability prongs of standing, the court rejected EPA's assertion that its decision not to regulate would contribute "so insignificantly to petitioners' injuries" and thus there was "no realistic possibility that the relief sought would . . . remedy petitioners' injuries, especially since predicted increases in emissions from China, India, and other developing nations will likely offset any marginal domestic decrease EPA regulation could bring about."[377] First, the Court noted that, judged by any standard, U.S. motor vehicle emissions make a "meaningful contribution" to greenhouse gas concentrations and global warming (in 1999, they accounted for more than 6% of worldwide carbon dioxide emissions, or 1.7 billion metric tons).[378] The Court acknowledged that EPA could not by itself reverse global warming through motor vehicle standards but this did not mean that the court lacked jurisdiction to decide "whether EPA has a duty to take steps to *slow* or *reduce* it."[379] The majority explained that while a favorable decision would not totally remedy the problem, Massachusetts would not lose as much land as it otherwise would.[380] Thus, the majority treated redressability "as a matter of degree rather than an all-or-nothing proposition."[381]

ii. *Connecticut v. American Electric Power Company*

In subsequent cases, federal courts have raised questions about whether to grant standing to petitioners who are: (i) not states (and therefore have fewer interests of a different nature that could be affected by climate change), (ii) seeking regulation of emission sources with a much smaller greenhouse gas footprint than the U.S. motor vehicle fleet, or (iii) not alleging a procedural injury.

Connecticut v. American Electric Power Company was a case that involved state plaintiffs but lacked a procedural injury claim. There, a group of state, city, and non-governmental plaintiffs sued five power companies, alleging that their contribution to climate

376. *Id.* at 523, n.21.
377. *Id.* at 523–24.
378. *Id.* at 525.
379. *Id.* at 525.
380. *Id.* at 525–26.
381. Lee & Ellis, *supra* note 341, at 192.

change constituted a public nuisance under both federal and state common law. The plaintiffs alleged a combination of existing and future injuries associated with climate change. For example, the states cited studies showing that climate change was already causing sea level rise and snowpack melt and that this had an adverse effect on their interests and their residents.[382]

The U.S. Court of Appeals for the Second Circuit, responding to a motion to dismiss, held that at least some of the plaintiffs had standing, finding that both the existing and future harms were sufficient to establish injury-in-fact. The court began its standing analysis by explaining that "[t]he procedural posture of a case is important when assessing standing", and that when considering a motion to dismiss, courts should "presume that general factual allegations embrace those facts necessary to support the claim."[383] The court further noted that defendants "may certainly test [plaintiffs'] standing as the litigation progresses by requesting an evidentiary hearing or by challenging [plaintiffs'] standing on summary judgment or even at trial" but that the "allegation of a credible risk" is sufficient at the pleading stage, as "[a]dopting a more stringent view of [standing requirements] would essentially collapse the standing inquiry into the merits."[384]

With regards to existing injuries, the court found that that California's alleged injuries from sea level rise and snowpack melt "far exceed the 'identifiable trifle' required by Article III."[385] With regards to whether the future harms were sufficiently imminent, the court cited precedent holding that, in cases involving exposure to a harmful substance, it is the exposure that must be imminent and not the onset of disease.[386] The court then explained that the plaintiffs' future injury claims in the present case were even "more compelling" because, according to plaintiffs, the "defendants are currently emitting large amounts of carbon dioxide and will continue to do so in the future" and the adverse impacts to the plaintiffs were "certain to occur because of the consequences, based on the laws of physics and chemistry, of the documented increase in carbon dioxide in the atmosphere."[387] Thus, the

382. *Am. Elec. Power Co.*, 582 F.3d 309, 318 (2d Cir. 2009), *rev'd*, 564 U.S. 410 (2011).
383. *Id.* at 333.
384. *Id.* (internal citations omitted).
385. *Id.* at 342.
386. *Id.* at 344.
387. *Id.*

"future injuries they predict are anything but speculation and conjecture."[388]

Turning to the questions of causation and redressability, the court briefly noted plaintiffs' allegations that the defendants were the "five largest emitters of carbon dioxide in the United States" and that their emissions accounted for 2.5% of global emissions, but did not examine whether this constituted a "meaningful contribution" to global climate change.[389] The court explained that the fact that the defendants "contribute to" climate change was sufficient to allege causation in the context of a motion to dismiss, and that the significance of the contribution was "an issue best left to the rigors of evidentiary proof at a future stage of the proceeding, rather than dispensed with as a threshold question of constitutional standing."[390] In other words, the court determined that this issue should be addressed as part of its evaluation of the factual merits of the nuisance claim.[391] The court concluded that, "[f]or purposes of Article III standing, [the Plaintiffs] are not required to pinpoint which specific harms of the many injuries they assert are caused by particular Defendants, nor are they required to show that Defendants' emissions alone cause their injuries. It is sufficient that they allege that Defendants' emissions contribute to their injuries."[392] Citing *Massachusetts*, the court also held that the possibility of partial redress in this context was sufficient for standing purposes.[393]

On appeal, the Supreme Court announced that the eight justices hearing the case were equally divided on the standing issue and thus affirmed the Second Circuit's decision.[394] Four justices would have granted standing cited *Massachusetts* and did not perform any additional analysis, indicating that they viewed that case as controlling even where a procedural injury was not at stake.[395] Ultimately, the Court unanimously held that the case was non-justiciable because the federal common law claims had been

388. *Id.*
389. *Id.* at 345–47.
390. *Id.* at 347.
391. For more information about how the causation requirement differs in the standing and nuisance context, *see* Section III(C)(5).
392. *Am. Elec. Power Co.*, 582 F.3d at 347.
393. *Id.* at 348.
394. *Id.*
395. *Id.*

displaced by the Clean Air Act's grant of authority to EPA to regulate greenhouse gas emissions.[396] The Court did not address the state law claims.

iii. *Kivalina v. Exxon Mobil*

In *Native Village of Kivalina v. Exxon Mobil* (*Kivalina*), a Native Alaskan village sued approximately two dozen fossil fuel and energy generation companies for their contribution to climate change and the corresponding damages to the village (specifically, the cost of relocation), alleging a public nuisance under federal common law.

The district court reviewing this case had a very different perspective on standing than the Second Circuit in *American Electric Power*. It found that Kivalina lacked standing because it had not demonstrated that its injuries were "fairly traceable" to the defendants' actions because there were many other actors responsible for the emissions leading to damages in the village.[397] The court reached this conclusion even though the emissions at issue were significantly larger than those at issue in *American Electric Power*—specifically, Kivalina alleged that the defendant companies were jointly responsible for more than 1.2 billion tons of direct greenhouse gas emissions annually, as well as an unspecified quantity of indirect (downstream) greenhouse gas emissions generated by the combustion of fossil fuels extracted and sold by these companies.[398] As Kivalina put it, the defendants were responsible for a "substantial portion" of global greenhouse gas emissions.[399] Kivalina's complaint also included a detailed description of how greenhouse gas emissions were contributing to global climate change and, in turn, to localized impacts on Kivalina, such as melting permafrost and rising sea levels, which would force the village to relocate in the near future.[400]

The district court found that Kivalina had not alleged facts sufficient to be granted standing. On the question of whether a "contribution" to a problem may be sufficient to establish standing, it held that a contribution was not in-and-of-itself sufficient

396. *Id.* at 429.
397. Native Vill. of Kivalina v. Exxon Mobil Corp., 663 F. Supp. 2d 863, 880–81 (N.D. Cal. 2009), *aff'd on other grounds*, 696 F.3d 849 (9th Cir. 2012).
398. Complaint for Damages and Demand for Jury Trial ¶¶ 18–122, Native Vill. of Kivalina v. Exxon Mobil Corp., 663 F. Supp. 2d 863 (N.D. Cal. 2009) (No. CV 08 1138).
399. *Id.* ¶ 3.
400. *Id.* ¶¶ 123–62, 181–184.

evidence of harm and that plaintiffs had failed to show a "substantial likelihood" that the conduct of any one of the defendants actually harmed the village.[401] The court explained that:

> In view of the Plaintiffs' allegations as to the undifferentiated nature of greenhouse gas emissions from all global sources and their worldwide accumulation over long periods of time, the pleadings makes clear that there is no realistic possibility of tracing any particular alleged effect of global warming to any particular emissions by any specific person, entity, group at any particular point in time. Plaintiffs essentially concede that the genesis of global warming is attributable to numerous entities which individually and cumulatively over the span of centuries created the effects they now are experiencing. Even accepting the allegations of the Complaint as true and construing them in the light most favorable to Plaintiffs, it is not plausible to state which emissions—emitted by whom and at what time in the last several centuries and at what place in the world—"caused" Plaintiffs' alleged global warming related injuries. Thus, Plaintiffs have not and cannot show that Defendants' conduct is the "seed of [their] injury." To the contrary, there are, in fact, a multitude of "alternative culprit[s]" allegedly responsible for the various chain of events allegedly leading to the erosion of Kivalina.[402]

The district court did not specifically address whether there was some threshold at which standing could be established to sue emitters based on damages caused by climate change, but the court's analysis suggests that it would have reached the same decision regardless of the magnitude of the emissions.

On appeal, the Ninth Circuit followed the Supreme Court's decision in *American Electric Power* and dismissed the case due to legislative displacement, rather than a lack of standing.[403]

401. *Kivalina*, 663 F. Supp. 2d 863 at 880, *aff'd on other grounds* 696 F.3d 849 (9th Cir. 2012).

402. *Id.* at 880–81.

403. Native Vill. of Kivalina, 696 F.3d at 869. Justice Pro, in a concurring opinion, stated that he would have dismissed the case for lack of standing: "It is one thing to hold that a State has standing to pursue a statutory procedural right granted to it by Congress in the CAA to challenge the EPA's failure to regulate greenhouse gas emissions which incrementally may contribute to future global warming. *See* Mass. v. EPA, 549 U.S. 497, 516–20 (2007). It is quite another to hold that a private party has standing to pick and choose amongst all the greenhouse gas emitters throughout history to hold liable for millions of dollars in damages."

iv. *Washington Environmental Council v. Bellon*

The U.S. Court of Appeals for the Ninth Circuit grappled more directly with the question of what constitutes a sufficient contribution to climate change as part of the standing causation analysis in *Washington Environmental Council v. Bellon.* There, the court, responding to an appeal of a motion for summary judgment, held that two non-profits did not have standing to challenge Washington State's failure to regulate greenhouse gas emissions from five oil refineries, because they had not shown that the refineries' emissions made a meaningful contribution to global greenhouse gas levels.[404] The non-profits alleged that their members would experience adverse health impacts and property damage as a result of climate change, as well as aesthetic and recreational injuries because changes in precipitation patterns, reductions of glaciers, changes in wildlife habitat, and forest fires would affect natural areas that they routinely visit.[405] The court held that these injuries were sufficient to satisfy the injury-in-fact prong of the standing analysis but that the plaintiff had failed to establish causation.

Specifically, the court found that the plaintiffs' causation argument "consist[ed] of a series of links strung together by conclusory, generalized statements of 'contribution,' without any plausible scientific or other evidentiary basis that the refineries' emissions are the source of their injuries."[406] The court explained that:

> Greenhouse gases, once emitted from a specific source, quickly mix and disperse in the global atmosphere and have a long atmospheric lifetime. Current research on how greenhouse gases influence global climate change has focused on the cumulative environmental effects from aggregate regional or global sources. But there is limited scientific capability in assessing, detecting, or measuring the relationship between a certain GHG emission source and localized climate impacts in a given region.[407]

404. Wash. Envtl. Council v. Bellon, 732 F.3d 1131, 1135 (9th Cir. 2013), *reh'g en banc denied*, 741 F.3d 1075 (9th Cir. 2014).

405. *Id.* at 1140–41.

406. *Id.* at 1142.

407. *Id.* at 1143.

With regards to the defendants, the court noted that the refineries were responsible for 101.1 million metric tons of CO_2 annually (5.9% of total greenhouse gas emissions produced in the state of Washington), and that unlike the much larger quantity of emissions at issue in *Massachusetts v. EPA* (1.7 billion tons), the effect of those emissions on global climate change was "scientifically indiscernible, given the emission levels, the dispersal of GHGs world-wide, and the absence of any meaningful nexus between Washington refinery emissions and global GHG concentrations now or as projected in the future."[408] Thus, the court concluded that the causal chain was "too tenuous to support standing."[409]

The *Bellon* decision and other cases discussed above raise two important questions. First, at what threshold do emissions from a source represent a "meaningful contribution" to global climate change such that an adequate causal nexus can be found between those emissions and localized climate impacts? Or, in the words of the *Bellon* court, at what point is the effect of the emissions on global climate change sufficiently "scientifically discernible"? Detection and attribution research can help to answer this question, but there are also legal and policy judgments embedded in any determination of what constitutes a "meaningful" or "significant" contribution. Second, should this inquiry be conducted as part of the standing analysis, or is the question so closely tied to the merits that the issue should, in all or some subset of cases, be deferred to that later stage of the litigation? We return to this question in Section IV.

v. *Comer v. Murphy Oil*

The U.S. Court of Appeals for the Fifth Circuit also grappled with the question of standing for non-governmental entities to sue fossil fuel companies in *Comer v. Murphy Oil USA*. There, residents and

408. *Id.* at 1145. The court noted that the *Bellon* case also differed from *Massachusetts* because no procedural right was implicated and there was no state plaintiff that should be granted "special solicitude" in the standing analysis, but found that even if it "assume[d] that the Plaintiffs' members are entitled to a comparable relaxed standard, the extension of *Massachusetts* to the present circumstances would not be tenable."

409. *Id.* at 1144. *See also* Barnes v. U.S. Dep't of Transp., 655 F.3d 1124 (9th Cir. 2011) (finding that it was not possible to establish a link between greenhouse gas emissions from an increase in aviation activities caused by airport expansion and specific harmful impacts of climate change).

owners of lands and property along the Mississippi Gulf coast filed a class action lawsuit against energy, fossil fuel, and chemical companies alleging that the greenhouse gas emissions generated by these companies contributed to global warming, which in turn caused a rise in sea levels which exacerbated the effects of Hurricane Katrina.[410] The plaintiffs asserted claims for damages based on state common law actions of public and private nuisance, trespass, negligence, unjust enrichment, fraudulent misrepresentation, and civil conspiracy.[411] Unlike in *American Electric Power*, the plaintiffs did not pursue any federal common law action nor did they seek injunctive relief.[412] As in other cases, the defendants argued that the plaintiffs had not established an adequate causal connection between defendants' conduct and plaintiffs' harm.

The district court in Mississippi initially held that plaintiffs lacked standing,[413] but the Fifth Circuit reversed, holding that the landowners had Article III standing to bring their nuisance, trespass, and negligence claims.[414] The court noted that fully addressing the defendants' causation arguments would require the court to address the merits of plaintiffs' claims and was therefore "misplaced at this thresholds standing stage of the litigation."[415] It further explained that "the Article III traceability requirement need not be as close as the proximate causation needed to succeed on the merits of a tort claim" and that "an indirect causal relationship will suffice" for the purposes of Article III standing.[416] The Fifth Circuit thus took a very different approach from the Ninth Circuit in *Bellon*, noting that it must take the plaintiff's allegations that the defendants' emissions caused their injuries as true at the pleading stage, recognizing that the plaintiffs would be required to support those assertions at a later stage in the litigation.[417]

410. Comer v. Murphy Oil USA, 585 F.3d 855, 859 (5th Cir. 2009).
411. *Id.* at 859–60.
412. *Id.* at 860.
413. Comer v. Murphy Oil USA, Inc., No. 1:05-CV-436-LG-RHW, 2007 WL 6942285, at *1 (S.D. Miss. Aug. 30, 2007), *rev'd sub nom* Comer v. Murphy Oil USA, 585 F.3d 855 (5th Cir. 2009).
414. Comer v. Murphy Oil USA, 585 F.3d at 879–80.
415. *Id.* at 864.
416. *Id.*
417. *Id.*

The decision did not stand for long: the Fifth Circuit granted a rehearing en banc shortly after issuing the decision, and subsequently lost its quorum to decide the case before hearing it. The court ultimately held that it must dismiss the appeal due to lack of quorum and thus, the vacatur of the original panel decision remained in place.[418]

vi. *Juliana v. United States*

More recently, in *Juliana v. United States,* a federal district court in Oregon held that plaintiffs suing the U.S. government for affirmatively contributing to climate change and failing to control emissions from fossil fuel development and use had adequately alleged that they had standing to sue.[419] The court, responding to a motion for dismiss, noted that "general factual allegations" were sufficient to establish Article III standing.[420] The court found that the plaintiffs had established sufficiently personalized and concrete injuries—such as lost income for a ski resort employee, and harmful impacts to a family farm—that were fairly traceable to the greenhouse gas emissions resulting from U.S. fossil fuel production and use.[421] The court distinguished the case from *Bellon* on two grounds:

> (1) The procedural posture of the case was different: *Bellon* involved a motion for summary judgment, which is typically filed after the parties have completed discovery, whereas the *Juliana* court was responding to a motion to dismiss, which is filed shortly after the complaint is filed and which can only be granted where there is no genuine issue of material fact.[422]
>
> (2) The emissions at issue in *Juliana* (from all U.S. fossil fuels) were significantly larger than the emissions at issue in *Bellon* (from five refineries), and by no means represented a "minor contribution" to climate change.[423]

418. Comer v. Murphy Oil USA, 607 F.3d 1049, 1055 (5th Cir. 2010).
419. Juliana v. United States, 217 F. Supp. 3d 1224, 1248 (D. Or. 2016).
420. *Id.* at 1268.
421. *Id.* at 1267–68.
422. *Id.* at 1245.
423. *Id.*

The court also rejected the idea put forth by the district court in *Kivalina*—that causation between emissions and impacts cannot be established where there are "a multitude of alternative culprits" that are also responsible for climate change—and found that "a causal chain does not fail simply because it has several links, provided those links are not hypothetical or tenuous and remain plausible."[424] It summarized the causal chain as follows:

> DOT and EPA have jurisdiction over sectors producing sixty-four percent of United States emissions, which in turn constitute roughly fourteen percent of emissions worldwide; they allow high emissions levels by failing to set demanding standards; high emissions levels cause climate change; and climate change causes plaintiffs' injuries.[425]

Finally, with regards to redressability, the court noted that the requested remedy—ordering the U.S. government to "prepare and implement an enforceable national remedial plan to phase out fossil fuel emissions"—would "slow or reduce" the harm caused to plaintiffs, and that was sufficient for standing.[426]

The court subsequently denied a motion for summary judgement, again declining to find that plaintiffs lacked standing to sue, and citing many of the considerations noted above. The court acknowledged that a different standard applies when reviewing a motion for summary judgment (which is typically filed after the parties have completed discovery) as compared with a motion to dismiss.[427] At this stage, plaintiffs must establish that there is a "genuine question of material fact as to the standing elements."[428] The court found that the affidavits and expert testimony submitted by plaintiffs during discovery met this requirement, and noted that it would revisit all elements of standing after the factual record had been fully developed at trial.[429]

The district court's summary judgment decision was reversed by the Ninth Circuit in early 2020 based on the appellate court's

424. *Id.* at 1268.

425. *Id.* at 1246.

426. *Id.* at 1247.

427. Juliana v. United States, 339 F. Supp. 3d 1062, 1086 (D. Or. 2018), *mandamus dismissed sub nom.* In re United. States, No. 18-505, 2019 WL 3462578 (U.S. July 29, 2019).

428. *Id.* at 1086–87.

429. *Id.* at 1096. *See infra* section III(C)(5) for a more detailed discussion of the expert testimony submitted during discovery.

determination that plaintiffs had not satisfied the redressability prong of Article III standing.[430] Specifically, the court concluded that it could not provide the redress plaintiffs were seeking—an order requiring the government to develop a plan to phase out fossil fuel emissions and reduce atmospheric CO_2—because providing such relief would implicate policy choices reserved for the elected branches of government and thus violate the separation of powers doctrine.[431] Importantly, the Court of Appeals did find that the plaintiffs had satisfied the injury and causation requirements of Article III standing, for the purposes of summary judgment, because the plaintiffs had claimed concrete and particularized injuries and there was a genuine factual dispute as to whether federal policies were a "substantial factor" in causing the plaintiffs' injury.[432] In reaching this conclusion, the court cited the U.S.'s historical and current contribution to global emissions and evidence submitted by plaintiffs that federal subsidies and leases had increased those emissions.[433] It also rejected the government's reliance on *Bellon* to argue that the causal chain is too attenuated for standing purposes, noting that the plaintiff's alleged injuries arose from "a host of federal policies, from subsidies to drilling permits, spanning over 50 years" (whereas *Bellon* involved a failure to regulate five oil refineries).[434] Thus, the Court of Appeals' decision was not based on any deficiencies in the underpinning science or causal chain linking government inaction to climate impacts.

vii. Foreign Jurisdictions

Some foreign courts have also grappled with the question of what constitutes a "meaningful contribution" to climate change for standing purposes. For example, in *Dual Gas Pty Ltd. v. Environment*

430. Juliana v. United States, No. 18-36082 (9th Cir. Jan. 17, 2020).

431. This is similar to the separation of powers arguments cited by some judges in dismissing lawsuits brought against fossil fuel companies. See Section III(C)(5) *infra*. In *Juliana*, the plaintiffs argued that the court need not itself make policy decisions in issuing an order to the government to take action, since the court defer to the elected branches of government to decide how to implement the order. The court disagreed, finding that the plaintiff's requested relief would require it to pass judgment on the *sufficiency* of the government's implementation of the order, which would necessarily entail a broad range of policymaking. *Juliana*, No. 18-36082 at *26.

432. *Juliana*, No 18-36082 at *19–21.

433. *Id.*

434. *Id.* at 20.

Protection Authority, the Victorian Civil and Administrative Tribunal in Australia made the following observations when determining whether plaintiffs had standing to sue the government's approval of a new power plant:

> [D]espite the global nature of the GHG issue, there must still be a materiality threshold in relation to the type or size of the works or emissions that is relevant to whether a person's interests are genuinely affected, as opposed to being too remote or too general. The emission of a few tonnes of GHG from a small factory in Gippsland would not in our view give rise to standing under s 33B(1) to an objector in Mildura even though it represents an incremental GHG increase. It is unnecessary for us to determine where the line of materiality might be drawn. As we noted in our introduction, the DGDP is a major power station that will generate up to 4.2 million tonnes of GHG per annum over a 30 year projected life cycle and increase Victoria's GHG emissions profile by 2.5% over 2009 levels. In our view, this clearly raises potential issues of material interest or concern to all Victorians, and creates an almost unique level of "affected interests" and standing compared to the more usual sort of works approval matters that come before the Tribunal.[435]

Of course, standing requirements in states and most, if not all, foreign jurisdictions are not as stringent as standing requirements in U.S. federal courts. In some decisions, there is no standing analysis.[436] In others, the standing analysis is of a more general nature and does not require plaintiffs to show that they incurred a particularized harm as a result of the greenhouse gas emissions that might be controlled as a result of judicial intervention, with the result that attribution science plays a less critical role in the standing analysis.[437] Because the standards are more permissive, standing has not been a significant obstacle to climate change cases outside of the United States, nor have attribution questions factored heavily in the standing analyses.[438]

435. *Dual Gas Pty Ltd. v Env't Protection Authority* [2012] VCAT 308, ¶ 134. (Austl.).

436. *See, e.g.*, Leghari v. Republic Fed'n of Pakistan (2015) W.P. No. 25501/2015. For more on standing to bring climate-related lawsuits in non-U.S. jurisdictions, see BURGER & GUNDLACH, *supra* note 10.

437. *See, e.g.*, Rb Den Haag 24 juni 20015, m.nt. C/09/00456689 HA ZA 3-1396 (Urgenda Stichting/Staat der Nederlanden) (Neth.) [hereinafter *Urgenda* District Court Decision (2015)].

438. *See* BURGER & GUNDLACH , *supra* note 10.

The inconsistencies within the case law on standing in the United States, and as between U.S. courts and foreign jurisdictions, reinforce the conceptual and practical difficulties that have bedeviled analysis of climate change litigation. In *Massachusetts*, 6% of global GHG emissions was found to be a "meaningful contribution" sufficient to show causation, and states were granted "special solicitude" in proving standing.[439] In *American Electric Power*, 2.5% of global GHG emissions was enough for the Second Circuit, and for at least four judges then sitting on the Supreme Court.[440] In *Kivalina*, a district court judge focused not on the quantity of emissions or the question of their significance, but the impossibility of tracing specific impacts to specific emissions.[441] In *Bellon*, the Ninth Circuit determined that 5.9% of Washington State's GHG emissions could not be effectively disaggregated from the global co-mingling of GHGs to establish causation.[442] In *Comer*, a Fifth Circuit panel found that allegations that a large number of companies had made a significant contribution were sufficient to survive a motion to dismiss. In *Juliana*, the district court noted that U.S. agencies had regulatory authority over at least 14% of global GHGs and found it sufficient.[443]

All of which leaves open a number of questions: What quantity of emissions matters? Which sources or actors are relevant for calculating contributions? What is the best, or at least an appropriate, means of aggregating the actors and their emissions for the purposes of calculating contributions? What is the state of the science in measuring the relationship between individual sources/actors and localized impacts? These questions matter for standing. As discussed further below, they matter on the merits, as well.

2. Evidentiary Standards for Scientific Testimony and Reports

A threshold consideration regarding the role of attribution science in the courtroom is whether expert testimony on attribution is admissible in court. The *Daubert* standard, first articulated by the Supreme Court in *Daubert v. Merrell Dow*

439. *See supra* Section III(C)(1)(b)(i).
440. *See supra* Section III(C)(1)(b)(iii).
441. *See supra* Section III(C)(1)(b)(iv).
442. *See supra* Section III(C)(1)(b)(v).
443. *See supra* Section III(C)(1)(b)(vi).

Pharmaceuticals,[444] is the contemporary standard for admissibility in federal courts and many states have adopted this standard as well. That standard charges the judge with ensuring that the basis of the expert's testimony is "scientific knowledge"[445] and outlines the following factors for making this determination:

- Whether the scientific theory or technique can be (and has been) tested
- Whether it has been subjected to peer review and publication
- Whether it has a known error rate
- Whether it has a degree of "general acceptable" within a "relevant scientific community."[446]

Most states now follow the *Daubert* standard, but some adhere to the less exacting *Frye v. United States* standard (the previous federal standard),[447] which only requires "general acceptance" of the science within the relevant scientific community.[448] These standards are typically only evoked when the opposing side challenges expert testimony.

Most attribution studies accord with the *Daubert* standard insofar as they rely on scientific theories that can be tested using models, statistical analyses, and observations; they are typically published in peer reviewed journals; they typically discuss known sources of bias and the potential for Type I and Type II errors; and they are based on generally accepted techniques. However, defendants in climate lawsuits may argue that some of the more novel impact and event attribution techniques do not meet all four requirements, and in particular, the requirement of "general acceptance" within the scientific community. Defendants are also highly likely to challenge testifying scientists who draw inferences from attribution studies with respect to impacts not explicitly covered in those studies, even where the underlying studies would clearly satisfy

444. Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579 (1993).
445. *Id.* at 592.
446. *Id.* at 592–95.
447. 293 F. 1013 (D.C. Cir. 1923).
448. Michael Morgenstern, Daubert *v.* Frye*: A State-by-State Comparison*, THE EXPERT INST. (Apr. 3, 2017), https://www.theexpertinstitute.com/daubert-v-frye-a-state-by-state-comparison/ [https://perma.cc/5UF2-F5JQ].

Daubert.[449] This highlights the benefits of using attribution studies of an appropriate scale and scope.

One important question is whether and to what extent confidence levels will affect the admissibility of and weight given to attribution studies presented to courts. As noted in Part II, attribution findings are frequently presented in terms of confidence levels and intervals—for example, a study may find with ">90% confidence" that anthropogenic forcing on climate doubled the risk of an extreme event occurring. The National Academy of Sciences ("NAS") *Reference Manual on Scientific Evidence* notes that a 95% confidence level is the "standard" for scientific studies but does not recommend a threshold for admissibility in court, nor does it discuss how confidence levels might affect the weight afforded to a scientific study.[450] Apart from that manual, there does not appear to be any clear standard for dealing with confidence levels and intervals in courtrooms. Many, but not all, attribution studies present findings at the 95% confidence level, consistent with general scientific practice. This bodes well for the utilization of the research in courts, but there may be situations where it is also useful to discuss findings at lower confidence levels (the goal being to identify what is plausible, even if not highly certain). Part IV presents recommendations on how researchers might frame their research to satisfy the demands of the courtroom as well as other applications.

There is no single numeric standard that juries and courts rely on in assessing the weight of scientific expert testimony.[451] Generally speaking, judges and juries will consider factors such as believability, persuasiveness, thoroughness, and whether the evidence has been refuted.[452] Evidence that is indefinite, vague, or improbable will generally be given less weight than evidence that is

449. For more on this topic, *see* Kirsten Engel & Jonathan Overpeck, *Adaptation and the Courtroom: Judging Climate Science*, 3 MICH. J. ENVTL. & ADMIN. L. 1 (2013).

450. FED. JUD. CTR., REFERENCE MANUAL ON SCIENTIFIC EVIDENCE: THIRD EDITION 284–85 (National Academies Press 2011) https://www.fjc.gov/sites/default/files/2015/SciMan3D01.pdf [https://perma.cc/3SEB-JN9L].

451. Note the burden of proof in civil trials is the "preponderance of evidence" standard, which requires a plaintiff to convince the trier of fact that the evidence in support of her case outweighs the evidence offered by the defendant to oppose it.

452. *Weight of the Evidence*, WEST'S ENCYCLOPEDIA OF AMERICAN LAW (2d ed. 2008), https://legal-dictionary.thefreedictionary.com/weight+of+evidence [https://perma.cc/44VB-TD4W].

direct and unrefuted.[453] The weight afforded to attribution findings will thus depend on the level of uncertainty underpinning those findings as well as the extent to which the findings are a subject of scientific debate.

3. Lawsuits Challenging the Failure to Regulate Greenhouse Gas Emissions

Environmental and citizen groups in the United States and other jurisdictions have brought numerous challenges seeking to compel governments to take action to curtail greenhouse gas emissions.[454] There are three types of lawsuits that fall within this category: (i) lawsuits challenging the government failure to implement statutory mandates with respect to air pollution control; (ii) lawsuits challenging the failure to protect public health pursuant to general legal mandates recognized in constitutions, public trust doctrines, human rights law, and other legal sources; and (iii) lawsuits involving administrative decisions undertaken within an existing regulatory scheme, typically decisions to grant or refuse an authorization for a particular activity (such as coal mining or the construction of an airport). In all three types of cases, attribution science comes into play when plaintiffs need to establish a causal connection between the government's action or inaction and concrete harms caused by climate change to succeed on the merits.

a. Lawsuits Challenging the Failure to Implement Statutory Mandates With Respect to Air Pollution Control

i. *Massachusetts v. EPA*

The most noteworthy case involving a government failure to regulate greenhouse gas emissions pursuant to an existing statutory scheme for air pollution control was *Massachusetts*. In the same way that attribution science helped plaintiffs establish standing in this

453. *Id.*

454. Cases involving a common law breach of a government duty owned to plaintiffs are sometimes referred to as "public liability" cases in contrast to the "private liability" cases discussed in subsequent sections. *See* Jutta Brunnée et al, *Overview of Legal Issues Relevant to Climate Change*, in CLIMATE CHANGE LIABILITY: TRANSNATIONAL LAW AND PRACTICE 23 (Richard Lord et al. eds., Cambridge University Press 2012).

case, it also helped them to rebut EPA's assertion that it there was too much scientific uncertainty about climate change to regulate.[455]

The case history is illuminating. The D.C. Circuit initially dismissed the case but did not reach consensus on the basis for dismissal, in part due to disagreements about the scientific underpinnings of EPA's views about scientific uncertainty. In Judge Randel's plurality opinion, he wrote that EPA had properly declined to regulate based on its conclusions that there was too much scientific uncertainty about the causal effects of greenhouse gases on climate change.[456] In reaching this conclusion, the judge referred to EPA's reliance on a 2001 National Research Council ("NRC") report, which found that "a causal linkage" between greenhouse gas emissions and global warming "cannot be unequivocally established."[457] He summarized the NRC's findings as follows:

> The earth regularly experiences climate cycles of global cooling, such as an ice age, followed by periods of global warming. Global temperatures have risen since the industrial revolution, as have atmospheric levels of carbon dioxide. But an increase in carbon dioxide levels is not always accompanied by a corresponding rise in global temperatures. For example, although carbon dioxide levels increased steadily during the twentieth century, global temperatures decreased between 1946 and 1975. Considering this and other data, the National Research Council concluded that "there is considerable uncertainty in current understanding of how the climate system varies naturally and reacts to emissions of greenhouse gases." This uncertainty is compounded by the possibility for error inherent in the assumptions necessary to predict future climate change. And, as the National Research Council noted, past assumptions about effects of future greenhouse gas emissions have proven to be erroneously

455. Uncertainty was only one of the rationales proffered by EPA for not regulating motor vehicle emissions. EPA also argued that: (i) it did not have statutory authority to regulate greenhouse gas emissions, and (ii) even if did have authority to regulate, there were "policy considerations" which made it unwise for EPA to exercise that authority at this time. *Massachusetts*, 549 U.S. at 513–514. *See also* citing EPA, Control of Emissions from New Highway Vehicles and Engines: Notice of Denial of Petition for Rulemaking, 68 Fed. Reg. 52922, 52929–31 (Sept. 8, 2003).

456. *Massachusetts*, 415 F.3d at 58. (The court also supported EPA's determination that policy considerations weighed against regulating greenhouse gases at this time.)

457. *Id.* at 57 (citing NAT'L RES. COUNCIL, CLIMATE CHANGE SCIENCE: AN ANALYSIS OF SOME OF THE KEY QUESTIONS (2001)).

high.[458]

In light of this perceived uncertainty, Judge Randel concluded that it was neither arbitrary nor capricious for EPA to decline to regulate greenhouse gas emissions at the time.[459] Judge Sentelle, concurring in the decision to dismiss the case, asserted that the court lacked jurisdiction to hear the case on standing grounds.[460] Judge Tatel dissented, arguing that the NRC report actually did provide a sufficient basis for a finding that greenhouse gas emissions endangered public health and welfare and should therefore be regulated under the Clean Air Act.[461] Notably, the dissenting judge provided a more detailed synthesis of the NRC report's findings, which contradicted Judge Randel's interpretation of the report. Some of the key points highlighted were that:

The very first sentence of the NRC report stated that "Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise." The quote used by Judge Randel (that "a causal linkage" between greenhouse gas emissions and global warming "cannot be unequivocally established") had been taken out of context, and was merely a recognition that this linkage, as with many other scientific theories, could not be established with 100% certainty.[462]

The NRC report made clear that uncertainties about climate change related chiefly to the scope and magnitude of impacts caused by greenhouse gas accumulation, not whether there was a correlation between those emissions and global warming.[463]

The NRC report explicitly acknowledged that "national policy decisions made now and in the longer-term future will influence the extent of any damage suffered by vulnerable human populations and ecosystems later in this century."[464]

On review, the Supreme Court acknowledged that uncertainty *might* be a reasonable basis for not regulating, but held that EPA cannot defer regulation unless it issued a formal declaration that

458. *Id.* (internal citations omitted).
459. *Id.* at 58.
460. *Id.* at 60–61 (Sentelle, J., concurring).
461. *Id.*at 61–82 (Tatel, J., dissenting).
462. *Id.* at 63.
463. *Id.* at 64.
464. *Id.* at 64.

the uncertainty was "so profound that it preclude[d] EPA from making a reasoned judgment as to whether greenhouse gases contribute to global warming."[465] While the Court did not decide the issue, it did clearly indicate that it might not uphold a determination of uncertainty from EPA—it noted the "harms associated with climate change are serious and well-recognized" and that the "Government's own objective assessment of the relevant science and a strong consensus among qualified experts indicate that global warming threatens, *inter alia,* a precipitate rise in sea levels, severe and irreversible changes to natural ecosystems, a significant reduction in winter snowpack with direct and important economic consequences, and increases in the spread of disease and the ferocity of weather events."[466]

ii. *Coalition for Responsible Regulation v. EPA*

Following the Supreme Court's decision in *Massachusetts*, EPA issued an endangerment finding for GHG emissions from motor vehicles, finding that such emissions cause or contribute to the endangerment of public health and welfare. The D.C. Circuit upheld this determination in *Coalition for Responsible Regulation v. EPA*.[467] There, an industry group argued that there was "too much uncertainty" about the science underpinning climate change and that EPA had improperly relied on external studies from the IPCC, U.S. Global Change Research Program, and U.S. National Research Council in reaching its decision.[468] The court rejected these claims and held that EPA's reliance on external studies was entirely proper—noting that "EPA is not required to re-prove the existence of the atom every time it approaches a scientific question"—and held that the scientific body of evidence underpinning the endangerment finding was "substantial" and therefore legally sound.[469] In reaching this conclusion, the court explained that EPA had addressed each link in the causal chain connecting

465. *Massachusetts*, 549 U.S. at 534.

466. *Id.* at 499.

467. Coal. for Responsible Regulation, Inc. v. EPA., 684 F.3d 102, 121 (D.C. Cir. 2012), *aff'd in part, rev'd in part sub nom* Util. Air Regulatory Grp. v. EPA., 573 U.S. 302 (2014), and *amended sub nom* Coal. for Responsible Regulation, Inc. v. EPA, 606 F. App'x 6 (D.C. Cir. 2015). *See also* Biogenic CO2 Coal. v. EPA, No. 16-1358 (D.C. Cir. filed Oct. 14, 2016) (challenging endangerment finding for GHG emissions from aircraft).

468. *Coal. for Responsible Regulation, Inc.*, 684 F.3d at 121.

469. *Id.* at 120.

anthropogenic greenhouse gas emissions to harmful impacts on public health and welfare and that EPA had provided three lines of evidence to support the finding: (i) our "basic physical understanding" of the greenhouse gas effect, (ii) observational evidence of past climate change, and (iii) models predicting how the climate will response to greenhouse gas concentrations in the future.[470]

iii. Other Clean Air Act Cases

Above, we describe how attribution science has played a central role in the issuance and judicial review of Clean Air Act endangerment findings. This would also be the case if EPA exercised its authority to establish National Ambient Air Quality Standards ("NAAQS") for GHGs under Section 110 or if EPA developed a program to control GHG emissions as a source of international air pollution under Section 115 of the Act.[471] To establish NAAQS for GHGs, EPA would need to identify thresholds for ambient concentrations of GHGs that are sufficient to protect public health and welfare. Similarly, to establish a Section 115 program, EPA would need to establish targets for emission reductions as necessary to "prevent or eliminate the endangerment" that those emissions pose to foreign nations. In either case, it would be necessary to define the appropriate threshold for emission control based on, among other things, both existing impacts as well as predictions of future impacts of climate change.

The Clean Air Act and other air pollution control statutes also provide for the establishment of technology-based emission standards (e.g., standards reflecting the "best available technology" or the "best system of emission reduction.").[472] In this context, attribution science plays a less pivotal role in the establishment and judicial review of the standards, since the standards are primarily based on considerations pertaining to statutory authority, technological feasibility, and cost. However, challenges to and

470. *Id.* at 120–21.

471. See Michael Burger et al., *Legal Pathways to Reducing Greenhouse Gas Emissions under Section 115 of the Clean Air Act*, 28 GEO. ENVTL. L. REV. 359 (2016); Kassie Siegel et al., *Strong Law, Timid Implementation. How the EPA Can Apply The Full Force of the Clean Air Act To Address The Climate Crisis*, 30 UCLA J. ENVTL. L. & POL'Y 185 (2012).

472. *See, e.g.*, Clean Air Act § 111(a)(1), 42 U.S.C. § 7411 (2018).

defenses of these standards do involve attribution questions to some extent—for example, when defining the "best system of emission reduction" for controlling emissions from stationary sources under the Clean Air Act, EPA must take into account the public health benefits of the standards as well as technological feasibility and cost.[473] But to date, attribution science has not featured prominently in litigation over technology-based and hybrid rules and standards such as the Clean Power Plan.[474]

b. Cases Challenging the Government Failure to Protect Public Health Pursuant to Constitutional Mandates, Public Trust Doctrines, Human Rights Law, and Other Legal Sources

A number of cases have been brought challenging the failure to regulate greenhouse gas emissions and fossil fuel production on the grounds that government entities have violated more general mandates pertaining to fundamental rights. In the United States, there are at least two federal legal sources that have given or could give rise to such cases: the public trust doctrine, which holds that government actors have a duty to preserve certain "public trust" resources for future generations;[475] and the theory of substantive due process, which holds that the federal government must safeguard fundamental rights that are "implicit in the concept of ordered liberty" or "deeply rooted in this Nation's history and tradition."[476] States and other jurisdictions also have a variety of different common law, constitutional, and statutory requirements that oblige government actors to protect public welfare, human rights, or the environment, which can support such claims.[477] In these cases, attribution science is primarily used to demonstrate a causal connection between the under-regulated greenhouse gas emissions and specific injuries to public health and welfare or the

473. *Id.*

474. *See, e.g.*, West Virginia v. EPA, No. 15-1363 (D.C. Cir. 2015); North Dakota v. EPA, No. 15-1381 (D.C. Cir. 2015).

475. Ill. Ctr. R.R. Co. v. Illinois, 146 U.S. 387 (1892).

476. McDonald v. City of Chi., Ill., 561 U.S. 742, 761, 767 (2010).

477. For example, there have been a number of lawsuits filed under state constitutions and public trust doctrines due to state inaction on climate change, as well as foreign lawsuits filed pursuant to national constitutional obligations and human rights laws. *See, e.g.*, Funk v. Pennsylvania, 71 A.3d 1097 (Pa. Commw. Ct. 2013); Urgenda District Court Decision (2015); Leghari v. Pakistan (2015) WP No. 25501/201 (Lahore Hight Court) (Pak.). *See also Public Trust Doctrine*, SABIN CTR. FOR CLIMATE CHANGE L., http://climatecasechart.com/principle-law/public-trust-doctrine/ (last visited Jan. 6, 2020) [https://perma.cc/DH4B-N93K].

environment, which, in turn, give rise to the alleged breach of government duty.[478]

i. *Juliana v. United States*

In *Juliana*, the plaintiffs asserted that: (i) the U.S. government had violated "the fundamental right of citizens to be free from government actions that harm life, liberty, and property" by "approving and promoting fossil fuel development, including exploration, extraction, production, transportation, importation, exportation, and combustion" that had resulted in the degree of climate change we are now experiencing and are projected to experience in the future;[479] and (ii) the U.S. government also violated its public trust obligation to its citizens through this conduct.[480] To prove these claims, the plaintiffs would have needed to establish a causal connection between the emissions that the U.S. government had approved and/or failed to control and the alleged violations of their rights and/or the public trust doctrine.

The plaintiffs in *Juliana* emphasized the magnitude of the emissions at issue, noting that: (i) territorial emissions from the U.S. account for approximately 25.5% of the world's cumulative CO_2 emissions, and this figure would likely be higher using a consumption- or extraction-based accounting approach; (ii) emissions from U.S. energy consumption were 5.4 billion metric tons of CO_2 in 2014; (iii) if the government had acted on expert recommendations on how to limit emissions issued by EPA in 1990 and the Congressional Office of Technology Assessment in 1991, then U.S. CO_2 emissions would have been reduced by 35% from 1987 levels; and (iv) instead, since 1991, the U.S. government had "knowingly allowed at least an additional 130,466 million metric tons of CO_2 emissions from fossil fuel combustion."[481] Plaintiffs

478. In some instances it may also be the case that attribution science plays a role in positing the efficacy or level of protection available under the alternative scenario sought by plaintiffs.

479. Juliana v. United States, 217 F. Supp. 3d 1224, 1248 (D. Or. 2016).

480. The contours of the public trust doctrine, as interpreted by the plaintiffs and court in this case, are similar to the duty of care at issue in Urgenda District Court Decision (2015).

481. First Amended Complaint for Declaratory and Injunctive Relief ¶¶ 151–63, Juliana v. United States, 217 F. Supp. 3d. 1224 (D. Or. 2016) (No. 615-cv-01517-TC). This estimate of the U.S. emissions contribution was based on total emissions from energy production within the U.S. since 1991.

also dedicated a substantial portion of their complaint to explaining precisely how climate change is affecting and will affect their lives, liberty, and property interests, to support both their standing and merits claims.[482] The overarching theme of the complaint was that the plaintiffs, all being young people, are "especially vulnerable" to the threats caused by climate change.[483] It detailed existing and projected impacts on each of the individual children, such as adverse impacts on a farm where one of the children works and intends to pursue a livelihood;[484] lost income for a family that works at a ski resort;[485] and asthma attacks from the increased frequency of forest fires in Oregon (a result of hotter and drier temperatures).[486]

In her decisions denying the U.S. government's motion to dismiss and motion for summary judgment, the district court judge in Oregon held that the plaintiffs' allegations raised colorable substantive claims under the U.S. Constitution and the public trust doctrine.[487] The judge found that the substantive due process claim was supported by plaintiff's allegations that "the government has caused pollution and climate change *on a catastrophic level*, and that if the government's actions continued unchecked, they will permanently and irreversibly damage plaintiff's property, their economic livelihood, their recreational opportunities, their health, and ultimately their (and their children's) ability to live long, healthy lives."[488] With this in mind, the judge stated: "I have no doubt that the right to a climate system capable of sustaining human life is fundamental to a free and ordered society" and therefore was a constitutionally protected right.[489] The judge also found that the plaintiff's allegations were sufficient to establish a breach of the public trust doctrine, which prohibits government actors from "depriving a future legislature of the natural resources necessary to provide for the well-being and survival of its

482. *Id.* ¶¶ 16–97.
483. *Id.* ¶ 10.
484. *Id.* ¶¶ 23–28.
485. *Id.* ¶ 38.
486. *Id.* ¶ 46.
487. Juliana v. United States, 217 F. Supp. 3d. 1224 (D. Or. 2016); Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018).
488. *Juliana*, 217 F. Supp. 3d at 1250.
489. *Id.*

citizens."[490] She noted that it was unnecessary to determine whether the atmosphere was itself a public trust resource that must be preserved for future generations, because the territorial sea owned by the federal government has already been declared a public trust resource, and plaintiffs had alleged adequate harms to that resource caused by ocean acidification and rising ocean temperatures.[491]

As discussed above, the district court's decision was overturned by the Ninth Circuit Court of Appeals in early 2020.[492] Finding that the plaintiffs had failed to establish the redressability prong of Article III standing, the Court of Appeals remanded to the district court with orders to dismiss. Nonetheless, the work the parties put into preparation for an anticipated trial—and the district court's decision on the motion for summary judgment—reveals a great deal about how detection and attribution science would likely factor into resolution of other cases involving regulatory failures.

In preparation for trial, the plaintiffs submitted more than 1,000 pages of expert reports detailing the fundamental science of climate change, observed and projected impacts, and the ways in which the United States and the fossil fuel industry have contributed to the problem.[493] In some cases, the experts linked observed impacts directly to the plaintiff's alleged injuries, but some of these linkages draw on qualitative inferences about how broader trends related to climate change have affected or may affect the plaintiffs. For example, with respect to a plaintiff who

490. *Id.* at 1253. *But see* Alec L. v. Jackson, 863 F. Supp. 2d 11 (D.D.C. 2012) (holding that the public trust doctrine is a matter of state, not federal, law) (citing PPL Montana, LLC v. Montana, 565 U.S. 576 (2012)).

491. *Juliana*, 217 F. Supp. 3d at 1256 (citing First Amended Complaint ¶ 16 ("An important part of Kelsey's diet includes food that comes from the marine waters and freshwater rivers, including salmon, cod, tuna, clams, mussels, and crab."); *id.* ¶ 27 ("Other food sources for Alex, including crab and seafood, are negatively impacted by ocean acidification, warming, and sea level rise caused by Defendants."); *id.* ¶ 33 ("Ocean acidification caused by Defendants has already begun to adversely impact shellfish along the coast, and is predicted to take its toll on crab, mussels, and all shelled seafood."); *id.* ¶ 45 ("On the Oregon coast, Sahara enjoys climbing rocks and sand dunes, swimming, and tidepooling to see marine life. Sahara's enjoyment of these activities is being increasingly harmed in the future by sea level rise, greater erosion, enhanced ocean acidification, and increased water temperatures.").

492. *See infra* Section III(C)(1).

493. *See U.S. Climate Change Litigation:* Juliana v. United States, SABIN CTR. FOR CLIMATE CHANGE L., http://climatecasechart.com/case/juliana-v-united-states/ [https://perma.cc/7DBD-37KP] (last visited Jan. 6, 2020).

had to move from her home in Cameron, Arizona because the springs her family depended on for water were drying up, one expert noted that the "pattern of drought in places like Arizona is directly linked to climate change" without citing research specifically attributing the arid conditions in the area to climate change.[494] Similarly, experts reporting on public health impacts noted that the youth plaintiffs, like all children, are at a higher risk of certain health problems such as asthma due to climate change but did not attribute specific health problems experienced by individual plaintiffs to climate change.[495] In other cases, statements about impacts on plaintiffs were based on observed trends and impacts without reference to attribution studies like those described in Section II.[496] Arguably more robust linkages were drawn between climate change and alleged injuries based on downscaled climate impact data—for example, data on historic and projected sea level rise in the town where one plaintiff lived,[497] and attribution studies linking specific extreme events that affected plaintiffs to anthropogenic climate change.[498]

Regarding the question of source attribution and the U.S. contribution to climate change, Dr. James Hansen prepared a lengthy expert report and an accompanying paper on *Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*, which he co-authored with other scientists and economists.[499] Hansen cited research finding that the U.S. is an "unambiguous leader" in cumulative GHG emissions, having generated approximately 25% of emissions since 1751 ("more than double that of China, which

494. Expert Report of Steven W. Running, Ph.D at 6, Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018) (No. 6:15-cv-1517).

495. Expert Report of Susan E. Pacheco, M.D. and Jerome A. Paulson, M.D., FAAP, Juliana v. United States, 339 F. Supp. 3d 1062 (2018) (No. 6:15-cv-1517).

496. *See*, *e.g.*, Expert Report of Steven Running, *supra* note 494, at 9 ("Ski areas like Hoodoo Pass and Willamette Pass in Oregon, where Plaintiff Zealand recreates and his family has been employed, and Stevens Pass in Washington, where Plaintiff Aji recreates, have recently had years with so little snow the areas could not even open for business.")

497. Expert Report of Dr. Harold R. Wanless at 24, Juliana v. United States, 339 F. Supp. 3d 1062 (2018) (No. 6:15-cv-1517).

498. Expert Report of Dr. Kevin Trenberth at 18–22, Juliana v. United States, 339 F. Supp. 3d 1062 (2018) (No. 6:15-cv-1517).

499. Expert Report of James E. Hansen, Juliana v. United States, 339 F. Supp. 3d 1062 (2018) (No. 6:15-cv-1517).; *see also* James E. Hansen et al., *Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*, 8 PLOS ONE 12 (Dec. 2013).

falls second in the ranking"), and that the United States alone is responsible for a 0.15°C increase in global temperature. Dr. Hansen discussed emission reduction targets for the U.S. based on a global climate budget.[500] Dr. Hansen also discussed impacts such as sea level rise but did not explicitly quantify the proportional contribution of the United States to those impacts.

The question of the United States' responsibility for climate change was further explored in an expert report from Peter Erickson, a scientist at the Stockholm Environment Institute. He noted that the U.S. produces a substantial quantity of "territorial" emissions but that this is an incomplete indicator of responsibility for climate change.[501] He called for consideration of the United States' consumption emissions, which are approximately 20% higher than territorial emissions in recent decades, as well as extraction-based emissions, since the country also bears some responsibility for emissions from the burning of fossil fuels produced in the United States.[502] His expert testimony contained a comparison of U.S. emissions under all three accounting approaches. Erickson also noted that the United States has contributed to climate change by leasing and subsidizing the production of fossil fuels, but did not quantify the effect of those leases and subsidies on climate change (vis-à-vis global mean temperature change) or its impacts. Notably, Erickson did not suggest that one accounting approach should dominate—but rather that all three approaches should be considered when assessing U.S. responsibility for climate change.

The U.S. government also solicited numerous expert reports primarily aimed at countering the idea that plaintiffs' injuries could be traced to U.S. government conduct. With respect to impact attribution, the defense experts argued that the plaintiffs' experts have failed to establish a conclusive link between anthropogenic climate change and the plaintiffs' alleged injuries because they infered that climate change caused the injuries based

500. Expert Report of James Hansen, *supra* note 499, at 26–27.

501. Expert Report of Peter A. Erickson at 3, Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018) (No. 6:15-cv-1517).

502. *Id.* ("To more fully reflect its contribution to global climate change, it is my opinion that the Federal Government should also regularly conduct both a consumption-based and an extraction-based GHG emissions inventory.").

on observations and general trends[503] without accounting for other confounding factors that may have been responsible for the injuries.[504] The defendants' experts also addressed the question of source attribution—that is, the question of U.S. government responsibility and ability to provide redress for climate change-related injuries. They argued that the plaintiffs' experts have failed to specify the degree to which U.S. government conduct is responsible for climate change or the plaintiffs' alleged injuries, [505] and failed to demonstrate that the U.S. government could provide adequate redress for the alleged injuries through policy and regulatory actions.[506] They also disputed the share of global

503. *See, e.g.*, Notice of Supplemental Disputed Facts Raised By Defendants' Expert Reports In Support Of Plaintiffs' Response In Opposition To Defendants' Motion For Summary Judgment, Juliana v. United States, 6:15-cv-01517, Dkt. 338 (Aug. 24, 2018) (plaintiffs' health impact experts "never directly link[ed] any of the [psychiatric and medical consequences of climate change] to any individual plaintiffs. They remain theoretical possibilities, reported in various studies of natural disasters, but *not* conclusively identified in any of the Plaintiffs she examined."), Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018) (No. 6:15-cv-1517); Expert Report of Dr. Norman I. Klein at 5 ("Drs. Frumkin, Pacheco, and Paulson confuse general correlations from abstract epidemiological studies with clinical examination of specific instances of asthma and allergy symptoms), Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018) (No. 6:15-cv-1517).

504. *See, e.g.*, Expert Report of Norman Klein, *supra* note 503, at 3 ("[e]ven if the individual Plaintiffs' complaints of allergy and asthma symptoms were credited, an exemption of other potential contributing factors must be evaluated before climate change could be determined as a contributing, much less primarily contributing, factor to these specific Plaintiffs."); Expert Report of Dr. John P. Weyant at 10 ("By failing to analyze the potential confounding effect of local conditions, Dr. Trenberth reaches conclusions about the impacts on Plaintiffs that are unsupported and therefore unreliable."), Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018) (No. 6:15-cv-1517); Expert Report of Dr. John P. Weyant at 15 ("When Prof. Running makes claims about injuries to Plaintiffs, he simply presumes that human-induced climate change is the major cause of the multiple hydrological and ecological changes that he discusses, despite the fact that population growth and migration, forest and water management practices, and wildfire and flood prevention measures are also important determinants of the climate events he analyzed."), Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018) (No. 6:15-cv-1517); Expert Report of Dr. John P. Weyant at 18 ("Complicated interactions are emblematic of the confounding factors that scientists need to consider when examining the influence of climate change. It is the part of the reason why Prof. Running's statement that an increased wildfire season due to climate change has and will affect many of the Plaintiffs is an overbroad assertion."), Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018) (No. 6:15-cv-1517).

505. *See, e.g.*, Expert Report of John Weyant *supra* note 504, at 11 ("Overall, Dr. Trenberth's conclusions are not supported by analysis that allows one to determine how and to what degree Jaime's experiences with water shortages, wildfires, droughts, or heat waves are exacerbated by human-induced climate change.").

506. *See, e.g.*, Expert Report of David G. Victor at 12 , Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018) (No. 6:15-cv-1517) ("US oil and gas producers extract

emissions attributable to U.S. government action or inaction.[507] One expert estimated that the U.S. government is responsible for no more than 4% of global emissions and that the other 96% of emissions are generated by: (i) countries other than the U.S., or (ii) fossil fuel consumption by entities other than the federal government that would have occurred regardless of federal policies and regulations.[508] Another expert estimated that, even under a consumption-based accounting approach, the share of emissions attributable to the U.S. government is only 5%.[509] Notably, both experts acknowledged that total U.S. emissions are much higher than these estimates regardless of whether a territorial-, consumption-, or extraction-based methodology is used, but they dispute the notion that the U.S. government is responsible for all U.S. emissions.[510] This was consistent with the approach taken by defendants in their answer to the original complaint, in which they admitted key facts about the proportion of global CO_2 emissions generated within the U.S. while maintaining that the U.S.

commodities worth $245b per year. The subsidy embodied in the output is only about 1.9% of the total market value of production. In my view, subsidies worth that tiny fraction of the total value are not material to an industry whose prices can swing many multiples of this percentage in a financial quarter."); Expert Report of David G. Victor at 19, Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018) (No. 6:15-cv-1517) ("The effect of oil subsidy reforms on emissions will be much smaller than suggested by Erickson, because other factors have a much larger impact on production decisions, the industry is highly competitive and responsive to changes in market conditions and production costs."); Expert Report of Dr. Daniel Sumner at 8 , Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517) ("I conclude that there is considerable doubt as to whether Dr. Robertson's proposed agricultural methods can deliver the amount of GHG abatement that Dr. Robertson claims at any price."). *See, e.g.*, Expert Report of David G. Victor at 4, Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018) (No. 6:15-cv-1517) ("The effect of oil subsidy reforms on emissions will be small to zero.") ; Expert Report of Dr. James L. Sweeney at 13, Juliana v. United States, 339 F.Supp.3d 1062 (D. Or. 2018) (No. 6:15-cv-1517) ("If the U.S. halted its use and production of fossil fuels, the prices of these fuels would fall and other counties would increase their use of fossil fuels.").

507. *See, e.g.*, Expert Report of James Sweeney, *supra* note 506, at 66 ("Plaintiffs and their experts offer no analysis to link the failure to develop policies to the impacts on GHG emissions."); Expert Report of David G. Victor, *supra* note 506, at 5 ("Stiglitz fails to identify plausible, real-world actions that the U.S. government could have taken that would have led to appreciably different outcomes with respect to domestic and international energy systems."); Expert Report of James Sweeney, *supra* note 506, at 56 ("Only a very small fraction of these sources [of U.S. greenhouse gas emissions are] directly controlled by the federal government.").

508. Expert Report of James Sweeney, *supra* note 506, at 60.

509. Expert Report of David G. Victor, *supra* note 506, at 4.

510. Expert Report of James Sweeney, *supra* note 506, at 60; Expert Report of David G. Victor, *supra* note 506, at 8–10.

government is not responsible for those emissions.[511] Reviewing these materials in the context of the defendants' motion for summary judgment, the district court found "that plaintiffs have provided sufficient evidence showing that causation for their claims is more than attenuated," that "[t]he ultimate issue of causation will require perhaps the most extensive evidence to determine at trial," and that a "final ruling on this issue will benefit from a fully developed factual record where the Court can consider and weigh evidence from both parties."[512]

Thus, even without the "trial of the century," we can see the contours of the "battle of experts" such a trial would entail. Plaintiffs' primary goal with their expert testimony was to establish that the defendant is responsible for a meaningful contribution to climate change—an amount sufficient to prove causal relationships that satisfy the standing requirements and the even more demanding standards for showing a violation of public trust obligations and/or constitutional rights—and that climate change is the legal cause of specific injuries suffered by the plaintiffs. Defendants' primary strategy was to undermine the reliability of plaintiffs' proffers, and their tactic was to poke holes in plaintiffs' expert reports by challenging the science of source attribution and highlighting the importance of confounding factors.

ii. Other Atmospheric Trust Litigation in the U.S.

There have been a number of similar cases asking state courts to find that state governments have a public trust duty to address climate change (frequently referred to as "atmospheric trust" cases).[513] These cases involve the same sort of inquiry into the

511. *See, e.g.*, Federal Defendants' Answer to the First Amended Complaint for Declaratory and Injunctive Relief at ¶ 151, Juliana v. United States, 339 F. Supp. 3d 1062 (D. Or. 2018) ("Federal Defendants aver that from 1850 to 2012, CO_2 emissions from sources within the United States (including from land use) comprised more than 25 percent of cumulative global CO_2 emissions").

512. *Juliana*, 339 F. Supp. 3d at 1062, 1093.

513. *See, e.g.*, Kanuk ex rel. Kanuk v. State Dep't of Nat. Res., 335 P.3d 1088 (Alaska 2014); Sinnok v. Alaska, No. 3AN-17-09910, 2018 WL 7501030 (Alaska Super. Ct. 2018); Butler ex rel. Peshlakai v. Brewer, No. 1 CA–CV 12–0347, 2013 WL 1091209 (Ariz. Ct. App. Mar. 14, 2013); Filippone ex rel. Filippone v. Iowa Dep't of Nat. Res., 829 N.W.2d 589 (Iowa Ct. App. 2013) (declining to extend the public trust doctrine to the atmosphere because the Iowa Supreme Court had previously declined to extend the doctrine to forested areas and public alleyways); Aronow v. State, No. A12–0585, 2012 WL 4476642 (Minn. Ct. App. Oct. 1, 2012) (declining to apply the public trust doctrine to the atmosphere because no court in

extent to which harmful impacts on a public trust resource can be linked to under-regulated greenhouse gas emissions. For example, in *Sanders-Reed v. Martinez*, youth plaintiffs in New Mexico sought a judgment establishing that the state had a public trust duty under state law to protect the atmosphere and that its "failure to investigate the threat posed by climate change" and to devise a plan to "mitigate the effects of climate change" was a breach of that duty.[514] The state district court initially dismissed the case, in part because it determined that New Mexico regulators had properly determined that New Mexico regulation of greenhouse gas emissions "would have no perceptible impact on climate change."[515] The appellate court took a different approach and found that Article XX, Section 21 of the New Mexico state constitution recognizes that a public trust duty exists for the protection of New Mexico's natural resources, including the atmosphere.[516] However, the court also concluded that the state had established legislative and administrative procedures for raising arguments concerning the duty to protect the atmosphere and that these arguments could not be made through a separate common law cause of action.[517] Similarly, courts in Washington State and Alaska have affirmed that those states' public trust doctrines apply to climate change but deferred to existing legislation and executive processes as the appropriate means to regulate GHGs.[518]

Minnesota or any other jurisdiction has done so, and because it had previously held that the public trust doctrine did not apply to land); Chernaik v. Kitzhaber, 328 P.3d 799 (2014); Svitak ex rel. Svitak v. State, 178 Wash. App. 1020, No. 69710–2–I, 2013, 2013 WL 6632124 (Wash. Ct. App. Dec. 16, 2013); Sanders-Reed ex rel. Sanders-Reed v. Martinez, 350 P.3d 1221 (N.M. 2015); Foster v. Wash. State Dep't of Ecology, 362 P.3d 959 (2015).

514. *Sanders-Reed*, 350 P.3d at 1223 (citing plaintiff's amended complaint to district court).

515. Order Granting Defendants' Motion for Summary Judgement and Denying Plaintiffs' Motion for Summary Judgement, Exhibit A, at TR-3, Sanders-Reed ex rel. Sanders-Reed v. Martinez, No. D-101-CV-2011-01514 (N.M. Dist. July 04, 2013).

516. *Sanders-Reed*, 350 P.3d at 1225.

517. *Id.*

518. *Foster*, 362 P.3d 959; Kanuk ex rel. Kanuk v. State Dep't of Nat. Res., 335 P.3d 1088 (Alaska 2014) (ruling that claims for relief raised nonjusticiable political questions); Sinnok v. Alaska, No. 3AN-17-09910, 2018 WL 7501030 (Alaska Super. Ct. 2018).

iii. Foreign Jurisdictions

Similar types of "atmospheric trust" cases have also been brought in foreign jurisdictions to protect rights enumerated in foreign constitutions, human rights instruments, and international treaties. Perhaps most famously, the Supreme Court of the Netherlands recently upheld decisions from the Hague Court of Appeals and the District Court of the Hague in *Urgenda Foundation v. Kingdom of the Netherlands*, finding that the Dutch government had breached its obligations to its citizens by backing away from the previous administration's mitigation commitments, and ordered the government to limit GHG emissions to 25% below 1990 levels by 2020, consistent with what the court viewed as the country's fair contribution towards the U.N. goal of limiting global temperature increases to 2°C above pre-industrial conditions.[519] The Supreme Court supported its decision by referring to IPCC assessments of how climate change is affecting and will affect human and natural systems and an explanation of why the 25% reduction target is necessary to limit global warming to 2°C.[520] Detection and attribution science factored into this analysis in two ways: first, by providing evidence of the harms incurred by Dutch people as a result of climate change (impact attribution); and second, by providing information about the emissions reductions necessary to meet the 2°C target (contribution attribution).

Similar lawsuits have been brought against governments in the United Kingdom,[521] Germany,[522] Canada,[523] Belgium,[524]

519. Urgenda Foundation v. Kingdom of the Netherlands, Hoge Raad, ECLI:NL:HR:2019:2007 (Dec. 20, 2019) [hereinafter *Urgenda* decision (2019)]. (English translation available at http://blogs2.law.columbia.edu/climate-change-litigation/wp-content/uploads/sites/16/non-us-case-documents/2020/20200113_2015-HAZA-C0900456689_judgment.pdf).

520. *Id.* at ¶¶ 2.1, 4.1– 4.8, 7.1–7.3.6.

521. Plan B Earth and Others v. Sec'y of State for Bus., Energy, and Indus. Strategy [2018] EWHC 1892 (Admin), (UK), http://climatecasechart.com/non-us-case/plan-b-earth-others-v-secretary-state-business-energy-industrial-strategy/ [https://perma.cc/KPY8-HPF6].

522. Bundesverfassungsgericht [BVerfG] [Federal Constitutional Court], Nov. 26, 2018, (Germany),http://climatecasechart.com/non-us-case/friends-of-the-earth-germany-association-of-solar-supporters-and-others-v-germany/[https://perma.cc/E3B4-9TF6];Verwaltungsgericht [VG] [Berlin Administrative Trial Court] Oct. 31, 2019, No. 00271/17 R/SP, (Germany), http://climatecasechart.com/non-us-case/family-farmers-and-greenpeace-germany-v-german-government/ [https://perma.cc/4PBK-8DNV].

523. ENVironnement JEUnesse v. Canada, 2018 QCSC 500-06 (Can.), http://climatecasechart.com/non-us-case/environnement-jeunesse-v-canadian-government/ [https://perma.cc/E9NR-EF8D].

Switzerland,[525] India,[526] Pakistan,[527] Colombia,[528] and Uganda,[529] as well as the European Parliament and Council.[530] At the time of this writing, most of these cases are still pending.[531] Four were dismissed by courts on procedural grounds or lack of justiciability

524. Tribunal de Première Instance [Civ.] [Tribunal of First Instance] Brussels, 2016, VZW Klimatzaak v. Kingdom of Belgium, (Belg.), http://climatecasechart.com/non-us-case/vzw-klimaatzaak-v-kingdom-of-belgium-et-al/ [https://perma.cc/E3C9-JWLT].

525. Petition (Summary in English) at ¶ 1(a), Bundesverwaltungsgericht [BVGE] [Federal Administrative Court, Section 1] Nov. 27, 2018, A-2992/2017 (Switz.), http://climatecasechart.com/non-us-case/union-of-swiss-senior-women-for-climate-protection-v-swiss-federal-parliament/ [https://perma.cc/Q2SM-SCEQ].

526. Pandey v. India, (2017) National Green Tribunal, http://climatecasechart.com/non-us-case/pandey-v-india/ [https://perma.cc/VT8P-P6AX].

527. Ali v. Pakistan, Constitutional Petition No. ___ / I of (2016) (SC) (Pak.), http://climatecasechart.com/non-us-case/ali-v-federation-of-pakistan-2/ [https://perma.cc/L228-XQ8T]; Leghari v. Pakistan, (2015) W.P. No. 25501/201 (Lahore High Court) (Pak.), http://climatecasechart.com/non-us-case/ashgar-leghari-v-federation-of-pakistan/ [https://perma.cc/JBN3-XGYJ].

528. Corte Suprema de Justicia [C.S.J.] [Supreme Court], abril 5, 2018, STC4360, No. 11001-22-03-000-2018-00319-01 (Colom.), http://climatecasechart.com/non-us-case/future-generation-v-ministry-environment-others/ [https://perma.cc/53WU-NLJK].

529. Mbabazi and Others v. The Attorney General and National Environmental Management Authority, Civil Suit No. 283 of 2012 (Uganda), http://climatecasechart.com/non-us-case/mbabazi-et-al-v-attorney-general-et-al/ [https://perma.cc/J5RL-U426].

530. Armando Ferrão Carvalho and Others v. The European Parliament and the Council, Case No. T-330/18 (EU General Court 2018), http://climatecasechart.com/non-us-case/armando-ferrao-carvalho-and-others-v-the-european-parliament-and-the-council/ [https://perma.cc/JN4R-3K2Q].

531. Bundesverfassungsgericht [BVerfG] [Federal Constitutional Court], Nov. 26, 2018, (Germany), http://climatecasechart.com/non-us-case/friends-of-the-earth-germany-association-of-solar-supporters-and-others-v-germany/ [https://perma.cc/E3B4-9TF6]; Verwaltungsgericht [VG] [Berlin Administrative Trial Court] Oct. 31, 2019, No. 00271/17 R/SP, (Germany), http://climatecasechart.com/non-us-case/family-farmers-and-greenpeace-germany-v-german-government/ [https://perma.cc/4PBK-8DNV]; Pandey v. India, (2017) National Green Tribunal, http://climatecasechart.com/non-us-case/pandey-v-india/ [https://perma.cc/VT8P-P6AX]; Ali v. Pakistan, Constitutional Petition No. ___ / I of (2016) (SC) (Pak.), http://climatecasechart.com/non-us-case/ali-v-federation-of-pakistan-2/ [https://perma.cc/L228-XQ8T]; Mbabazi and Others v. The Attorney General and National Environmental Management Authority, Civil Suit No. 283 of 2012 (Uganda), http://climatecasechart.com/non-us-case/mbabazi-et-al-v-attorney-general-et-al/ [https://perma.cc/J5RL-U426]; Tribunal de Première Instance [Civ.] [Tribunal of First Instance] Brussels, 2016, VZW Klimatzaak v. Kingdom of Belgium, (Belg.), http://climatecasechart.com/non-us-case/vzw-klimaatzaak-v-kingdom-of-belgium-et-al/ [https://perma.cc/E3C9-JWLT]; Armando Ferrão Carvalho and Others v. The European Parliament and the Council, Case No. T-330/18 (EU General Court 2018), http://climatecasechart.com/non-us-case/armando-ferrao-carvalho-and-others-v-the-european-parliament-and-the-council/ [https://perma.cc/JN4R-3K2Q].

(e.g., due to lack of standing).[532] Decisions have been issued in the Pakistan and Colombia cases holding that the government violated fundamental rights by failing to address the risks posed by climate change (in both cases, the failure to adapt was discussed along with the failure to mitigate emissions).[533] Attribution science plays the same role in these cases as it did in the *Urgenda* decision—supporting claims about impacts and the government's contribution to those impacts.

c. Cases Challenging Permitting and Licensing Decisions

Plaintiffs have also filed cases challenging permitting and licensing decisions that could increase fossil fuel production and/or GHG emissions. For example, petitioners brought a case in Austria alleging that the government's authorization of the Vienna airport expansion would run afoul of emission reductions targets set forth in Austria's Climate Protection Law as well as the country's commitments under the newly enacted Paris Agreement.[534] An administrative court initially held in favor of petitioners, but that decision was overruled by the Austrian Constitutional Court.[535] In Norway, plaintiffs challenged the issuance of licenses for deep-sea

532. Armando Ferrão Carvalho and Others v. The European Parliament and the Council, Case No. T-330/18 (EU General Court 2018), http://climatecasechart.com/non-us-case/armando-ferrao-carvalho-and-others-v-the-european-parliament-and-the-council/ [https://perma.cc/JN4R-3K2Q]; Plan B Earth and Others v. Sec'y of State for Bus., Energy, and Indus. Strategy [2018] EWHC 1892 (Admin), (UK), http://climatecasechart.com/non-us-case/plan-b-earth-others-v-secretary-state-business-energy-industrial-strategy/ [https://perma.cc/KPY8-HPF6]; Bundesverwaltungsgericht [BVGE] [Federal Administrative Court, Section 1] Nov. 27, 2018, A-2992/2017 (Switz.), http://climatecasechart.com/non-us-case/union-of-swiss-senior-women-for-climate-protection-v-swiss-federal-parliament/ [https://perma.cc/Q2SM-SCEQ]. ENVironnement JEUnesse v. Canada, 2018 QCSC 500-06 (Can.), http://climatecasechart.com/non-us-case/environnement-jeunesse-v-canadian-government/ [https://perma.cc/E9NR-EF8D].

533. Leghari v. Pakistan, (2015) W.P. No. 25501/201 (Lahore High Court) (Pak.) http://climatecasechart.com/non-us-case/ashgar-leghari-v-federation-of-pakistan/ [https://perma.cc/JBN3-XGYJ]; Corte Suprema de Justicia [C.S.J.] [Supreme Court], April 5, 2018, STC4360, No. 11001-22-03-000-2018-00319-01 (Colom.), http://climatecasechart.com/non-us-case/future-generation-v-ministry-environment-others/ [https://perma.cc/53WU-NLJK].

534. Verwaltungsgerichtshof [VwGH] [Administrative Court of Justice] Feb. 2, 2017, W109 2000179-1/291E (Autstria), http://climatecasechart.com/non-us-case/in-re-vienna-schwachat-airport-expansion/ [https://perma.cc/BEL8-KWXF].

535. *Id.*; Verfassungsgerichtshof [VfGH] [Constitutional Court] June 29, 2017, E 875/2017, E 886/2017, http://climatecasechart.com/non-us-case/in-re-vienna-schwachat-airport-expansion/ [https://perma.cc/BEL8-KWXF].

oil and gas exploration on similar grounds.[536] The Oslo District Court dismissed the challenge, finding, among other things, that "[e]missions of CO2 abroad from oil and gas exported from Norway are irrelevant" in analyzing the constitutionality of the lease sale;[537] petitioners have appealed that decision. Swedish plaintiffs challenged the sale of coal mines and coal-fired power plants in Germany by Vattenfall—an energy company owned by the Swedish state—again, on similar grounds.[538] The Stockholm District Court denied these requests after determining that the plaintiffs had not experienced an injury from the governmental decisions at issue.[539] Similar lawsuits have been filed in the United Kingdom and Australia.[540] In these types of cases, petitioners can use attribution data to link the emissions generated from the project to harmful effects of climate change.[541] However, as illustrated by the Stockholm District Court's dismissal on standing grounds, it may be more difficult to establish injury based on emissions from specific licensing decisions as compared with cases challenging broader government failures to act on climate change.

536. Greenpeace Nordic Ass'n at 18–19, Case No. 16-166674TVI-OTIR/06, (Oslo District Court, Jan. 4, 2018), http://climatecasechart.com/non-us-case/greenpeace-nordic-assn-and-nature-youth-v-norway-ministry-of-petroleum-and-energy/ [https://perma.cc/7R8N-EW2Q].

537. *Id.* at 21.

538. Tingsrätt [TR] [Stockholm District Court] 2016-09-15 (Sweden), http://climatecasechart.com/non-us-case/push-sweden-nature-youth-sweden-et-al-v-government-of-sweden/ [https://perma.cc/MX84-N5QW].

539. *Id.*

540. *Ironstone Community Action Group Inc. v. NSW Minister for Planning and Duralie Coal Pty. Ltd.*, (2011) NSWLEC 195 (Austl.), http://climatecasechart.com/non-us-case/ironstone-community-action-group-inc-v-nsw-minister-for-planning-and-duralie-coal-pty-ltd/ [https://perma.cc/9YBF-XS5J]; Plan B Earth and Others v. Sec'y of State for Transport, [2019] EWHC 1070 (Admin) (UK),http://climatecasechart.com/non-us-case/plan-b-earth-v-secretary-of-state-for-transport/ [https://perma.cc/N9R8-JBY8].

541. *See, e.g.*, Complaint at 3, Tingsrätt [TR] [Stockholm District Court] 2016-09-15 (Sweden), http://climatecasechart.com/non-us-case/push-sweden-nature-youth-sweden-et-al-v-government-of-sweden/ [https://perma.cc/MX84-N5QW]; Complaint at Section 3.6.1, Verwaltungsgerichtshof [VwGH] [Administrative Court of Justice] Feb. 2, 2017, W109 2000179-1/291E (Autstria), http://climatecasechart.com/non-us-case/in-re-vienna-schwachat-airport-expansion/ [https://perma.cc/BEL8-KWXF]. Plaintiffs in these cases also argued that emissions from the proposed projects would prevent the country from achieving its fair share of emissions reductions as called for in the UNFCCC and the Paris Agreement.

4. Legal Defense of Greenhouse Gas Emission Standards and Related Actions

As governments introduce an increasing number of laws, policies, and programs aimed at addressing the causes and impacts of climate change, the number of lawsuits challenging these actions will also increase.[542] These are similar to lawsuits challenging the failure to regulate greenhouse gas emissions—the key difference being that these lawsuits involve allegations that regulations are *too* stringent or that other actions taken to curtail emissions (e.g., permit denials) are unjustified. Indeed, both types of claims could be, and often are, brought with respect to the same regulatory action, with one side arguing that emission standards are insufficient and another arguing that they are too stringent.[543]

One example of a defense case which involved considerable attention to attribution science was *Green Mountain Chrysler Plymouth Dodge Jeep v. Crombie.*[544] In a legal challenge to Vermont's Low Emission Vehicle Program, automobile manufacturers and retailers specifically challenged the scientific basis for the standards, arguing that the program would impose significant costs but "do nothing concrete to improve air quality or the health of Vermont residents."[545] To support this claim, the petitioners emphasized that CO_2 is unlike other air pollutants in that it disperses globally throughout the upper atmosphere and then cited this fact as the

542. *See, e.g.*, Société Arcelor Atlantique et Lorraine v. [EU] Parliament and Council (environment and consumers), Case T-16/04 (EU General Court 2010), http://climatecasechart.com/non-us-case/societe-arcelor-atlantique-et-lorraine-v-eu-parliament-and-council-environment-and-consumers/ [https://perma.cc/VD3V-7VTM]; Essent Belgium NV v. [Flemish region of] Vlaams Gewest, Case C-492/14 (Netherlands 2016), http://climatecasechart.com/non-us-case/essent-belgium-nv-v-flemish-region-of-vlaams-gewest/ [https://perma.cc/JNQ7-N66U]; Maia Filho v. Federal Environmental Agency (IBAMA), Special Appeal 1000.732 – RO (Brazil 2015), http://climatecasechart.com/non-us-case/maia-filho-v-environmental-federal-agency-ibama/ [https://perma.cc/AZ4L-TTM8]; Gloucester Resources Limited v. Minister for Planning, [2019] NSWLEC 7 (Australia 2019), http://climatecasechart.com/non-us-case/gloucester-resources-limited-v-minister-for-planning/ [https://perma.cc/XDW3-WLJY] (in a legal challenge appealing the denial of a company's application to construct a coal mine, an Australian court upheld the government's denial of permit on climate change grounds).

543. *See, e.g.*, Coal. for Responsible Regulation v. EPA, No. 09-1322 (D.C. Cir. Dec 23, 2009); Sierra Club v. EPA, No. 10-1215 (D.C. Cir. Aug 2, 2010) (both challenging EPA's Tailoring Rule).

544. Green Mountain Chrysler Plymouth Dodge Jeep v. Crombie, 508 F. Supp. 2d 295 (D. Vt. 2007).

545. Complaint ¶ 4, *Green Mountain Chrysler*, Dkt. 1, 508 F. Supp. 2d 295 (2:05-cv-302) filed Nov. 18, 2005.

basis for arguing that CO_2 reductions in Vermont would not have any practical impact on public health in Vermont.[546] Vermont, joined by other defendants, solicited expert testimony from scientists to contradict these claims, and the petitioners attacked the credibility of these scientists. The reviewing court issued a lengthy opinion evaluating the scientific claims and finding that the scientific basis for the emission standards was sound.[547] The court cited specific examples of climate-related harms, including potentially severe effects on Vermont, as well as language from the Supreme Court's decision in *Massachusetts* highlighting the legitimacy of small and incremental regulatory steps to address climate change.[548] The decision also contained a lengthy explanation of why expert testimony from climate scientists such as James Hansen was admissible under the *Daubert* test.[549]

5. Lawsuits to Hold Emitters Liable for Damages Caused by Climate Change Impacts

In addition to suing governments for failure to regulate greenhouse gas emissions, some plaintiffs have gone directly to the source, suing major emitters, such as utilities, as well as fossil fuel companies, in an attempt to obtain an injunction against future emissions or monetary damages for adaptation costs. To date, these lawsuits have been predominately domestic, and based on tort or tort-like theories such as public nuisance, private nuisance, and negligence.[550] In one instance, an environmental organization and Philippine citizens filed a petition with the Human Rights Commission of the Philippines claiming that fossil fuel companies' activities constitute a violation of their human rights.[551] In the future, it is possible that climate change lawsuits may be brought by foreign nations or citizens against private actors in either U.S. courts or within their domestic jurisdictions.[552] Attribution science is central to any and all such cases, as it is necessary to establish a causal connection between the defendant's emissions or activities

546. *Id.* at 9–11.
547. *Green Mountain Chrysler*, 508 F. Supp. at 339–40.
548. *See, e.g.*, *id.* at 309.
549. *Id.* at 310–33.
550. Burger & Wentz, *supra* note 8.
551. In re Greenpeace Southeast Asia and Others, Case No. CHR-NI-2016-0001 (2015).
552. *See* Michael Byers et al., *The Internationalization of Climate Damages Litigation*, 7 WASH. J. ENVTL. L. & POL'Y 264 (2017).

and plaintiffs' injuries, and that the injuries were a foreseeable result of the emissions.

Much has been written on the prospect of climate change torts.[553] As others have noted, these analyses sit along a "spectrum," ranging from "those who are optimistic about the prospects for climate damages litigation [and] argue that climate damages are not fundamentally different from other types of common law damages

553. *See* Albert C. Lin & Michael Burger, *State Public Nuisance Claims and Climate Change Adaptation*, 36 PACE ENVTL. L. REV. 49 (2018); Byers et al., *supra* note 552; R. Henry Weaver & Douglas A. Kysar, *Courting Disaster: Climate Change and the Adjudication of Catastrophe*, 93 N.D. L. REV. 295 (2017); CLIMATE CHANGE LIABILITY: TRANSNATIONAL LAW AND PRACTICE (Richard Lord et al. eds., Cambridge University Press 2012); David Weisbach, *Negligence, Strict Liability, and Responsibility for Climate Change*, 97 IOWA L. REV. 521 (2011–2012); CLIMATE CHANGE LIABILITY (Michael Faure & Marjan Peeters, eds., Edward Elgar 2011); Amy Sinden, *Allocating the Costs of the Climate Crisis: Efficiency Versus Justice*, 85 WASH. L. REV. 293, 323–39 (2010); Matthew F. Pawa, *Global Warming: The Ultimate Public Nuisance*, 39 ENVTL. L. REP. 10230 (2009); Christopher R. Reeves, *Climate Change on Trial: Making the Case for Causation*, 32 AM. J. TRIAL ADVOC. 495 (2009); Kirk B. Maag, Note, *Climate Change Litigation: Drawing Lines to Avoid Strict, Joint, and Several Liability*, 98 GEO. L.J. 185 (2009); Randall S. Abate, *Automobile Emissions and Climate Change Impacts: Employing Public Nuisance Doctrine as Part of a "Global Warming Solution" in California*, 40 CONN. L. REV. 591 (2008); Shi-Ling Hsu, *A Realistic Evaluation of Climate Change Litigation Through the Lens of a Hypothetical Lawsuit*, 79 U. COLO. L. REV. 701 (2008); Timothy D. Lytton, *Using Tort Litigation to Enhance Regulatory Policy Making: Evaluating Climate-Change Litigation in Light of Lessons from Gun-Industry and Clergy-Sexual-Abuse Lawsuits*, 86 TEX. L. REV. 1837 (2008); James R. May, *Climate Change, Constitutional Consignment, and the Political Question Doctrine*, 85 DENV. L. REV. 919 (2008); Amelia Thorpe, *Tort-Based Climate Change Litigation and the Political Question Doctrine*, 24 J. LAND USE & ENVTL. L. 79 (2008); Jonathan Zasloff, *The Judicial Carbon Tax: Reconstructing Public Nuisance and Climate Change*, 55 UCLA L. REV. 1827 (2008); Erin Casper Borissov, Note, *Global Warming: A Questionable Use of the Political Question Doctrine*, 41 IND. L. REV. 415 (2008); David A. Dana, *The Mismatch Between Public Nuisance Law and Global Warming*, 18 SUP. CT. ECON. REV. 9 (2010); David Hunter & James Salzman, *Negligence in the Air: The Duty of Care in Climate Change Litigation*, 155 U. PA. L. REV. 1741 (2007); Myles Allen et al., *Scientific Challenges in the Attribution of Harm to Human Influence on Climate*, 155 U. PA. L. REV. 1353 (2007); Daniel J. Grimm, Note, *Global Warming and Market Share Liability: A Proposed Model for Allocating Tort Damages Among CO2 Producers*, 32 COLUM. J. ENVTL. L. 209 (2007); Sarah Olinger, Comment, *Filling the Void in an Otherwise Occupied Field: Using Federal Common Law to Regulate Carbon Dioxide in the Absence of a Preemptive Statute*, 24 PACE ENVTL. L. REV. 237 (2007); Benjamin P. Harper, Note, *Climate Change Litigation: The Federal Common Law of Interstate Nuisance and Federalism Concerns*, 40 GA. L. REV. 661 (2006); Thomas W. Merrill, *Global Warming as a Public Nuisance*, 30 COLUM. J. ENVTL. L. 293 (2005); Matthew F. Pawa & Benjamin A. Krass, *Global Warming as a Public Nuisance:* Connecticut v. American Electric Power, 16 FORDHAM ENVTL. L. REV. 407 (2005); James R. Drabick, Note, *"Private" Public Nuisance and Climate Change: Working Within, and Around, the Special Injury Rule*, 16 FORDHAM ENVTL. L. REV. 503 (2005); Myles R. Allen & Richard Lord, *The Blame Game: Who Will Pay for the Damaging Consequences of Climate Change?*, 432 NATURE 551 (2004); David A. Grossman, *Warming Up to a Not-So-Radical Idea: Tort-Based Climate Change Litigation*, 28 COLUM. J. ENVTL. L. 1 (2003); Eduardo M. Peñalver, *Acts of God or Toxic Torts? Applying Tort Principles to the Problem of Climate Change*, 38 NAT. RESOURCES J. 563 (1998).

that already give rise to liability," to those who "accept that existing legal concepts could form a basis to recover climate damages, [but] they caution that such cases face a series of challenges often centered around causation," to those who "argue that climate damages claims face threshold issues that will likely prevent them from ever being argued on their merits."[554] Among these, Professor Douglas Kysar has done the most to conceptualize and articulate the problems confronting any such claim:

> Tort law seems ill-equipped to address the causes and impacts of climate change: diffuse and disparate in origin, lagged and latticed in effect, anthropogenic greenhouse gas emissions represent the paradigmatic anti-tort, a collective action problem so pervasive and so complicated as to render at once both all of us and none of us responsible. Thus, courts will have ample reason—not to mention doctrinal weaponry—to prevent climate change tort suits from reaching a jury.[555]

This leads Kysar to the conclusion that "tort law is unlikely to play a substantial role in the ultimate effort to reduce greenhouse gas emissions,"[556] placing him on the relatively skeptical end of the spectrum. At the same time, however, Kysar exposes the potential for encounters with climate change tort claims to shift "the bar for exoticism in tort":

> Various suits that have frustrated judges because of their scale, scientific complexity, and widespread policy implications—such as claims involving toxic and environmental harm, tobacco and handgun marketing, or slavery and Holocaust reparations—may come to seem less daunting and intractable when juxtaposed against "the mother of all collective action problems." Current debate over whether courts are engaging in "regulation through litigation" may come to appear miscast in the face of suits that raise at once both an ordinary pollution nuisance and a challenge to the very foundations of modern industrial life. At long last, courts and commentators may come to view tort claims in degrees of polycentricity, rather than in crude binary terms of conventional civil disputes, on the one hand, and political or regulatory matters, on the other.[557]

554. Byers et al., *supra* note 552, at 270–71.

555. Douglas A. Kysar, *What Can Climate Change Do About Tort Law*, 41 ENVTL. L. 1, 4 (2011).

556. *Id.*

557. *Id.* at 4–5.

If the bar shifts, it may well be that the bar shifts not only after but *during* the course of climate tort litigation.[558] To date, Kysar's first prediction, at least, has proved correct. While there have been quite a few successful cases brought against governments for failure to regulate greenhouse gas emissions,[559] the same cannot be said for lawsuits aimed at holding emitters liable for damages caused by climate change impacts. The authors are not aware of any such lawsuit that has been successful to date. Moreover, the influence of these cases on the shape of tort law remains to be seen. But our purposes here are more limited than Kysar's deep conceptualization of tort law: namely, to provide a summary of key issues confronting common law climate change cases and to identify the role attribution science has played, is playing, and might yet play in resolving them.

Accordingly, in this section we describe the basic elements of tort—duty, breach, causation, and harm—and how climate change insinuates itself into an analysis of them. We then assess the role attribution science might play in meeting evidentiary standards in a court of law, and ultimate persuasive outcomes on the merits. Finally, we describe the way attribution science played into a number of high-profile climate tort cases in the past, to give an inkling of what may lie ahead in the future.

a. Elements of Negligence & Nuisance

The legal elements required to prevail on different tort claims differ from one another: to prevail on a negligence claim, the plaintiff must establish that the defendant has breached a duty or standard of care, that this breach caused a personal injury to the plaintiff, and that the defendant's conduct is the "proximate cause" of the injury.[560] To prevail on a private nuisance claim, the plaintiff must establish that the defendant's conduct has caused a "substantial and unreasonable interference with plaintiff's use and enjoyment of property."[561] To prevail on a public nuisance claim,

558. Weaver & Kysar, *supra* note 553; *see also* Douglas A. Kysar, *The Public Life of Private Law: Tort Law as a Risk Regulation Mechanism*, 9 EUR. J. RISK. REG. 48 (2018).

559. *See supra* Part III(C)(3)(a)(i) (Massachusetts v. EPA); *see supra* Part III(C)(3)(c)(iii) (Foreign Jurisdictions).

560. RESTATEMENT (SECOND) OF TORTS § 281 (AM. LAW INST. 1965).

561. RESTATEMENT (SECOND) OF TORTS § 822 (AM. LAW INST. 1979).

the plaintiff must establish that the defendant's conduct has caused an "unreasonable interference with a right common to the public."[562] Despite the differences, they do all share some common elements. The concepts of duty and breach, explicit in negligence, are imported into nuisance through the concept of "unreasonable interference." Proximate causation and a resulting harm or injury are required in all three.

Below, we summarize the key elements of tort cases and briefly touch on how attribution science may help with establishing these elements. This summary is followed by a more in-depth overview of the role of attribution science in climate change cases.

i. Duty

It is a well-worn story that tort law's notion of a legal duty is a confusing, muddled concept, generally bounded by the competing opinions by Judge Cardozo and Judge Andrews set forth in *Palsgraf v. Long Island Railroad Company* some ninety years ago.[563] In Judge Cardozo's view, "antisocial conduct only triggers a duty of tort responsibility when its potential harmful effects can be attached to particular, identifiable victims" and the risk of harm is "apparent to the eye of ordinary vigilance."[564] In other words, "the risk reasonably to be perceived defines the duty to be obeyed, and risk imports relation; it is a risk to another or to others within the range of apprehension."[565] Foreseeability, then, is part of Cardozo's definition of tort duty. In contrast, Judge Andrews' dissent presents a "communal notion of responsibility in which all actors are under a duty to avoid unreasonable behavior, irrespective of whether that behavior implies a particular relation of responsibility to plaintiffs."[566] Judge Andrew explained: "Due care is a duty imposed on each one of us to protect society from unnecessary danger, not to protect A, B, or C alone."[567] For Judge Andrews, the issue of foreseeability of injury to a particular plaintiff may be relevant to the proximate cause inquiry, but not the nature of the

562. Connecticut v. Am. Elec. Power Co., 582 F.3d 309, 369–70 (2d Cir. 2009), *rev'd*, 564 U.S. 410 (2011).

563. Palsgraf v. Long Island R.R. Co., 162 N.E. 99 (N.Y. 1928).

564. Kysar, *supra* note 555, at 13; *Palsgraf*, 162 N.E. at 99.

565. *Palsgraf*, 162 N.E. at 100.

566. Kysar, *supra* note 555, at 14.

567. *Palsgraf*, 162 N.E. at 102.

defendant's duty.[568] Federal and state courts wrestling with cases sounding in negligence and nuisance fall somewhere within this range, with some courts embracing foreseeability of harm to the specific plaintiff as an element of duty[569] and others rejecting it.[570]

The identification of a legal duty under Cardozo's concept is deeply complicated by the facts of climate change. Climate change is, after all, a "geophysical problem . . . centuries in the making (and studying) with causes ranging from volcanoes, to wildfires, to deforestation to stimulation of other greenhouse gases . . . . to the combustion of fossil fuels."[571] What's more, "the range of consequences is likewise universal—warmer weather in some places that may benefit agriculture but worse weather in others, e.g., worse hurricanes, more drought, more crop failures and . . . the melting of the ice caps, the rising of the oceans, and the inevitable flooding of coastal lands."[572] Would the "eye of ordinary vigilance" demanded by Judge Cardozo[573] foresee a pathway leading from a particular activity located somewhere in the "train of industry"[574] to a particular climate change-related injury experienced by a particular person in a particular place and time? Is the duty more easily recognizable if the entity suffering the injury is a state, a city, a tribe, or a certified class? If the particularized harms that come from producing, transporting, storing, marketing, selling, combusting, and/or consuming fossil fuels so as to emit greenhouse gases are foreseeable now, at what point did they become so?

Where foreseeability is an element of tort duty, the history and current and future states of attribution science will play a role in establishing and defending against it. However, even in a case

568. *Id.* at 104.

569. *See, e.g.,* Norris v. Corr. Corp. of Am., 521 F. Supp. 2d 586, 589 (W.D. Ky. 2007).

570. *See, e.g.,* Rodriguez v. Del Sol Shopping Ctr. Assocs., L.P., 326 P.3d 465, 467 (N.M. 2014); Thompson v. Kaczinski, 774 N.W.2d 829, 835 (Iowa 2009). The decisions rejecting foreseeability as an element of duty are consistent with the Third Restatement of Torts, which notes: "Despite widespread use of foreseeability in no-duty determinations, this Restatement disapproves that practice and limits no-duty rulings to articulated policy or principle in order to facilitate more transparent explanations of the reasons for a no-duty ruling and to protect the traditional function of the jury as factfinder." RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 7, cmt. j (AM. LAW INST. 2010).

571. California v. BP P.L.C., No. C 17-06011 WHA, 2018 WL 1064293 (N.D. Cal. Feb. 27, 2018).

572. *Id.*

573. *Palsgraf*, 162 N.E. at 99.

574. California v. BP P.L.C., 2018 WL 1064293, at *4.

governed by Judge Andrews' more expansive view—for instance, a public nuisance case where the duty is more widely distributed—plaintiffs cannot evade the issue of foreseeability. It will come up in establishing proximate cause. As Kysar explains, "plaintiffs will face the challenge of establishing foreseeability in a way that does not strain liberal notions of limited obligation beyond the breaking point."[575] The end result could be a global duty owed by some select group of actors to people everywhere. Or it could mean that no legal duty exists to constrain these types of behaviors.

ii. Breach

Once a duty has been established, liability can only attach if there has been a breach, in some form, of that duty. The key issue in assessing a breach, under a conventional analysis, involves balancing competing values, both in negligence and nuisance. In the negligence context, a breach occurs where the plaintiff has failed to exercise reasonable care to protect others from a foreseeable risk of harm. What constitutes "reasonable care" is typically defined by what a "reasonable person" would do under similar circumstances.[576] In nuisance, the breach factors into an assessment of whether defendant's interference with plaintiff's person, property, or public goods was "unreasonable." To determine what constitutes an "unreasonable interference," courts may weigh factors such as the utility of the conduct giving rise to the alleged nuisance, the cost of abating the alleged nuisance, and the severity of the harm caused by defendant's conduct when deciding whether the conduct is indeed a nuisance.[577]

In both instances, the "reasonableness" inquiry involves something of a "social welfare cost-benefit test,"[578] with one critical factor being whether the cost of taking precautions is greater or less than the cost of potential harm.[579] Attribution science has a

575. Kysar, *supra* note 555, at 17.

576. RESTATEMENT (SECOND) OF TORTS § 283 (AM. LAW INST. 1965).

577. RESTATEMENT (SECOND) OF TORTS § 826 (AM. LAW INST. 1979). While a balancing of harm versus utility is typically required in nuisance cases seeking injunctive relief, some courts have held that such balancing is not required where plaintiffs are seeking monetary damages. *See, e.g.*, Nat'l Energy Corp. v. O'Quinn, 233 VA. 83, 86 (1982).

578. Kysar, *supra* note 555, at 21.

579. United States v. Carroll Towing Co., 159 F.2d 169, 173 (2d Cir. 1947) (liability in negligence will be found if the probability of harm multiplied by the gravity of the potential injury exceeds the cost of precaution).

role to play in calculating the costs of climate change. As discussed in Part II, attribution science is the connective tissue tying particular impacts resulting in particular costs back to climate change and anthropogenic influence on climate change, and it can help improve calculations of the social cost of greenhouse gas emissions.[580]

In some instances, attribution science may have a role to play in calculating the benefits of climate change. As has been long-recognized, climate change does produce some "winners."[581] Changes that lead to increased agricultural production in some northern latitudes may be identified through attribution science. However, many of the benefits of defendants' activities will fall outside the scope of attribution science. These include things like the economic, social, health, and welfare benefits of fossil fuel development, power production, transportation, materials manufacturing, cement, shipping, aviation, and so forth and so on.

Courts will also consider foreseeability when assessing the reasonableness of conduct (a concept that cuts across the elements of duty, breach, and proximate cause). Again, attribution science plays an obvious role in this inquiry, helping to establish that a reasonable person would anticipate that activities which generate greenhouse gas emissions or otherwise contribute to climate change[582] will eventually result in specific types of harmful impacts. But there are limitations on the extent to which attribution science can establish foreseeability with respect to specific impacts and specific plaintiffs, which we discuss in further detail below.

There are other factors underpinning the "reasonableness" analysis that do not implicate climate change attribution science—these include custom, common practice, and regulatory treatment (e.g., whether the conduct is proscribed by law). Thus, while attribution studies can give weight to the idea that major contributions to climate change are "unreasonable," a court may

580. *See also* Kysar, *supra* note 555, at 22–23 (discussing application of SC-CO_2 to *American Electric Power*).

581. *See, e.g.*, J.B. Ruhl, *The Political Economy of Climate Change Winners*, 97 MINN. L. REV. 206 (2012); Michael H. Glantz, *Assessing the Impacts of Climate: The Issue of Winners and Losers in a Global Climate Change Context*, 65 STUD. IN ENVTL. SCI. 41 (1995).

582. Deforestation and the marketing of fossil fuels would be examples of conduct which does not directly generate greenhouse gas emissions but nonetheless contributes to climate change.

nonetheless conclude that such conduct is reasonable because it is a customary pattern of behavior.

iii. Causation

In addition, the plaintiff must show that the defendant's conduct was both the factual and the proximate, or legal, cause of the injury.[583] Factual causation concerns the scientific relationship between the defendant's action or behavior and the alleged injury.[584] To show factual causation, one must show both general, or generic, causation, and specific, or individualized, causation.[585] One commentator offered this useful summary: "General causation refers to whether the action in question *could have* caused the alleged injury, while specific causation refers to whether the action in question 'more likely than not' *actually caused* the alleged injury."[586] These are separate inquiries, that raise distinct questions for attribution science.

In regards to general causation, one critical question is whether and under what circumstances courts will impose liability on an actor who is not the sole cause of the injury. Underpinning this is the question of how courts might apportion liability among multiple emitters. In failure-to-regulate cases, some courts have granted standing based on a showing that the unregulated emissions made a "meaningful contribution" to climate change.[587] Courts have devised alternative tests for apportioning liability in tort cases. Consider the example of "toxic tort" cases, which involve claims of injury caused by exposure to harmful substances, and where there are multiple potential defendants that caused the exposure (e.g., by producing or releasing the harmful substance into the environment).[588] These cases have much in common with tort actions undertaken against greenhouse gas emitters, insofar as there is a "basic problem of proving, even defining, causal relationships in an environment where multiple causation

583. Byers et al., *supra* note 552, at 279.
584. *Id.*
585. *Id.*
586. *Id.*
587. *See supra* Part III(C)(1)(b) (Case Law on Standing to Sue for Climate Change-Related Harms).
588. *See* Glen O. Robinson, *Probabilistic Causation and Compensation for Tortious Risk*, 14 J. LEGAL STUD. 779 (1985).

confounds the possibility of isolating one 'responsible' cause as the touchstone of legal liability."[589]

As in toxic tort cases, there are several ways that liability may be apportioned among potentially responsible parties in this context, including the use of statistical, probabilistic, and epidemiological studies.[590] Due to the nature of the claims in toxic tort cases, it is typically impossible to show that a particular plaintiff's health condition is directly and solely caused by exposure to a substance generated by a specific defendant.[591] To overcome this hurdle, the plaintiffs in toxic tort cases have used statistical analyses and computer modeling to present: (i) probabilistic estimates of health risks associated with chemical exposures, and (ii) relative contributions to that risk from different parties.[592] Where the probability that a particular defendant's substance caused a substantial portion of the harm reaches a certain threshold, then courts may be willing to impose liability for the harm. For example, some courts require plaintiffs to show that their injuries were "more likely than not" caused by the defendant's conduct, and this requirement has been met through showings that the behavior increased the risk of the harm occurring by a factor of 2.[593] However, other courts have held that probabilistic proof is insufficient for imposing liability and have demanded "particularistic proof" of a causal connection.[594]

In regards to specific causation, the critical question is "whether defendant's actions or behavior were 'a necessary element' in bringing about the injury."[595] Assuming one can show that climate change is responsible for a particular local climate-related phenomenon or event that produced an injury, and before one

589. *Id.* at 780.

590. Byers et al., *supra* note 552, at 279.

591. Note, *Causation in Environmental Law: Lessons from Toxic Torts,* 128 HARV. L. REV. 2256, 2259 (2015) ("Because of the nature of the substances generally involved, the harms due to exposure typically are not discovered until long after the exposure occurred. In addition, over that period of time, the injured party may have been exposed to a variety of potentially harmful substances, likely as a result of actions by a variety of different actors. As a result, identifying any responsible party, much less identifying all responsible parties, can be quite difficult.").

592. *Id.* at 2268–69 (citing Daniel Farber, *Toxic Causation,* 71 MINN. L. REV. 1219, 1220 n.7 (1987)).

593. Albert C. Lin, *Beyond Tort: Compensating Victims of Environmental Toxic Injury,*78 S. CAL. L. REV. 1439, 1450 (2005); Grossman, *supra* note 553, at 23.

594. Lin, *supra* note 593, at 1450.

595. Byers et al., *supra* note 552, at 280.

gets to issues of contributory negligence, the problem for proving climate harms here is clear: emissions of any one actor, or even any small set of actors, will be difficult to pin down as a "but-for" cause of impacts arising from anthropogenic climate change.[596]

Again, though, toxic tort law has encountered similar situations—even if at an entirely different scale—and developed approaches through which to assign liability. The "substantial factor" or "material contribution" test allows a court to find liability where a defendant's conduct was a "substantial factor" in bringing about or a "material contribution" to a plaintiff's injury.[597] The "commingled approach" offers another possible approach. In litigation over groundwater contamination from MTBE, a court held that "[w]hen a plaintiff can prove that certain gaseous or liquid products . . . of many suppliers were present in a completely commingled or blended state at the time and place that the risk of harm occurred, and the commingled product caused a single indivisible injury, then each of the products should be deemed to have caused the harm."[598] Under a market share theory of liability, defendants may be held liable for injuries caused by a product based on their respective "shares" in the manufacture and sale of the product.[599]

In contrast to the factual causation inquiry, which focuses on scientific relationships, proximate cause is intended to address whether the injury is sufficiently closely related to the allegedly wrongful conduct, such that it makes sense to impose liability on the defendant.[600] To answer this question, courts may consider factors such as the geographic and temporal proximity between the conduct and the injury (and more generally, the directness of the relationship between conduct and injury), and whether the injury was a foreseeable result of the conduct.[601] As Justice Andrews

596. *See, e.g.* Kysar, *supra* note 555, at 31; Michael Duffy, *Climate Change Causation: Harmonizing Tort Law and Scientific Probability,* 28 TEMP. J. SCI. TECH. & ENVTL. L. 185 (2009).

597. Byers et. al., *supra* note 552, at 281–82.

598. In re Methyl Tertiary Butyl Ether (MTBE) Prod. Liab. Litig., 379 F. Supp. 2d 348, 377–78 (S.D.N.Y. 2005).

599. Byers et al., *supra* note 552, at 283.

600. Another way of posing this question is to ask whether the defendant should be shielded from liability even if he or she is the cause-in-fact of the injury. *See* Luke Meier, *Using Tort Law to Understand the Causation Prong of Standing,* 80 FORDHAM L. REV. 1241, 1249 (2011).

601. KENNETH S. ABRAHAM, THE FORMS AND FUNCTIONS OF TORT LAW 124 (3d ed. 2007). The Supreme Court has held that defendants must establish a direct link between conduct

explained in his *Palsgraf* dissent, "open-ended concepts such as fairness, justice, policy, practical politics, and common sense" may also factor into the proximate cause analysis.[602]

We have already touched on how attribution science can be used to establish causation (in the context of standing) and foreseeability (in the context of duty and breach). A more detailed analysis of the role of attribution science with respect to these two elements is provided in Section III.C.4.b.

iv. Harm or Injury

Regardless of the tort, actual harm must be shown. For a negligence claim, breach must give rise to an injury that is similar to, but not always identical to, the sort of "injury-in-fact" required for standing purposes. Courts have yet to articulate a clear distinction between standing and negligence injuries, but there are some subtle differences in terms of how these concepts are typically defined. For example, most courts have held that negligence liability requires proof of actual harm, whereas standing can be based on a harm that has yet to occur but is imminent.[603] At the same time, the types of harms that can support a negligence claim are defined more broadly to include emotional distress, and in some jurisdictions, this has become a vehicle for imposing liability on defendants whose negligent conduct increases the risk of harm to a plaintiff, thereby causing emotional distress.[604]

and injury to satisfy proximate cause requirements under various statutory frameworks that mirror common law doctrines, and that courts should not go beyond the "first step" of the causal chain to establish that link under these statutes. *See* Bank of Am. Corp. v. City of Miami, 137 S.Ct. 1296 (2017). While directness is certainly relevant to the proximate cause inquiry for tort liability, this narrow interpretation of what qualifies as a sufficient "direct" cause has not been extended to common law cases.

602. David Owen, *Figuring Foreseeability*, 44 WAKE FOREST L. REV. 1277 (2009) (citing *Palsgraf*, 162 N.E. at 103–05 (Andrews, J., dissenting)).

603. Albert Lin, *The Unifying Role of Harm in Environmental Law*, 3 WIS. L. REV. 897, 911 (2006); Cass Sunstein, *Standing Injuries*, 1993 SUP. Ct. REV. 37 (1993).

604. *See* RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 8, Scope Note (AM. LAW INST. 2012). Courts may require that the emotional injury be linked to some sort of physical harm or impact, such as exposure to a toxic substance, which gives rise to a "reasonable fear" of a physical harm. *See, e.g.*, Sterling v. Velsicol Chem. Corp., 855 F.2d 1188, 1205–06 (6th Cir. 1988) (holding that mental distress from a reasonable fear of cancer is an adequate injury for tort liability under Tennessee law). But some jurisdictions recognize a cause of action for negligent infliction of emotional distress absent any physical impact or injury. *See* Lin, *supra* note 603, at 903–07.

Like negligence, there is some precedent for treating risk as an injury in the context of nuisance claims. Specifically, under the doctrine of "anticipatory nuisance," courts may enjoy an anticipatory or prospective nuisance activity that has not yet caused harm but threatens to do so.[605] In most cases, to prevail on an anticipatory nuisance claim, the plaintiff must show that there is a "high probability" or "reasonable certainty" of injury.[606] Here, again, attribution science would be used in the ways described above—both as a means of characterizing the injury (interference) to the plaintiff, and as a means of explaining why the interference is unreasonable and a threat.

b. Role of Attribution Science

As noted above, attribution science can be used to establish three key elements in tort litigation: foreseeability, causation, and injury. The foregoing discussion of standing illustrates how attribution science is used to establish injury, and while there are subtle differences in how "injury" is defined in standing and on the merits of tort cases, the role of attribution science in these two contexts is roughly the same. We therefore focus here on how attribution science can support findings of foreseeability and causation.

Foreseeability and causation are closely linked—the same research that can be used to establish a causal connection between climate change and impacts can also be used to establish the foreseeability of impacts—but they are not one in the same. To the contrary, there may be circumstances where an impact may have been caused by climate change but was not foreseeable, and circumstances where an impact is a foreseeable consequence of climate change but cannot be causally linked to climate change. It is therefore important to discuss these as distinct applications of attribution science.

With regards to foreseeability: the existing detection and attribution literature highlights a wide array of impacts that are already occurring as a result of climate change and lends credibility to predictions of future impacts. A court's determination as to

605. PROSSER & KEETON ON THE LAW OF TORTS 640-41 (5th ed. 1984); George P. Smith, II, *Re-Validating the Doctrine of Anticipatory Nuisance,* 29 VT. L. REV. 687, 689 (2005).

606. Smith *supra* note 605, at 689; Charles J. Doane, *Beyond Fear: Articulating a Modern Doctrine in Anticipatory Nuisance for Enjoining Improbable Threats of Catastrophic Harm,* 17 B.C. ENVTL. AFF. L. REV. 441 (1990).

whether an impact is a foreseeable consequence of activities that increase greenhouse gas emissions would likely depend on: (i) the degree of confidence with which the impact has been attributed to climate change or projected to occur as a result of climate change; (ii) the amount of scientific research linking the impact to climate change (and level of consensus among scientists); and (iii) the timeframe in which that research was performed. If there are only a handful of studies on a particular impact or if the studies were all published after the allegedly tortious conduct, then courts might conclude that the impacts are not foreseeable.[607]

Establishing that certain physical impacts such as sea level rise and increasing temperatures are foreseeable outcomes of activities that contribute to climate change is a relatively straightforward task. However, as discussed in Part II, the actual injuries associated with climate change are often secondary or tertiary impacts that are influenced by a multitude of confounding factors in addition to anthropogenic influence on climate. The greater the number of confounding factors, the more difficult it may be to establish that a particular injury was foreseeable. It may also be challenging to establish the foreseeability of specific low-probability, high-impact events even where those events are part of a broader trend that has been attributed to or predicted to come about as a result of climate change. For instance, a catastrophic flood that is far more severe than what any climate model predicted may not be foreseeable, even where increased intensity of extreme precipitation events is generally accepted.

In most tort cases invoking climate change, it may be significantly more challenging for plaintiffs to establish causation—and in particular, specific causation—than it is to establish foreseeability. Indeed, this appears to be the most difficult element to prove across all cases. As discussed above, standing law requires a showing of factual or but-for causation. This is also required for

607. Another factor that might be considered in the foreseeability analysis is the scale of the emissions impact—the idea being that a small emissions impact will not result in foreseeable harms. However, technically speaking, even a very small emissions contribution would foreseeability contribute to all impacts associated with climate change due to the dispersion of greenhouse gases in the atmosphere. It is the authors' view that the magnitude of the emissions impact is more relevant to the analysis of harm and causation in the tort context.

negligence and nuisance cases.[608] As with standing, the challenge here is proving a counter-factual: what would have happened in the absence of defendant's conduct? Sometimes this is a relatively easy exercise, but for harms related to climate change, this is a fact-intensive inquiry that can involve a fair amount of assumption and speculation, testimonies from competing experts, and weighing of evidence.[609] Whereas this inquiry is treated as a question of law in the standing context in most cases, it is treated as a question of fact in the tort context, and would therefore be decided "only at the end of trial, after all of the evidence has been received and all of the experts have testified."[610]

The causal questions implicated by tort lawsuits against the range of likely defendants in climate cases are complex. To succeed in such a case, a plaintiff would need to establish several lines of causation:

- The plaintiff must link a specific change or event to anthropogenic climate change (e.g., sea level rise or a flooding event)—i.e., climate change and extreme event attribution.
- The plaintiff must link a specific loss to that change or event (e.g., the cost of adaptation measures or residual losses that were not or could not be avoided through adaptation)—i.e., impact attribution.
- The plaintiff must link the defendant's conduct (i.e., release of greenhouse gas emissions) to anthropogenic climate change and identify the defendant's relative contribution to the harm incurred by the plaintiff—i.e., source attribution.

Regarding the first line of causation: proving that a specific change or event is caused by climate change will be easier for long-term changes such as mean temperature increases and sea level rise—but as discussed in Part II, there are challenges to establishing

608. This is known as "factual causation," "but for causation," or the *sine qua non* test. These are basically the same concepts because "an act is a factual cause of an outcome if, in the absence of the act, the outcome would have occurred even if the defendant had acted non-negligently." RESTATEMENT (THIRD) OF TORTS: LIABILITY FOR PHYS. & EMOT. HARM § 26 Factual Cause (AM. LAW INST. 2012).

609. Luke Meier, *Using Tort Law to Understand the Causation Prong of Standing*, 80 FORDHAM L. REV. 1241, 1248–49 (2011).

610. *Id.* at 1249 (citing KENNETH S. ABRAHAM, THE FORMS AND FUNCTIONS OF TORT LAW 105–07 (3d ed. 2007).

causation even in that context. For example, plaintiffs will need to establish that flooding or saltwater inundation is caused by sea level rise even where coastal erosion and subsidence are also occurring as a result of coastal development.

Linking a specific extreme weather event to climate change poses another test. The probabilistic approach to event attribution, whereby scientists quantify the extent to which anthropogenic climate change affected the probability of the event occurring (expressed as FAR—fraction of attributable risk), would likely be the best vehicle for establishing causation for the purposes of tort litigation.[611] As discussed above, some probabilistic attribution assessments have identified a relatively strong climate signal on certain events with a relatively high level of certainty. For example, the study of the 2003 European Heat Wave found that climate change had increased the probability of this event at least a factor of two, more likely a factor of six.[612] In other studies, the climate signal is evident but less strong. For example, a study of the 2000 United Kingdom floods found that climate change increased the probability of the flood occurring by a factor of two in most simulations, but in 10% of cases, the risk increase was less than 20%.[613]

There is precedent for courts accepting this type of statistical data as evidence of causation. For example, in U.S. tort law, plaintiffs typically must show that their individual injuries were "more likely than not" caused by the behavior question, and this requirement has been met through showings that the behavior increased the risk of the harm occurring by a factor of two.[614] Applying that same standard to the 2003 European Heat Wave, a court could conclude that climate change was "more likely than not" the proximate cause of the heat wave. As discussed in the standing section, courts also consider probabilistic assessments when determining whether a future injury is sufficiently "imminent" such that plaintiffs have satisfied the injury-in-fact requirement.

611. Allen et al., *supra* note 553, at 1385 (citing Myles Allen, *Liability for Climate Change,* 421 NATURE 891, 891–92 (2003); Dáithí A. Stone & Myles R. Allen, *The End-to-End Attribution Problem: From Emissions to Impacts,* 71 CLIMATIC CHANGE 303, 303–04 (2005).

612. Allen et al., *supra* note 553, at 1393.

613. A. Kay et al., *Attribution of Autumn / Winter 2000 Flood Risk in England to Anthropogenic Climate Change; A Catchment-Based Study*, 406 J. OF HYDROLOGY 91 (2011).

614. Grossman, *supra* note 553, at 23.

Probabilistic event attribution can also be supplemented with observational evidence showing trends in the frequency of an event growing over time.[615] Observational evidence of trends probably would not, by itself, suffice for the purposes of establishing liability for a particular event for the reasons noted above. However, it is possible that such evidence could be used to establish liability for the aggregated impacts of additional extreme weather events over time—for example, a state that has experienced a 10% increase in extreme heat days may be able to establish that climate change more likely than not was responsible for that increase. This type of argument has been accepted in the context of the lawsuits noted in the previous sections (defense of government regulation and lawsuits seeking to compel regulation)[616] but has not been tested in the context of private liability lawsuits.

The storyline or mechanistic approach could also be used to link an extreme event or even a long-term change to anthropogenic influence on climate. That approach would yield different types of quantitative findings—for example, that anthropogenic climate change increased the magnitude of a storm or flood by 10%.

Even if the plaintiff is able to establish that a physical change or extreme event was caused by climate change, he or she must also establish the second and third lines of causation. The second causation challenge—establishing and quantifying the specific loss caused by the change or event—involves determining the extent to which the loss was caused by anthropogenic climate change as compared with other confounding factors. As discussed in Part II, a probabilistic approach can also be used in impact attribution to generate this sort of information. However, to date, most impact attribution studies do not produce findings that are as quantitatively robust as studies conducted on extreme events due to the number of confounding factors that influence impacts such as public health outcomes.

The third causation challenge—defining the defendant's relative contribution to the damage—is a matter of source attribution. As discussed above, courts have grappled with a related question in the context of lawsuits challenging government failure to regulate—specifically, whether the total greenhouse gas

615. *See, e.g*, S.K. Min et al., *Human Contribution to More-Intense Precipitation Extremes*, 470 NATURE 378 (2011).

616. *See* Sections III(C)(3) and III(C)(4).

contribution from the unregulated source category is sufficiently large such that: (i) the plaintiffs have standing by virtue of some actual or imminent harm caused by those emissions, and (ii) the government has violated some sort of obligation by failing to regulate those emissions.[617]

Importantly, even if a source's emissions are considered to be a "material", "substantial", or "significant" contribution to climate change, this does not mean that the source caused a specific impact and can therefore be held liable for all harms associated with that impact. Imposing liability in this context would be akin to imposing joint and several liability on all emitters that surpass a materiality threshold—something courts may be reluctant or even unwilling to do, given the possible ramifications of such a judicial policy. Recognizing this, some petitioners are now seeking to obtain monetary damages from emissions sources that are proportional to the emissions contribution from that source.[618]

One possible way to avoid some of the challenges associated with quantifying the defendants' contribution to plaintiffs' injuries is to seek injunctive relief rather than monetary damages in a tort lawsuit. Plaintiffs seeking injunctive relief have thus far faced the same challenges as those seeking monetary relief when attempting to establish causation for standing purposes, but there has not yet been a trial in which courts have fully evaluated the merits of causation claims in either context. Another option for plaintiffs seeking monetary damages would be to rely on lower bound damage estimates that can be attributed to defendants' conduct with high confidence—but this approach might require some re-framing of attribution studies—an issue which we explore in Part IV.

It may also prove easier to establish a causal nexus between defendants' conduct and plaintiffs' injuries where plaintiffs aggregate harms from multiple types of climate change-related impacts and across multiple persons. It is easier to establish, for example, that climate change (and defendants' conduct contributing to climate change) has caused injury to an entire state, city, or trade organization as opposed to an individual private plaintiff.

617. *See* Part III(C)(3)(b).
618. Lliuya v. RWE AG, VG Essen 15.12.2016 (2 O 285/15) (Germany).

c. Cases

i. *Connecticut v. American Electric Power* (Second Circuit)

The Second Circuit's review of *American Electric Power*, discussed above, provides some insights into how courts might handle tort claims pertaining to climate change. First, the court determined that whether a given quantity of emissions is a "meaningful" or "significant" contribution to global climate change is an evidentiary issue that should be addressed at a future stage of the proceedings—at least where those emissions appear on their face to potentially meet that standard.[619] Second, the court found that contributing sources of GHG emissions can be called to account, explaining that "[t]he Court has not imposed a requirement upon all federal common law of nuisance cases that the challenged pollution must be 'directly traced' or that plaintiffs must sue all sources of the pollution complained of in order to state an actionable claim. On the contrary, 'the fact that other persons contribute to a nuisance is not a bar to the defendant's liability for his own contribution.'"[620] Third, the court held that, to prevail on a public nuisance theory, plaintiffs need not demonstrate that they have suffered an actual harm or even an immediate harm—rather, a threatened harm would suffice. The court cited numerous precedents showing that federal courts have the authority to enjoin a threatened nuisance before irreparable harm results.[621] These

619. *Am. Elec. Power*, 582 F.3d at 345.

620. *Am. Elec. Power*, 582 F.3d at 356–57 (citing RESTATEMENT (SECOND) OF TORTS § 840E). (Am. Law Inst. 2008). *See also, e.g.*, Illinois ex. rel Scott v. Milwaukee, No. 72 C 1253, 1973 U.S. Dist. LEXIS 15607, (N.D. Ill. Nov. 1, 1973) ("[I]t is sufficient for plaintiffs to show that defendants' nutrient discharges [leading to eutrophication of Lake Michigan] constitute a significant portion of the total nutrient input to the lake. The correct rule would seem to be that any discharger who contributes an aliquot of a total combined discharge which causes a nuisance may be enjoined from continuing his discharge. Either that is true or it is impossible to enjoin point dischargers."), *aff'd in relevant part and rev'd in part,* 599 F.2d 151 (7th Cir. 1979), *vacated on other grounds*, Milwaukee v. Illinois, 451 U.S. 304 (1981). *Cf.* Student Pub. Interest Research Grp. of N.J., Inc. v. Tenneco Polymers, Inc., 602 F. Supp. 1394, 1397 (D.N.J.1985) (holding, in the context of finding causation for standing purposes, that pollution may derive from multiple sources and that it is not necessary to pinpoint which polluter caused a specific harm).

621. *Am. Elec. Power*, 582 F.3d at 357 (citing Mugler v. Kansas, 123 U.S. 623 (1887) (observing that courts of equity, in adjudicating public nuisance cases, can both prevent threatened nuisances, "before irreparable mischief ensues," as well as abate those in progress); United States v. Ira S. Bushey & Sons, 346 F. Supp. 145, 150 (D. Vt. 1972) ("[o]ne distinguishing feature of equitable relief is that it may be granted upon the threat of harm which has not yet occurred.") (quoting WILLIAM L. PROSSER, HANDBOOK OF THE LAW OF

conclusions would tend to support the notion that a nuisance claim can be predicated on a contribution to threatened harm, and that emitters might be held liable based on their proportional contribution to climate change.

ii. *Kivalina v. Exxon Mobil* (Northern District of California)

The district court's analysis of standing in *Kivalina* also provides some insight into how a court might address a climate nuisance claim. In particular, that the district court found an inadequate causal connection between the defendants' emissions (which were significantly more than those at issue in *AEP*—more than 1.2 billion tons per year of direct emissions) suggests that the district court would not have found adequate causation to support a nuisance claim.[622]

While not explicitly stated in the decision, the court's decision to dismiss the case may have been influenced by the fact that Kivalina was seeking damages to cover the full costs of its injuries, while defendants were only partially responsible for those injuries. In a sense, Kivalina was asking the court to impose joint and several liability on the companies.[623] Consider the following excerpt from the court's discussion of why the political question doctrine (as well as a lack of standing) barred its consideration of the case:

> Plaintiffs also fail to confront the fact that resolution of their nuisance claim requires the judiciary to make a policy decision about *who* should bear the cost of global warming. Though alleging that Defendants are responsible for a "substantial portion" of greenhouse gas emissions . . . Plaintiffs also acknowledge that virtually everyone on Earth is responsible on some level for contributing to such emissions. Yet, by pressing this lawsuit, Plaintiffs are in effect asking

TORTS 624 (3d ed. 1964)); Texas v. Pankey, 441 F.2d 236, 242 (10th Cir. 1971) (reversing district court refusing to issue injunction against pesticide spraying that was both threatened at the time the suit was instituted and had since been done); 7 STUART M. SPEISER, CHARLES F. KRAUSE & ALFRED W. GANS, THE AMERICAN LAW OF TORTS § 20.19 (Thomson West 2003) ("We deem it necessary to explain that a prospective nuisance is a fit candidate for injunctive relief. . . . One distinguishing feature of equitable relief is that it may be granted upon the threat of harm which has not yet occurred."); Andrew H. Sharp, Comment, *An Ounce of Prevention: Rehabilitating the Anticipatory Nuisance Doctrine,* 15 B.C. ENVTL. AFF. L. REV. 627, 633–36 (1988).

622. Native Vill. of Kivalina v. ExxonMobil Corp., 663 F. Supp. 2d 863, 881 (N.D. Cal. 2009), *aff'd,* 696 F.3d 849 (9th Cir. 2012).

623. However, courts might not be receptive to such claims. *See* Maag, *supra* note 553, at 187.

> this Court to make a political judgment that the *two dozen Defendants named in this action should be the only ones to bear the cost of contributing to global warming*. Plaintiffs respond that Defendants *should be* the ones held responsible for damaging Kivalina allegedly because "they are responsible for more of the problem than anyone else in the nation . . ." [] But even if that were true, Plaintiffs ignore that the allocation of fault—and cost—of global warming is a matter appropriately left for determination by the executive or legislative branch in the first instance.[624]

iii. *Lliuya v. RWE AG*

For plaintiffs seeking damages, an alternative approach to *Kivalina* is to request compensation for a proportion of damages that corresponds with the proportion of global greenhouse gas emissions emitted by the defendant. This is the strategy deployed in *Lliuya v. RWE AG*, in which a Peruvian farmer filed suit in German court against a German utility company, seeking damages to offset the costs of protecting his town from melting glaciers.[625] The farmer only sought damages proportional to the utility's relative contribution to global GHG emissions.[626] A district court in Germany dismissed the case, finding that there was no "linear causal chain" between RWE's emissions and the alleged injury because so many emitters had contributed to the risk of flooding in the farmer's town,[627] but the appellate court reversed and directed that the case move forward to an evidentiary phase to determine whether the plaintiff's home is threatened by flooding or mudslide as a result of the melting glacier, and the extent to which RWE's greenhouse gas emissions contribute to that risk.[628] The court will be reviewing expert opinions on the RWE's CO_2 emissions, the contribution of those emissions to climate change, the resulting impact on the glacier, and RWE's contributory share of responsibility for causing that impact.

624. Native Vill. of Kivalina, 663 F. Supp. 2d at 876–77.

625. *Lliuya v. RWE*, *supra* note 618.

626. *Id.*

627. FRANKFURTER ALLGEMEINE ZEITUNG [*David Loses the Fight Against Goliath*], Dec. 15, 2016, https://www.faz.net/aktuell/wirtschaft/energiepolitik/peruanischer-bauer-scheitert-mit-klage-gegen-rwe-14575835.html [https://perma.cc/3JNZ-9ADV] ("Eine Flutgefahr wäre jedoch der RWE AG nicht individuell zuzuordnen." ["A flood risk would however not be attributed singly to RWE AG."]).

628. Lliuya v. RWE AG, Landgericht Essen 30.11.2017 (I-5 U 15/17) (Germany).

Providing an accurate and precise estimate of a particular emitter's contribution to climate change remains challenging—in part due to limited information about historical and current emissions from individual sources, and in part due to uncertainty about the total amount of emissions being generated and sequestered as well as the relative contribution of different greenhouse gases to the greenhouse effect. There is also the question of how to apportion responsibility for emissions, with one critical question being whether fossil fuel production companies, electric generating units, or both should be viewed as "responsible" for emissions in the context of a private liability lawsuit. While this is an "attribution" question, it does not fall within the scope of detection and attribution science; rather, it involves social, political, and legal determinations about how to apportion responsibility.

iv. Pending U.S. Cases Against Fossil Fuel Companies

In 2017 and 2018, local governments across the United States initiated a new wave of litigation seeking to hold fossil fuel companies liable for their contribution to climate change and to recover damages for the cost of adapting to climate change.[629] Similar lawsuits have been filed by Rhode Island and the Pacific Coast Federation of Fishermen's Associations.[630] The plaintiffs in these cases allege that companies like ExxonMobil, BP, and Shell knowingly contributed to climate change by extracting and selling fossil fuels, obscuring the science of climate change, and fighting policies aimed at mitigating climate change, and should therefore

629. Complaint, City of Imperial Beach v. Chevron Corp., No. C17-01227 (Cal. App. Dep't Super. Ct. Jul. 17, 2017); Complaint for Public Nuisance, City of Oakland v. BP P.L.C., No. RG17875889 (Cal. App. Dep't Super. Ct. Sep. 19, 2017); Complaint, City of Santa Cruz v. Chevron Corp., No. 17CV03243 (Cal. App. Dep't Super. Ct. Dec. 20, 2017); Complaint, Cty. of Marin v. Chevron Corp., No. CIV1702586 (Cal. App. Dep't Super. Ct. Jul. 17, 2017); Complaint, Cty. of San Mateo v. Chevron Corp., No. 17CIV03222 (Cal. App. Dep't Super. Ct. Jul. 17, 2017); Complaint, Cty. of Santa Cruz v. Chevron Corp., No. 17CV03242 (Cal. App. Dep't Super. Ct. Jul. 17, 2017); Complaint for Public Nuisance, City of San Francisco v. BP P.L.C., No. CGC-17-561370 (Cal. App. Dep't Super. Ct. Sep. 19, 2017); Complaint, City of Richmond v. Chevron Corp., No. C18-00055 (Cal. App. Dep't Super. Ct. Jan. 22, 2018); Complaint and Jury Demand, Bd. of Cnty. Comm'rs of Boulder Cty. v. Suncor Energy (U.S.A.), No. 2018CV030349 (Colo. Dist. Ct. Apr. 17, 2018); Complaint, City of New York v. BP P.L.C., No. 1:18-cv-00182 (S.D.N.Y. Jan. 9, 2018); Plaintiff's Complaint, Mayor & City of Baltimore v. BP P.L.C., No. 24-C-18-004219 (Md. Cir. Ct. Jul. 20, 2018).

630. Complaint, Rhode Island v. Chevron Corp., No. PC-2018-4716 (R.I. Super. Ct. Jul. 2, 2018); Complaint, Pac. Coast Fed'n. of Fishermen's Ass'ns, Inc. v. Chevron Corp., No. CGC-18-571285 (Cal. Super. Ct. Nov. 14, 2018).

be held liable for some of the adaptation costs incurred by governments. They are pursuing multiple state law legal theories: public nuisance, private nuisance, negligence, trespass, failure to warn, and design defect, among others. These are not the first tort cases against emitters involving state rather than federal law claims—as noted in the above discussion of standing,[631] both *American Electric Power* and *Comer* also involved state law claims, but those decisions did not address the merits of those claims.

The complaints submitted by petitioners in these cases touch on all aspects of attribution. They discuss the basic science of climate change and attribution of climate change to increasing concentrations of greenhouse gas emissions; they identify specific extreme events and impacts of climate change that are injuring petitioners; and they examine "known causes" of those impacts, looking at the effect of anthropogenic climate change as well as other factors.[632] With regards to source attribution, petitioners quantify the cumulative emissions from the fossil fuels produced, sold, and marketed by defendant companies (e.g., "15% of global fossil fuel product-related CO2 between 1965 and 2015, with contributions currently continuing unabated"[633]) and assert that this is a "substantial" contribution to the impacts on petitioners.[634] The complaints are thus drafted in a manner which clearly anticipates that questions of climate change attribution will be at the heart of the inquiry into whether defendants have caused a nuisance or other actionable harm under common law. The attribution statements contained therein are relatively robust because: (i) petitioners represent the aggregated interests of all individuals within their jurisdiction (or trade association) and can therefore allege a broader array and greater magnitude of harms, and (ii) emissions from the combustion of fossil fuels produced by defendants constitute a relatively large (and quantifiable) share of global cumulative emissions. From the standpoint of attribution

631. *See supra* Section III (C)(1).

632. *See, e.g.*, Complaint for Public Nuisance, City of San Francisco v. BP P.L.C., *supra* note 629; Plaintiff's Complaint, Mayor & City of Baltimore v. BP P.LC., *supra* note 629; Complaint, Rhode Island v. Chevron Corp., *supra* note 630.

633. Complaint for Public Nuisance, City of San Francisco v. BP P.L.C., *supra* note 629, at 35.

634. *See, e.g.*, Complaint, Rhode Island v. Chevron Corp., *supra* note 630, at 48; Complaint for Public Nuisance, City of San Francisco v. BP P.L.C., *supra* note 629, at 35; Complaint, Maryland & Mayor of Baltimore v. BP P.L.C., *supra* note 629, at 49.

science, petitioners have made compelling arguments as to why a substantial proportion of their injuries can be traced to those emissions.

It remains unclear whether these cases will actually go to trial and whether the reviewing courts will fully evaluate the attribution questions presented therein. While plaintiffs are pursing state law theories, defendants have argued (and some judges have agreed) that all of the claims are "necessarily governed by federal law" because a "uniform standard of decision is necessary to deal with the issues raised" by plaintiffs.[635] Cases decided under federal law are more likely to be dismissed due to federal precedent in cases such as *American Electric Power*. To date, two cases have been dismissed by district court judges who held that claims were non-justiciable because they raised questions that should be resolved by the legislative and executive branches of the federal government.[636] One of these federal judges held a "climate science tutorial" in which both sides were asked to brief him on climate science. However, the opinion granting defendants' motion to dismiss explicitly recognized that "[t]he issue is not over science" but rather precedent and the separation of powers.[637]

v. Philippines Carbon Majors Inquiry

Plaintiffs in foreign jurisdictions have also begun to use human rights law and other legal sources as the basis for holding companies responsible for their contribution to climate change. In 2016, environmental and human rights advocates submitted a petition to the Philippines Commission on Human Rights requesting an investigation into the responsibility of forty-seven "Carbon Majors" (carbon producing companies) for human rights violations or threats of violations resulting from the impacts of climate change.[638] The claims raised by petitioners are similar to those raised in tort—that the companies produced and promoted the use of massive quantities of fossil fuels with full knowledge that the consumption of these fuels would contribute significantly to

635. City of Oakland v. BP P.L.C., No. C 17-06011 WHA, 2018 WL 1064293, at *3 (N.D. Cal. Feb. 27, 2018).

636. City of Oakland v. BP P.L.C., 325 F. Supp. 3d 1017 (N.D. Cal. 2018); City of New York v. BP P.L.C., 325 F. Supp. 3d 466 (S.D.N.Y. 2018).

637. City of Oakland v. BP P.L.C., 325 F. Supp. at 1022 (N.D. Cal. 2018).

638. In re Greenpeace Southeast Asia v. Chevron, Case No. CHR-NI-2016-0001 (2016).

global climate change (and the corresponding harmful impacts on lives and livelihoods), and that this knowing contribution constituted a violation of fundamental human rights.[639] The petition emphasizes the scientific basis for the claim, referring to scientific studies on climate change attribution as well studies on the emissions that can be attributed to the carbon majors. A joint summary brief submitted by a group of amici curiae in support of the petitioners contains an even more detailed overview of climate and attribution science, including the latest research on how climate change is affecting and will continue to affect the Philippines.[640] The joint summary brief was a collaboration between legal experts and climate scientists—the goal being to present a credible overview of the best available science in relatively straightforward terms. In December 2019, the Commission announced its finding that major fossil fuel companies can be held liable for climate change impacts and that existing civil law in the Philippines provided grounds for holding such companies criminally liable where there is clear proof that they have engaged in acts of obstruction, deception, or fraud.[641]

d. Concluding Notes on Tort Liability

The role of attribution science in climate torts is, at the moment, front and center in the public's eye. But our analysis is consistent with Professor Kysar's:

> Make no mistake: a conceivable set of arguments on behalf of climate change tort plaintiffs *does* exist. The problem, however, is that the winning scenario for most climate-related harms requires a court to stretch in plaintiffs' direction at nearly every stage of the traditional tort analysis: duty would have to encompass "negligence in the air," rather than more particularized relations of responsibility; nuisance would have to be interpreted as an absolute protection against significant invasions, irrespective of social welfare balancing; actual cause would have to embrace—at long last—a probabilistic, risk-

639. *Id.*

640. CENTER FOR INTERNATIONAL ENVIRONMENTAL LAW ET AL., JOINT SUMMARY OF THE AMICUS Brief CURIAE: IN RE: NATIONAL INQUIRY ON THE IMPACT OF CLIMATE CHANGE ON THE HUMAN RIGHTS OF THE FILIPINO PEOPLE (Mar. 19, 2018), https://www.ciel.org/philippines-joint-amicus [https://perma.cc/66P4-KBU7].

641. Press Release, CIEL, Groundbreaking Inquiry in Philippines Links Carbon Majors to Human Rights Impacts of Climate Change, Calls for Greater Accountability (Dec. 9, 2019).

> enhancement conception of causation; exceptional measures of apportionment would have to be invoked to address a multiple defendant problem of unprecedented magnitude; proximate cause would have to be interpreted such that the scope of foreseeable harm from greenhouse gas emissions both tracks projections from climate models that stand at the very forefront of scientific inquiry and, in many cases, applies retroactively as a form of imputed knowledge tantamount to strict liability; and harm would have to be expanded to include much more by way of anticipatory injury than courts currently recognize.[642]

Science can be used to support arguments but it does not necessarily answer fundamental questions over the appropriate logic of blame.

6. Lawsuits Involving Climate Change Impacts, Adaptation, and Risk Disclosures

Attribution science also plays a more limited role in lawsuits involving climate change impacts, adaptation, and disclosures about climate change-related risks. These include: (i) failure-to-adapt lawsuits, which involve allegations that an actor has failed to account for the effects of climate change and this resulted in an adverse outcome that would not have occurred if the actor had accounted for those effects, or else failed to develop adequate plans to prevent foreseeable adverse outcomes in the future;[643] (ii) lawsuits involving legal defense of adaptation measures;[644] (iii) lawsuits in which defendants seek to shield themselves from liability for climate-related harms by alleging that climate change, and not their own conduct, was responsible for those harms;[645] and (iv)

642. Kysar, *supra* note 555, at 44.

643. *See, e.g.*, ExxonMobil Complaint for Declaratory and Injunctive Relief and Civil Penalties at para 170; Conservation Law Found. v. Exxon Mobil Corp., No. 1:16-cv-11950 (D. Mass. Sep. 9, 2016); Complaint and Jury Demand, Conservation Law Foundation, Inc. v. Shell Oil Products US, No. 1:17-cv-00396 (D.R.I. Aug. 28, 2017). *See also* Jennifer Klein, *Potential Liability of Governments for Failure to Prepare for Climate Change*, SABIN CENTER FOR CLIMATE CHANGE LAW (2015); Jacqueline Peel & Hari M. Osofsky, *Sue to Adapt?,* 99 MINN. L. REV. 2177, 2193–95 (2015).

644. *See, e.g.*, cases cited *supra* note 643.

645. For example, utilities may cite climate change as a defense in wildfire litigation. *See* Mark Chediak, *Facing $17 Billion in Fire Damages, a CEO Blames Climate Change,* BLOOMBERG (August 13, 2018), https://www.bloomberg.com/news/articles/2018-08-13/facing-17-billion-in-fire-damages-a-ceo-blames-climate-change [https://perma.cc/9A38-YQUD].

lawsuits involving climate change-related risk disclosures in contexts, such as environmental reviews and financial statements.[646]

One critical question in such cases is whether the present or future effects of climate change are foreseeable. This bears on questions such as whether it was reasonable for a defendant to omit climate change-related risks from a security disclosure or an environmental report; whether it was reasonable for a defendant to ignore climate change-related risks in the approval, construction, or operation of a facility or development project; and whether it was reasonable for a government officer to impose new restrictions on private development due to climate change-related risks. For example, attribution science has been used in cases involving listing decisions under the U.S. Endangered Species Act ("ESA") to both justify listing decisions predicated on consideration of climate change-related risks to the species[647] and to compel consideration of climate change impacts where the government failed to do so in listing decisions.[648] Attribution science may also be used to

646. *See, e.g.*, AquAlliance v. Bureau of Reclamation, F. Supp. 3d 969 (E.D. Cal. 2018) (agency violated NEPA by failing to adequately assess climate change impacts on water supply); Sierra Club v. FERC, 867 F.3d 1357 (D.C. Cir. 2017) (agency violated NEPA by failing to adequately disclose GHG emissions from pipeline project); People of the State of New York v. Exxon Mobil Corp., N.Y. No. 452044 (Dec. 10, 2019) (Exxon did not violate Martin Act through public disclosures concerning how it accounted for past, present, and future climate change risks). *See also* Michael Burger & Jessica Wentz, *Downstream and Upstream Emissions: The Proper Scope of NEPA Review*, 41 HARV. ENVTL. L. REV. 109 (2017); Jessica Wentz, *Planning for the Effects of Climate Change on Natural Resources,* 47 ENVTL. L. REP. 10220 (March 2017); Jessica Wentz, *Assessing the Impacts of Climate Change on the Built Environment: A Framework for Environmental Reviews*, 45 ENVTL. L. REP. 11015 (2015).

647. *See, e.g.*, Alaska Oil & Gas Ass'n v. Pritzker, 840 F.3d 671 (9th Cir. 2016) (upholding NMFS's use of climate science in deciding to add Pacific bearded seal subspecies to endangered species list); Alaska Oil & Gas Ass'n v. Jewell, 815 F.3d 544, 558, 46 ELR 20042 (9th Cir. 2016) (upholding FWS's decision to account for climate change impacts in designating critical habitat for species); In re Polar Bear Endangered Species Act Listing & §4(d) Rule Litig., 794 F. Supp. 2d 65, 41 ELR 20318 (D.D.C. 2011), *aff'd*, 709 F.3d 1, 43 ELR 20132 (D.C. Cir. 2013) (upholding the polar bear listing); Ctr. for Biological Diversity v. Lubchenco, 758 F. Supp. 2d 945 (N.D. Cal. 2010) (upholding NMFS decision not to list ribbon seal as threatened or endangered despite climate-related threats).

648. *See, e.g.*, Defs. of Wildlife v. Jewell, No. 14-247-M-DLC, 2016 WL 1363865, at *20, 46 ELR 20070 (D. Mont. Apr. 4, 2016) (FWS failed to use best available science, including science on climate change, when deciding not to list wolverine as threatened); In re Polar Bear Endangered Species Act Listing §4(d) Rule Litig., 748 F. Supp. 2d 19, 30 (D.D.C. 2010) (holding that a species may be listed as "endangered" even if it is not in danger of imminent extinction, and remanding FWS's decision to list the polar bear as "threatened" rather than "endangered" for additional consideration of foreseeable future threats, particularly changes in future sea ice conditions); Ctr. for Biological Diversity v. Zinke, No. 3:18-cv-00064-SLG,

establish the extent to which anthropogenic climate change is the cause of harmful effects, which bears on the question of whether the defendant's failure to adapt actually caused or contributed to the plaintiff's alleged injury.

IV. FUTURE DIRECTIONS IN THE LAW AND SCIENCE OF CLIMATE ATTRIBUTION

As courts and policy-makers continue to grapple with appropriate responses to the increasingly urgent climate crisis, attribution science will continue to play a critical role in shaping discussions around responsibility and liability for climate change and its impacts. Here, we discuss future directions in the law and science of climate change attribution, addressing questions such as how attribution science might better support policy-making, planning and litigation; how plaintiffs might utilize attribution science in lawsuits against government and private defendants; and how defendants and courts might respond to the realities and limitations of climate attribution science. Some of these functions may be best performed by a third party organization that focuses on the synthesis and communication of scientific research, such as the Intergovernmental Panel on Climate Change.[649]

A. How Can Attribution Science Better Support Climate Law, Policy and Planning?

There are a variety of ways in which the scientific community could work towards supporting applications of attribution research, such as the use of this research to inform loss and damage negotiations and judicial determinations of liability for climate change impacts. These include: (i) continuing to lead the development of scientific knowledge and understanding by

2018 WL 8805325, at *1 (D. Alaska 2018) (challenging the determination that the listing of the Pacific walrus as endangered or threatened was not warranted).

649. The IPCC chapters on detection and attribution of climate change are a good example of how attribution research can be summarized, synthesized, and communicated in an accessible format. Krishna Mirle Achuta Rao et al., *Detection and Attribution of Climate Change: from Global to Regional*, *in* CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS 867–952 (2013). Other entities that are engaged in the synthesis and communication of attribution research include the World Weather Attribution (WWA) project and the Bulletin of Atmospheric Scientists (particularly in the publication of the annual reports on extreme event attribution).

advancing detection and attribution research across the board; (ii) generating attribution findings at different confidence levels to better communicate uncertainty about the "upper bound" and "lower bound" of plausible anthropogenic influence on an observed change; (iii) communicating findings clearly and in an accessible format; (iv) engaging stakeholders; and (v) linking individual studies to other advancing research areas that helps to flesh out the causal chain from emissions to impact.

1. Continue to Conduct Attribution Research on the Full Range of Climate Change Impacts With An Eye Towards Improving Confidence Levels and Certainty In Findings

The body of attribution research has grown considerably in recent years, increasing levels of confidence and certainty regarding a wide range of climate impacts at multiple political and geographical scales. Climate scientists pursuing their collective and independent research agendas have already established an undeniable connection between anthropogenic GHG emissions and climate change, and between climate change and slow onset impacts and the increasing frequency and intensity of certain types of extreme events, assuring that there is a sound scientific basis for collective action to address the climate crisis through mitigation and adaptation measures. More recent emphasis in relatively novel areas such as source attribution and single-event attribution has already helped inform progressive advocacy strategies. So, in an important sense, the single most important thing the scientific community can do to support applications of attribution research is *more of the same*.

Indeed, international and national policy initiatives, as well as lawsuits in the United States and elsewhere, have relied on existing attribution research to claim that climate change is responsible for a broad range of impacts, including coastal impacts from sea level rise, loss of snowmelt, declines in agricultural productivity, and declines in fishery productivity, among other things. To our knowledge, international coordination, domestic efforts, and climate change litigation have never failed due to a shortfall in the attribution science—even despite a concerted disinformation campaign that has reduced political support for ambitious climate action for the last quarter century.[650] In short, the scientific findings compiled to date are already well-suited to support climate law and policy.

Yet, there are gaps in coverage, particularly with respect to extreme events and impacts in developing countries and in areas where the observational record is not as robust and where funding for research may be more limited. Moreover, even where attribution research has been performed for a particular variable, the scope and scale of the study may be incompatible with real-world applications. Geographic and temporal scope are both relevant in this context. For example, loss and damage negotiations would benefit from research attributing impacts over a long timeframe within specific countries, whereas the plaintiffs in a case like *Juliana*[651] would benefit most from research attributing impacts on them as individuals, which requires more downscaling than a country-wide analysis and a more complete reckoning with confounding factors.

Going forward, litigants, policy-makers, and planners will benefit from attribution research on all impacts and at all scales from the global to the highly individualized, the goal being to improve confidence levels and certainty in findings. It will be helpful for scientists to generate additional findings for slow-onset impacts such as sea level rise, temperature changes, ocean acidification, and desertification, as well as extreme events such as precipitation, heat, and wildfire. It would additionally be beneficial to work towards quantifying actual impacts or harms on communities and individuals.

The scientific community could work with affected stakeholders to address the incomplete coverage of attribution science and identify priority areas for research. Granted, working with affected people to determine what variables to focus on in attribution studies could contribute to concerns about selection bias (i.e., the bias introduced when data is selected for research without proper randomization). This practice could result in a larger proportion

650. *See* Fossil Free MIT, *The Fossil Fuel Industry's Role in Hindering Climate Change Action: Lobbying and Disinformation Against Science and Scientists* (April 2014) https://www.fossilfreemit.org/wp-content/uploads/2014/08/FossilFreeMIT-Lobbying-Disinformation.pdf [https://perma.cc/X8DD-S6ED]; Union of Concerned Scientists, *Climate Disinformation*, https://www.ucsusa.org/climate/disinformation [https://perma.cc/4976-NSKS].

651. 339 F. Supp. 3d 1062.

of attribution studies that focus on events or impacts with a clear connection to climate change than a purely random sampling of events and impacts. As such, scientists may need to be cautious about any overarching statements made with respect to the body of attribution research. But scientists are already cautious about making such statements,[652] and such concerns about selection bias would not undermine the credibility of the individual studies being performed.

2. Generate Findings at Different Confidence Levels

As discussed in Part II, attribution findings are often expressed in terms of probabilities and confidence levels. For example, an IPCC report might conclude with "high confidence" (80%) that a particular impact was "very likely" caused by anthropogenic climate change, or a probabilistic event attribution study might find with > 90% confidence that anthropogenic climate change quadrupled the risk of a particular storm occurring. These are compelling statistics, but depending on the application, it may also be helpful for researchers to also discuss lower-bound, higher confidence estimates (e.g., > 95% confidence that anthropogenic climate change at least doubled the risk of that same storm occurring) or higher-bound, lower confidence estimates (e.g., > 80% confidence that anthropogenic climate change made the storm at least six times more likely). Lower-bound estimates with higher confidence levels would be more useful for applications where certainty in findings is needed, such as litigation seeking to hold fossil fuel companies liable for their contribution to climate change. Upper-bound estimates with lower confidence levels would be more useful in policy and planning applications where decision-makers would benefit from understanding the potential extent of anthropogenic influence on an observed change but certainty about that data is less important.

There is an inevitable tradeoff between the level of confidence in findings and the magnitude of the "human fingerprint" identified in an attribution study. Scientists can issue higher confidence findings that anthropogenic climate change contributed "at least" a certain amount to the probability or magnitude of an event without

652. *See, e.g.*, BAMS 2016, *supra* note 76 (studies contained within these reports contain clear explanations of research parameters and uncertainty).

ruling out the possibility that the effect of anthropogenic climate change was actually much larger. Again, discussing both lower and upper bound estimates in this context is helpful for navigating uncertainty and clarifying findings. Consider the study of the 2003 European heat wave: Stott et al. (2004) found that it was very likely (confidence level > 90%) that anthropogenic climate change had at least doubled the risk of a heat wave of the sort experienced that summer (FAR = 0.5), but they also noted that the anthropogenic FAR could be substantially greater and that their "best estimate" was that climate change had increased the risk by a factor of four (FAR = 0.75) (no confidence interval was specified for this estimate, but it was clearly lower than 90%).[653] Without that additional information, a reader might assume that the FAR = 0.50 is the "best estimate" of the human fingerprint in this study, and without the more conservative FAR estimate, the findings might not hold up to scientific (or judicial) scrutiny.

This same approach could also be implemented in the context of a storyline or mechanistic study. For example, a storyline evaluation of a tropical storm might generate several findings at different confidence intervals (e.g., >95% chance that climate change increased the magnitude of a storm by at least 30%, >90% chance that climate change increased the magnitude of the storm by at least 40%, and >80% chance that climate change increased the magnitude of the storm by at least 50%).

3. Clearly Communicate Findings

Most attribution studies are written for a scientific audience, and the findings contained therein can be difficult to understand for people who lack expertise with terminology and concepts such as confidence intervals and p-values. These studies are sometimes "translated" for a broader audience, often by journalists, but when non-scientists summarize scientific findings there is a greater risk that complex topics will be over-simplified or inaccurate conclusions will be drawn from the research. For this reason, it is helpful for the scientists conducting the research to present their findings in a clear and accessible fashion, to the extent practicable.

Marjanac et al. (2017) highlight several best practices for communicating attribution science to courts, but their

653. Stott et al., *supra* note 153.

recommendations apply in equal force to communication with policy-makers, planners, companies, and the public at large:

> (i) areas of agreement should be clearly stated before discussion of areas of disagreement; (ii) methodology and results should be quantitatively and qualitatively transparent to enable interpretation and assessment of credibility by the courts; (iii) assumptions and uncertainties should be stated in a simple, concise and transparent manner; and (iv), results should discuss implications for foreseeability; that is, whether and to what extent a study can opine on the impact of anthropogenic emissions on the future likelihood of occurrence or severity of the event.[654]

An oft-lamented reality is that in communicating uncertainty, bias, and other limitations in their research, scientists risk giving the impression that the research is not credible or accurate. Careful communication of these concepts is also important to protect the credibility of the research against external attacks by parties antagonistic to climate action, or else defending themselves in lawsuits. Generally speaking, careful communication involves providing context for statements about uncertainty, bias, and limitations to help a non-scientific audience understand: (i) whether the level of uncertainty, bias, etc. is standard or unusual as compared with similar studies; and (ii) the effect of uncertainty and bias on the reliability and accuracy of the results. Scientists should also be careful not to overstate the novelty of this field—while attribution science is undergoing constant evolution, the vast majority of studies published in this field are based on well-established scientific techniques, carefully tested models, and detailed observational sets.

4. Engage with Stakeholders

Clear communication of findings is an important first step towards promoting the real-world application of attribution science; engagement is critical to successful communication, and to growing the impact of attribution research. Various researchers have already highlighted the need for dialogue between scientists and stakeholders on climate change science and attribution

654. Sophie Marjanac et al., *Acts of God, Human Influence and Litigation*, 10 NATURE GEOSCIENCE 616 (2017).

research to ensure practical relevance of this research.[655] Weaver et al. (2013) describe the importance of active-learning feedback loops—that is, processes which allow for policy-makers and other stakeholders "to communicate back to scientists any concerns, misunderstandings, relevance, or timeliness of the issues."[656] This type of co-generation of knowledge has played a central role in climate risk assessments, such as those conducted by the New York City Panel on Climate Change.[657] Some of the lessons learned from these co-generation efforts (e.g., risk management frameworks, focusing on the decision-needs of stakeholders, inclusion of social scientists and boundary spanners in the process, and working through existing, trusted networks) will help ensure attribution research is as impactful as possible. Given the expertise about impacts that resides with stakeholders, deeper stakeholder engagement can also be expected to lead to scientific advances not only in attribution science for decision-making, but also for attribution science itself, especially with respect to attribution of impacts. For example, a stakeholder engagement process with water managers encouraged attribution scientists to focus on a broader set of event metric definitions, including the duration of rain events, in order to make their research more relevant for decision-makers and sector experts.[658]

5. Link Individual Studies to Related Research To Help Flesh Out the Causal Chain from Emissions to Impact

Most attribution studies only focus on one part of the causal chain linking emissions and land use changes to impacts. To the extent that the scientists working on these studies are aware of related research, it would be helpful for them to explicitly discuss this research and explain how it ties into their own findings. For example, a study attributing specific impacts to increases in

655. *See, e.g.*, Sippel et al., *supra* note 111; Christopher P. Weaver et al., *Improving the Contribution of Climate Model Information to Decision-Making: The value and Demands of Robust Decision Frameworks*, 4 WIREs CLIMATE CHANGE 39 (2013); Hannah Parker et al., *Using a Game to Engage Stakeholders in Extreme Event Attribution Science*, 7 INT'L J. DISASTER RISK SCI. 353 (2016).

656. Sippel et al., *supra* note 111, at 225 (citing to Weaver et al., *supra* note 655).

657. *See, e.g.*, Cynthia Rosenzweig & William Solecki, New York City Panel on Climate Change, *Special Issue: Advancing Tools and Methods for Flexible Adaptation Pathways and Science Integration Policy* (The New York Academy of Sciences 2019).

658. Julie A. Vano et al., *Hydroclimatic extremes as challenges for the water management community: Lessons from Oroville Dam and Hurricane Harvey, in* BAMS 2016, *supra* note 76.

extreme heat could cite external studies demonstrating the link between increases in extreme heat and anthropogenic forcing on climate. Researchers and scientific organizations could also publish more synthesis reports linking individual studies and explaining the extent to which these studies, in aggregate, can support claims of end-to-end attribution. Where possible, it would be helpful to harmonize the scope and scale of connected studies such that the quantitative analyses conducted in one study can flow through and inform the quantitative analysis in the subsequent study, with the goal being to develop robust, quantitative findings across a larger section of the causal chain. More fundamentally, further standardization of attribution research—ranging from the selection of topics to study, to the metrics used, and the data and models brought to bear—will support cross-comparison, evaluation, and scaling up of findings across studies.

B. How Might Judges and Litigants Utilize Attribution Science in the Courtroom?

The IPCC's *Special Report on the Impacts of Global Warming of 1.5°C* highlights the necessity of achieving rapid GHG emission reductions in the immediate future.[659] With temperatures having already increased by approximately 1°C and many national governments failing to make the necessary cuts in GHG emissions, legal intervention and innovation may be necessary in order to avert catastrophic climate change. This raises the question of how judges and litigants can best utilize attribution science to help argue and decide cases, particularly those involving claims that a government or private actor should be held accountable for their contribution to or failure to regulate GHG emissions. Below, we discuss some approaches and legal innovations that could provide for a more robust assessment and application of attribution science in the courtroom.

1. Standing and Justiciability

The single greatest obstacle to the effective utilization of attribution science in the courtroom is the fact that climate cases raising complex attribution issues may be dismissed or decided

659. IPCC, SPECIAL REPORT: GLOBAL WARMING OF 1.5°C (Valerie Masson-Delmotte et al. eds., 2018).

without a trial, meaning that their scientific bases may never fully assessed and adjudicated. As discussed in Part III, the main reasons for dismissal are lack of standing, the political question doctrine, the doctrine of legislative displacement, and the doctrine of foreign affairs preemption.

With regards to standing, some courts have recognized that the questions implicated in the standing analysis are heavily fact dependent and tend to overlap with the merits of the case.[660] But other courts have denied standing based on a cursory assessment of these scientific questions, finding without trial that the causal connection between emissions and injury is too attenuated.[661] Plaintiffs should not be denied their day in court based on judicial hunches about the state of the science. Standing claims involving disputed facts should be addressed after discovery, when all issues are fully briefed and all evidence is submitted.[662] For example, the questions of what constitutes a "meaningful contribution" to GHG emissions and whether a court can provide meaningful relief should be considered factual issues to be evaluated at the merits stage.[663] The Second Circuit in *American Electric Power,* the Fifth Circuit Court in *Comer,* and the district court in *Juliana* all endorsed this approach.[664]

Some scholars have also recommended specific analytical techniques that are uniquely well-suited for assessing standing claims in cases involving climate change-related claims. For example, scholars have recommended that courts recognize that the risk of harm is itself an injury that can provide the basis for standing.[665] This would bear on how the courts interpret the

660. Juliana v. United States, 217 F. Supp. 3d 1224, 1242–1248 (D. Or. 2016). *See also* Meier, *supra* note 600, at 1248–49 (noting that the standing analysis involves many assumptions and speculation, fact-intensive inquiry, competing experts, and weighing of evidence).

661. *See, e.g.*, Native Vill. of Kivalina v. Exxon Mobil Corp., 663 F. Supp. 2d 863, 880 (N.D. Cal. 2009).

662. Causation in Environmental Law, *supra* note 591, at 2270–71; Meier, *supra* note 600, at 1265 ("the fact-specific nature of the cause in fact inquiry makes it difficult to conduct this inquiry at the threshold of litigation, and thus it is irreconcilable with the gatekeeper function of standing").

663. *See supra* Part III(C)(5).

664. *See supra* Part III(C)(1)(b).

665. Hessick, *supra* note 353, at 67–68 (arguing that all claims based on a risk of injury present an actual case or controversy that should be justiciable, no matter how small the risk, and that the "substantial risk" requirement is directly at odds with holdings that the size of the harm is irrelevant to whether a plaintiff has standing, since the risk itself is an injury);

"injury-in-fact" requirement for future harms (e.g., in cases where attribution science is primarily used to support model projections of those future harms). It may also bear on how courts interpret the causation and redressability requirements. For example, in cases involving procedural harms, the "harm" is really an increased chance of substantive harm in the future, and courts adjust their standing analysis to accommodate such harms by relaxing requirements for imminence and redressability.[666] There is some judicial precedent to support such an approach.[667]

Another approach could be to allow "fractional standing" for probabilistic injuries.[668] According to one commentator, a "fractional injury" is "one that, if manifest in one individual, would be insufficient to grant standing" but if "multiple individuals experience this injury and band together to demand relief . . . then their collective grievance would be sufficient to merit standing."[669] Fractional standing involves looking at the probability of the harm, the severity of the harm, and the number of people at risk and determining whether the aggregate harm is sufficient to grant

Lin, *supra* note 603 (involuntary risk is a harm); Sunstein, *supra* note 603 (arguing that an increased probability of harm is itself an injury-in-fact that should suffice for standing purposes in cases that involve public law claims); Claire Finkelstein, *Is Risk a Harm?* 151 U. PENN. L. REV. 963 (2003) (arguing that risk of harm is itself a harm); Meier, *supra* note 600, at 1288–91 (noting there is some precedent for this approach); Robinson, *supra* note 588, at 783 (explaining why the "basic objectives of tort law are better served if liability is based on risk of injury than if it is based on the actual occurrence of harm").

666. Burt, *supra* note 353, at 280 (citing Sierra Club v. Marsh, 872 F.2d 497, 500 (1st Cir. 1989) (Judge Breyer clarified that the underlying harm in procedural injury cases is not the "harm to procedure," but the increased risk of substantive harm (to the environment, for example) that occurs when procedures are not followed.). *See also* Hessick, *supra* note 353, at 69 (In procedural cases, "it is clear that the injury is *not* the effect of the agency action on the plaintiff" because the redress that a court could provide (making the agency follow proper procedures) will not necessarily remedy that injury. Rather "the relevant injury that is redressed in a procedural claim is the increased probability of harm.").

667. *See Duke Power Co.* 438 U.S. 59 at 73–74 (holding apprehension caused by risk of harm caused by radiation exposure was sufficient for standing); Covington v. Jefferson Cty., 358 F.3d 626, 641 (9th Cir. 2004) (holding fear that leaking hazardous material would contaminate property was sufficient for standing); Suttin v. St. Jude Med. S.C., Inc. 419 F.3d 568, 575 (6th Cir. 2005) (holding increased risk of future physical injury from the implantation of an allegedly defective device constituted injury-in-fact); Baur v. Veneman, 352 F.3d 625, 633 (2d Cir. 2003) (holding enhanced risk of disease transmission may constitute injury-in-fact); Friends of the Earth, Inc. v. Gaston Copper Recycling Corp., 204 F.3d 149, 160 (4th Cir. 2000) ("Threats or increased risk . . . constitute[] cognizable harm.").

668. Daniel E. Rauch, *Fractional Standing*, 33 YALE J. ON REG. 281 (2016).

669. *Id.* at 282.

standing.[670] The D.C. Circuit implicitly endorsed this approach in *Natural Resources Defense Council v. EPA*, discussed above.[671]

With regard to the other justiciability issues raised by courts, judges may be relying on overly broad applications of general principles, such as the separation of powers, and legal doctrines, such as political question or foreign affairs preemption, to dismiss cases involving climate claims. There are, of course, many potential reasons for judicial caution in this context. Regulation has been viewed as a more appropriate response to climate change than court intervention. It is argued that democratically elected officials and technically sophisticated bureaucrats should be making policy decisions that involve complex scientific determinations, economic tradeoffs, and difficult ethical questions. There are also concerns about opening the "floodgates" to litigation. Even with robust evidence of attribution, courts may be hesitant to adjudicate claims against governments or private actors given that the numbers of potential claimants and defendants in public trust and tort actions as well as the scope of potential court decisions and the scale of potential compensation awards are huge.

But there are important counterpoints to these arguments. First, as plaintiffs in the atmospheric trust litigation,[672] the cities' tort cases,[673] and numerous statutory cases[674] argue, these climate cases arguably fall neatly within courts' core areas of competence and well-settled legal causes of action. The scale of the problem is not a reason, in and of itself, for courts to refuse to engage in its solution. Second, there is a large gap between the level of action taken by political branches of government and the level of action needed to avert the worst impacts of climate change. Courts do have a role in policing government failures to protect people's rights, whether those be fundamental rights secured under the Constitution or a public trust inherent in our nation's and states' democracies, or substantive and procedural rights provided under statute. Finally, there is an expressive function the law can and arguably should serve. Put simply, the world will experience catastrophic climate change if we continue a business-as-usual trajectory. Judicial

670. *Id.* at 290–91.
671. *See supra* Part III(C)(1)(a)(iv).
672. *See supra* Part III(C)(3)(b).
673. *See supra* Part III(C)(5).
674. *See supra* Part III(C)(3)(a).

intervention at this time could help change our course by sending important messages to governments and private actors about responsibility for climate change, unearthing facts which will advance public discourse on this topic, and in some cases compelling action that is needed to mitigate and adapt to climate change.

2. Factual and Proximate Causation

As illustrated in Part III, some judges have expressed skepticism about whether plaintiffs pursuing climate change-related claims can establish an adequate causal nexus between the defendant's conduct and their injuries as necessary to support standing and their arguments on the merits. However, recent cases provide valuable insight into how attribution science can be used to establish both factual and proximate causation in these cases.

a. Defining Parties' Contributions to GHGs

The first step in determining whether a party is a legally relevant cause of damages associated with climate change is to define that party's contribution to increases in atmospheric GHG concentrations. Some form of quantification is necessary to establish both factual cause and proximate cause. Above, we note that there are several legal tests for determining whether a party's contribution to a larger problem is a factual cause of that problem, most of which focus on the relative size of that contribution as compared with others (e.g., whether the party made a "material contribution" to the problem).[675] Quantifying the party's GHG contribution is essential to applying these tests. As for proximate cause: the question here is whether the injury is sufficiently closely related to the allegedly wrongful conduct such that it would be reasonable to impose liability. Again, the size of the emissions contribution is relevant to this inquiry.

675. We do not mean to imply that these relative share tests are the only appropriate means of ascertaining factual causation. A court could conclude that even a small contribution to GHG emissions is a factual cause of at least some of the harmful effects of climate change. The concern, of course, is that imposing liability on small contributors would open the floodgates to litigation. But a court pursuing this approach could also rely on the proximate cause requirement to conclude that it would be unreasonable to impose liability for such a small contribution.

Defining a party's GHG contribution is not as straightforward as one might like. There may be data gaps that preclude accurate quantification. Even where adequate data exists, there are inevitably analytical questions that must be answered, such as which emissions accounting approach to use—territorial, consumption-based, or extraction-based—and how to account for historical as compared with present (and possibly even future) emissions. Lawyers and judges can turn to source attribution science to understand the relative contribution of sources under different accounting methods at different temporal scales.

Several of the cases brought to date illustrate how litigants and courts might use source attribution data to define GHG contributions:

> In *Urgenda*, the Supreme Court of the Netherlands used the Dutch national emissions inventory to define that country's GHG contribution and relied on scientific research on the global carbon budget to define its corresponding emissions reduction obligation. Specifically, the court referred to UNFCCC decisions finding that industrialized countries must reduce emissions 25–40% below 1990 levels by 2020 to limit global warming to 2°C, which was in turn based on IPCC reports outlining possible global emission reduction pathways for achieving this target.[676] The court also discussed reports which corroborated Urgenda's assertion that the Dutch government must reduce emissions by at least 25% in this timeframe, including UNEP Emissions Gap reports which found that industrialized country commitments were insufficient to limit warming to 2°C or 1.5°C, a report prepared by the PBL Netherlands Environment Assessment Agency finding that Dutch policy must be more ambitious to align it with the Paris Agreement, and data showing that Dutch per capita emissions were "relatively high" compared to other industrialized nations.[677]

The expert reports compiled in *Juliana* illustrate, among other things, how parties can disaggregate government responsibility for GHG emissions based on authorities and decisions. For example, plaintiffs provided a counterfactual scenario in which they estimated emission reductions that would have occurred if the government had pursued a certain course of action to address

676. *Urgenda* Decision (2019) at ¶¶ 7.1-7.3.6.
677. *Id.* at ¶¶ 2.2.2, 4.6, 7.3.4, 7.4.4, 7.2.9.

climate change in the past, in order to delimit the fact of government responsibility, while also presenting estimates of total emissions from energy emissions within the U.S. *and* data on potential emissions from U.S. energy exports and consumption.[678] Defendants, naturally, contested that scenario with their own experts, who argued that the U.S. government cannot be held responsible for all emissions generated within the U.S. (or by products consumed within the U.S. or fossil fuels extracted within the U.S.), and who estimated that U.S. government conduct is responsible for no more than 4–5% of total global emissions.[679] In denying the defendants' motion for summary judgement, the district court found that the pleadings submitted by both parties "make clear that plaintiffs and defendants agree that federal defendants' policies greenhouse gas emissions play a role in global climate change" even if there was a dispute as to extent of that role.[680] With regards to the quantity of emissions attributable to the U.S. government, the district court focused on the defendants' admissions regarding total U.S. emissions (e.g., defendants admitted in their answer that the U.S. is responsible for more than 25% of cumulative global CO_2 emissions from 1850 to 2012) and noted that this was much greater than the 6% of global emissions at issue in *Massachusetts*.[681] The judge did not explicitly rule on whether all cumulative U.S. emissions could be attributed to U.S. government conduct, but she did discuss the many lines of evidence demonstrating a causal connection between U.S. policies and third party emissions and found this sufficient to support causation for standing purposes at the summary judgement stage.[682]

The plaintiffs in *Juliana* also argued that territorial, consumption-based, *and* extraction-based accounting methodologies should be considered in determining the government's GHG contribution and corresponding responsibility for climate change. In their complaint, they relied primarily on estimates of cumulative

678. See *supra* Part III(C)(3)(b)(i).
679. *Id.*
680. Juliana v. United States, 339 F. Supp. 3d 1062, 1072 (D. Or. 2018).
681. *Id.* at 1092.
682. *Id.* at 1093. *See also* Juliana v. United States, 217 F. Supp. 3d 1224, 1246 (D. Or. 2016) ("DOT and EPA have jurisdiction over sectors producing sixty-four percent of United States emissions, which in turn constitute roughly fourteen percent of emissions worldwide; they allow high emissions levels by failing to set demanding standards; high emissions levels cause climate change; and climate change causes plaintiffs' injuries.").

territorial emissions to support their allegations, and then supplemented this with additional emissions attributable to U.S. consumption of fossil fuels and U.S. fossil fuel exports. As discussed in Part III, they also enlisted an expert to provide a detailed comparison of U.S. emissions under the three accounting approaches and to explain why the U.S. government should maintain consumption-based and extraction-based inventories in addition to a territorial inventory.[683] This "all-of-the-above" approach makes sense for the purposes of establishing national responsibility for climate change as a general matter or in qualitative terms. But in calculating a national and global emissions inventory and budget for the purpose of setting policy, one methodology must dominate, to avoid double and triple counting of emissions. Recognizing this, the plaintiffs in *Juliana* focused on consumption-based emissions in their requested remedy: they sought a court order compelling the U.S. government to "prepare a consumption-based inventory of U.S. CO_2 emissions" accompanied by an enforceable plan to phase out fossil fuel emissions and draw down excess atmospheric CO_2.[684] The defendants did not strongly object to a consumption-based accounting approach in their reply briefs (as their primary argument was that the U.S. government should not be held accountable for all U.S. emissions no matter what accounting approach is used), but one of their experts did express the view that transitioning to a consumption-based accounting system might be infeasible or difficult to implement.[685]

Other lawsuits rely on different emissions accounting methodologies. There is no strict requirement that different courts addressing different types of legal claims, in different jurisdictions, use the same accounting methods to impose responsibility on entities; it may well be that climate litigation results in two different parties being held responsible for the same emissions. However, while this may not strangle the litigation, it can raise concerns

683. *See* supra Part III(C)(3)(b)(i).

684. Amended Complaint, Prayer for Relief, at 94, Juliana v. United States, 217 F. Supp. 3d 1224 (D. Or. 2016) (No. 6:15-cv-01517-TC).

685. Expert Report of David G. Victor at 4, Juliana v. United States, 217 F. Supp. 3d 1224 (D. Or. 2016) (No. 6:15-cv-01517-TC) ("with respect to claims regarding the use of consumption-based accounting methods for 95 GHGs, it is my expert opinion that such methods are neither administratively, nor politically 96 straightforward to implement quickly.").

about fairness, justice, and the efficiency of the judicial system. For instance, in the lawsuits against fossil fuel companies, plaintiffs focus on extraction-based emissions, primarily relying on estimates of cumulative fossil fuel production to establish that the companies they are suing have made a "substantial contribution" to climate change.[686] In response, the defendants have argued that plaintiffs are seeking to evade precedent holding that the federal government's Clean Air Act authority displaces nuisance claims based on GHG emissions by focusing on the extraction of fossil fuels rather than consumption. The federal district court in California, in denying motions from San Francisco and Oakland to remand their cases back to state court, expressed agreement with defendants, stating that plaintiffs seek to avoid federal common law by "fixat[ing] on an earlier moment in the train of history, the earlier moment of production and sale of fossil fuels, not their combustion."[687] Relatedly, the district courts in both the Oakland case and in the New York City case dismissed the cases, in part, due to the extraterritorial implications of imposing liability for the extraction of fossil fuels and their belief that this would infringe on the foreign affairs power of the executive and legislative branches of government.[688] It remains to be seen whether other judges overseeing these lawsuits will adopt a similar perspective on the extraterritorial effects of holding fossil fuel companies liable for their contribution to climate change.

These cases also illustrate how other types of information are relevant to the analysis of proximate cause and supplement attribution data. Some of the normative considerations relevant to the proximate cause inquiry include the extent to which the company profited from the production and eventual use of fossil fuels, whether the company knew that it was producing and selling a harmful product, and whether the company engaged in unethical activities such as the obstruction of climate change science.[689]

686. *See supra* Part III(C)(5).

687. Order Denying Motion to Remand at 6, California v. BP P.L.C., (N.D. Cal. Feb. 27, 2018) (No. C 17-06011 WHA).

688. City of Oakland v. BP P.L.C., 325 F. Supp. 3d 1017 (N.D. Cal. 2018); City of New York v. BP P.L.C., 325 F. Supp. 3d 466 (S.D.N.Y. 2018).

689. The UCS publishes reports on "climate accountability" at fossil fuel companies in which it assesses companies based on these sorts of criteria. *See, e.g.*, *The Climate Accountability Scorecard,* UNION OF CONCERNED SCIENTISTS, (Oct. 23, 2018), https://www.ucsusa.org/global-warming/fight-misinformation/climate-accountability-scorecard-ranking-major-fossil-fuel-companies#.W_L31ZNKhaR [https://perma.cc/5K7X-VK9K].

Recognizing this, plaintiffs in lawsuits against fossil fuel companies have framed the allegedly tortious conduct in their complaints broadly, focusing not only on the companies' production and sale of fossil fuels, but also the fact that they knew about the potential harms of their products many years, actively concealed that information, pursued climate change disinformation campaigns, and lobbied against climate change regulations.[690] Plaintiffs in *Juliana* also touched on some similar arguments in their complaint, noting, for example, that the U.S. government "acted with deliberate indifference" when it ignored expert reports urging it to take immediate action on climate change in the early 1990s.[691]

Countries and companies may claim that they cannot be held responsible for emissions before the early 1990s because that was when the IPCC first warned the world about climate change and the UNFCCC first committed to take action to address the problem. Recognizing this, some plaintiffs, like those in *Juliana*, have focused on emissions since 1990 as the primary basis for their claims.[692] However, scholars have compiled a wealth of evidence from the 1960s, 1970s, and 1980s that put countries and companies on notice about the harmful effects of GHG emissions and the perils of climate change.[693] Plaintiffs in tort cases against fossil fuel companies rely on evidence showing that fossil fuel companies have known about the risks of their products since the 1950s to establish that they can be held responsible for historical emissions, but the plaintiffs also emphasize the point that most fossil fuel emissions have accumulated since 1980, at which time the industry already knew that their products posed a "catastrophic" threat to the global climate.[694] Given the level of industry knowledge regarding the harms of their products and the intentional concealment of these risks, some plaintiffs in these cases have also argued that companies

690. *See supra* Part III(C)(5).

691. Complaint for Declaratory and Injunctive Relief ¶ 8, Juliana v. United States, 217 F. Supp. 3d 1224 (2015) (No. 6:15-cv-01517-TC), 2015 WL 4747094.

692. First Amended Complaint, ¶¶ 141, 151, Juliana v United States, 217 F. Supp. 3d 1224 (2015) (No. 6:15-cv-01517-TC) (plaintiffs in *Juliana* also present data on historical emissions since the 1700s and cite evidence of the U.S. government knowing about the dangers of climate change as far back as 1965 to further bolster their claims).

693. Heede, *supra* note 31.

694. *See, e.g.*, Complaint for Public Nuisance ¶ 61, State of California v. BP P.L.C., No. CGC-17-561370 (filed Cal. Super. Ct., Sep. 19, 2017).

should be held strictly liable for failure to warn and for design defect.[695]

b. Establishing Causal Connections to Impacts

The cases litigated to date demonstrate that attribution science is sufficiently robust to establish causal connections between increases in GHG concentrations, global warming, and a broad range of on-the-ground impacts and harms. This is not to say *all* impacts of climate change can be definitively linked to anthropogenic influence on climate—but there is a sufficiently large subset of impacts that can be attributed with enough confidence to support litigation in one form or another. These include, for example, sea level rise, melting snowpack, increases in average temperatures and extreme heat, and ocean acidification.

The analysis in cases like *Massachusetts* and *American Electric Power* suggests that it should be relatively easy for entities like states, tribes, and cities to establish a causal connection between climate change and at least some injuries associated with it. This is not merely because of their sovereign status—it is also because these entities represent many people and assets and will experience greater harms from climate change as a result of the breadth of their interests. The same can be said for trade organizations, environmental groups with large memberships, and other non-governmental entities that represent many individuals.

Juliana illustrates some of the challenges plaintiffs may face in establishing a causal connection to individual injuries. As discussed in Part III, the plaintiffs dedicated a large portion of their briefs and expert testimony to defining that causal nexus between climate change and specific injuries, and if the case had gone to trial, this would have been one of the key factual disputes. One critical question for courts as they begin to grapple with such factual disputes is to what extent observational evidence of local impacts (e.g., loss of snowpack at ski resorts) can be used to support claims of injury in the absence of an attribution study of a matching geographic and temporal scope showing that the observed impact was caused by anthropogenic influence on climate change. The answer to this question of course depends on context, but generally

695. *See, e.g.*, Complaint, Richmond v. Chevon et al., No. C18-00055 (filed Cal. Super. Ct., Jan 22, 2018).

speaking, such observational evidence should be interpreted in light of the larger body of attribution research and assigned weight accordingly. For example, if plaintiffs submit evidence that anthropogenic influence on climate is driving snowpack declines throughout the Northern Hemisphere, then it would be reasonable to infer that the observed declines in snowpack at particular resorts in North America have also been caused by anthropogenic influence on climate even without a radically downscaled attribution study for those resorts.

We recognize that in cases like *Kivalina* and *Bellon*, courts have expressed doubt about whether it is possible to trace emissions from a particular source to specific impacts due to the nature of climate change. But if this argument was taken to its extreme, then no one could be held responsible for climate change. From a technical standpoint, given that GHG emissions disperse throughout the atmosphere and have a relatively uniform effect, it would be more accurate to say that *all* emissions can be traced to impacts. And as discussed below, the emissions contribution of a party can be used as a proxy for its contribution to an impact.

Litigants and courts should be aware of both the strengths and limitations of attribution science when framing and analyzing arguments. Plaintiffs may prove most successful where they base their claims on impacts which can be attributed to anthropogenic climate change with high confidence, such as sea level rise, melting snowpack, increases in average temperatures and extreme heat, and ocean acidification. Plaintiffs may also prove most successful where they rely on expert reports and peer-reviewed attribution studies and avoid making causal inferences even for those impacts for which there is a very robust connection to anthropogenic climate change. Judges, meanwhile, should be mindful of the fact that there are different levels of confidence for different impacts, pay close attention to the evidence submitted, and should not dismiss claims based on generalized conclusions about the uncertainty of the science. Judges should also be aware that, when translating global or regional impacts to specific injuries, it may be necessary to accept causal inferences, as with the snowpack example presented above.

3. Proving and Defending against Obligations and Redressability

Few jurisdictions have addressed in even a preliminary way critical questions regarding the scope and extent of private and governmental obligations to address climate change. As discussed above, there is some precedent affirming national obligations in other jurisdictions (e.g., *Urgenda*), but no U.S. court has yet found that the federal government is bound to any particular level of climate ambition. Recall that *Massachusetts* held that EPA had failed to justify its decision not to issue GHG regulations for motor vehicles; it did not mandate that EPA actually issue the regulations, far less that it issue regulations achieving one or another standard.[696]

Urgenda illustrates how attribution science can be used to help establish national emission budgets. Source attribution data is constantly improving and estimates of carbon budgets are constantly being revised in light of new emissions data, so it will be important for litigants and courts to rely on the most recent data in framing carbon budgets.[697] The understanding that carbon budgets are a moving target could also factor into the remedy prescribed by courts in cases like *Urgenda*. For example, rather than mandating a government achieve a specific target on a specific date, a court could require the government to establish and periodically update its target based on the best available science. Attribution science could also be used to define more specific obligations for national governments, such as obligations pertaining to fossil fuel development and subsidies (source attribution data on extraction emissions would be particularly relevant here). For example, in the Colombian case holding that the government violated fundamental rights by failing to address the risks posed by climate change, the court relied on research showing the contribution of deforestation to climate change in determining that the Colombian government had an obligation to protect, conserve, maintain, and restore the portion of the Amazon forest located within Colombia.[698] In particular, the court cited: (i) estimates from Colombia's Institute of Hydrology, Meteorology,

696. *See supra* Part III(C)(3)(a)(i).
697. *See* discussion *supra* Part II(B)(4).
698. Corte Suprema de Justicia [C.S.J.] [Supreme Court], April 5, 2018, STC4360, No. 11001-22-03-000-2018-00319-01 (Colom.), http://climatecasechart.com/non-us-case/future-generation-v-ministry-environment-others/ [https://perma.cc/53WU-NLJK].

and Environmental Studies (IDEAM) finding that the increase in GHG emissions resulting from deforestation in the Amazon forest would generate an increase in Colombia's temperature by 0.7–1.1°C between 2011 and 2040, by 1.4–1.7°C between 2041 and 2080, and by as much as 2.7°C between 2017 and 2100; (ii) qualitative findings from IDEAM that the GHG increase from deforestation would also result in more precipitation in some areas and less precipitation in other areas, potentially exacerbating problems such and pollutant loadings (during wet periods) and drought; and (iii) a government report finding that reducing deforestation to zero by 2020 would ensure that "44 megatons of greenhouse gases would not enter the atmosphere."[699]

In establishing obligations for private actors, one critical question will be how to allocate liability and damages among multiple companies. The plaintiffs in *RWE* have already provided the courts with one possible approach: they are seeking damages that are proportionate to the company's individual GHG contribution (thus pursuing several liability). The municipal plaintiffs suing fossil fuel companies have pursued a slightly different approach, seeking to hold these companies jointly and severally liable for their aggregate contribution climate change. Judges may view joint and several liability as a slippery slope in this context, given that there are so many potential defendants who could be joined in these cases. Another alternative would be to hold upstream manufacturers liable for the production and sale of harmful products under a market share theory of liability (e.g., apportioning liability among fossil fuel companies based on their share of fossil fuel sales).[700]

Arguably, imposing several liability based on the party's proportionate contribution to GHG increases is the approach which best reflects the party's "true" contribution to climate change impacts. A market-share approach would also accomplish this if

699. *Id.* ¶¶ 11.1, 11.3.

700. For more on this topic, *see* Grimm, *supra* note 553, at 216 ("Market share liability has often been found appropriate only where products are sufficiently interchangeable such that it is either impossible or overwhelmingly burdensome to isolate individual causation among defendants."); Andrew B. Nace, Note, *Market Share Liability: A Current Assessment of a Decade-Old Doctrine*, 44 VAND. L. REV. 395, 396–97 (1991); Samantha Lawson, *The Conundrum of Climate Change Causation: Using Market Share Liability to Satisfy the Identification Requirement in* Native Village of Kivalina v. ExxonMobil Co., 22 FORDHAM ENVTL L. REV. 433 (2010); Daniel A. Farber, *Basic Compensation for Victims of Climate Change*, 155 U. PA. L. REV. 1605, 1640–55 (2007). *But see* Kysar, *supra* note 555, at 37 (critiquing the market share liability approach and recommending that several liability is the appropriate form of recovery).

the "market share" were defined as the share of GHG emissions, (in which case this would be identical to the several liability approach)—but if the "market share" is the share of fossil fuels produced or electricity generated, then this approach might overestimate the actual contribution to the injury (insofar as other GHG sources, such as agriculture and land use change, would not be accounted for in the contribution determination). Imposing joint and several liability might also result in an overestimation of a party's contribution to the injury. However, there may be compelling reasons to impose joint and several liability in certain contexts—for example, in the municipal lawsuits against fossil fuel companies, the plaintiffs note that the companies colluded in climate change misinformation campaigns, and that each company was "the agent, servant, partner, aider and abettor, co-conspirator, and/or joint venture" of the other defendants to justify their request for joint and several liability.[701]

V. CONCLUSION

In this Article, we summarize the state of the art in climate change detection and attribution science; describe how that science is being used in policy, planning, and litigation; and discuss further directions in the law and science of climate change attribution. We focus, in particular, on the use of attribution science in the courtroom. Attribution science has always been a key component of climate change litigation. But, the recent waves of cases brought against national and subnational governments, seeking increased mitigation ambition, and against fossil fuel and energy companies, seeking compensation or abatement funds for the costs of adaptation, have made the relationship between the science and law of climate change attribution all the more salient.

The political sphere in the United States continues to be clouded with false debates over the validity of climate science. Things are far clearer in the courtroom, where to our knowledge no judge has questioned the scientific basis for the global community's shared understanding of the causes and effects of climate change. But there are significant scientific issues that remain to be clarified, for

701. *See, e.g.*, Complaint ¶ 40, Imperial Beach v. Chevon et al., No. C17-01227 (filed Cal. Super. Ct., July 17, 2017); Complaint ¶ 44, Richmond v. Chevon et al., No. C18-00055 (filed Cal. Super. Ct., Jan 22, 2018).

law and policy purposes, and it may well be that litigation provides the forum for achieving that clarity.