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COMMENTARY

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Key Points:

- Courts rely on physical and social science to resolve legal claims about responsibility for greenhouse gas (GHG) emissions and climate change
- Conversations with legal practitioners provide insight on the types of research that would inform climate litigation
- Key research areas include climate change detection and attribution, climate disinformation, and GHG mitigation obligations

Supporting Information:

Supporting Information may be found in the online version of this article.

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Research Priorities for Climate Litigation

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Abstract This article characterizes key research gaps and opportunities for scientists across disciplines to do work that informs the rapidly growing number of climate lawsuits worldwide. It focuses on research that can be used to inform legal decisions about responsibility for greenhouse gas emissions and climate damages. Relevant lawsuits include claims filed against government and corporate defendants alleging that they have violated environmental, human rights, constitutional, tort, and consumer protection laws due to their contributions to climate change and failures to control emissions. Constructive attention has recently been given to the important role of attribution science in informing some of these cases (Burger et al., 2020, <https://doi.org/10.7916/cjel.v45i1.4730>; Stuart-Smith et al., 2021, <https://doi.org/10.1038/s41561-021-00686-4>). Here, we draw upon both the published literature and conversations with diverse legal scholars and practitioners to characterize what further climate litigation-relevant research is most needed. In addition to key gaps in litigation-relevant attribution science, we identify and characterize the need and opportunity for further social science research to address the causes of climate inaction, and for further cross-disciplinary research to inform emerging legal questions on the allocation of responsibility for emissions reductions to align with temperature limits such as those set by the Paris Climate Agreement. Our primary goal is to identify areas for researchers who are interested in contributing to climate litigation and discussions about legal responsibility for climate change. We also seek to help the research community see this as a legitimate and important domain for timely, actionable scientific research.

Plain Language Summary People are increasingly turning to courts for climate remedies due to the mounting severity of the climate crisis and the inadequacy of public and private sector responses. One key goal in litigation is to establish obligations on the part of both government and corporate actors to reduce greenhouse gas (GHG) emissions, respond to climate change-related threats, and provide redress for climate damages. This article characterizes key research gaps and opportunities for scientists across disciplines to do work that informs the rapidly growing number of climate lawsuits cases worldwide. It focuses on research that can be used to establish government and corporate responsibility for GHG emissions and climate change-related damages.

1. Introduction

In 2004, climate scientist Peter Stott and colleagues published a paper in *Nature* that for the first time quantified how much human-caused climate change increased the risk of an extreme weather event (Stott et al., 2004). In July and August of the previous year, a sweltering heatwave had settled over Western Europe. Sustained maximum temperatures of 35°–40°C contributed to more than 70,000 premature deaths across the continent (Robine et al., 2008). In France, where temperatures soared to 40°C and remained dangerously high for weeks, nearly 15,000 died. Stott and his collaborators used climate models to simulate what weather patterns over Europe would have been expected that summer with and without anthropogenic emissions of carbon dioxide and other heat-trapping gasses. They found that climate pollution had more than doubled the probability of a heatwave so extreme.

In a *Nature* news commentary published alongside the scientific paper, Khamsi (2004) presciently noted that results such as these “could make it easier for groups attempting to sue large emissions-producers for the damages caused by global warming.”

Climate change-related lawsuits were then a rarity; only 11 cases were filed globally in 2004, 8 of them in the U.S. (Sabin Center for Climate Change Law, 2022b; Grantham Research Institute, 2022). Since then, climate litigation has dramatically increased (Figure 1). Between 2016 and 2019, more than 120 cases worldwide were filed each

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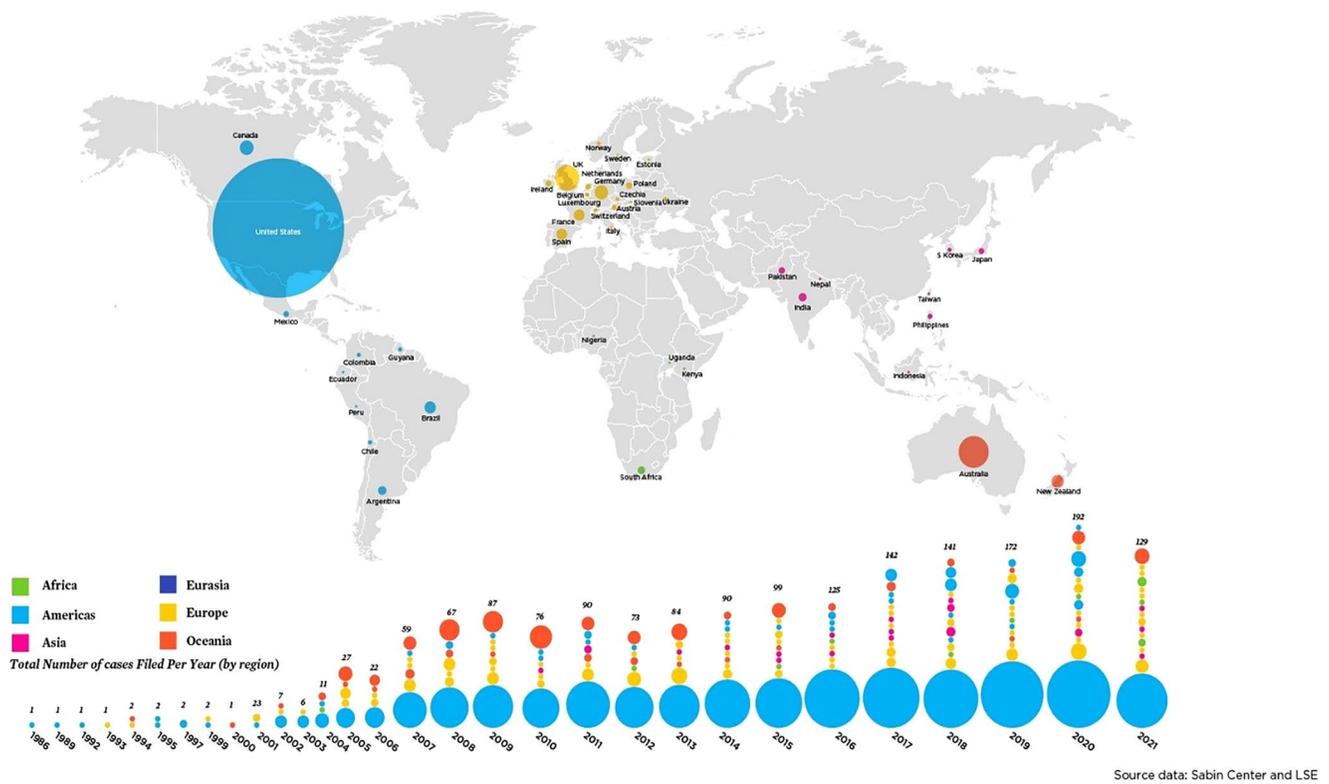


Figure 1. Global climate litigation since 1986.

year. A central goal of many lawsuits is to establish legal responsibility for contributions to climate change and corresponding obligations to reduce greenhouse gas (GHG) emissions and to provide remedies for losses and damage associated with climate change. To that end, lawsuits are often filed against government defendants for inadequate control of GHG emissions, but litigation against corporate actors is also on the rise (Franta, 2021a). In the U.S. alone, for example, over two dozen states and municipalities have filed lawsuits against fossil fuel companies seeking changes in corporate conduct or compensation for climate damages (Center for Climate Integrity, 2021).

Courts rely on scientific, historical, and other forms of evidence when adjudicating disputes about legal responsibility for climate change. Since Stott et al.'s pioneering paper, further research aimed at quantifying the contribution of different actors to climate change-related harms has laid the groundwork for lawsuits against both government and corporate defendants. For example, Richard Heede's "carbon majors" research helped spur the proliferation of lawsuits against fossil fuel companies. Through painstaking historical analyses, Heede found that nearly two-thirds of all industrially sourced carbon emissions between 1880 and 2010 could be traced to just 90 large companies—coal, oil and natural gas producers and cement manufacturers (Heede, 2014). Most of those emissions were generated in recent decades—and, as other research has shown, after companies knew of the serious harms of their products and sought to avoid regulation by promoting uncertainty and delay (Franta, 2021b, 2021c).

Courts and litigants, however, are not always well-equipped to access, draw upon and evaluate the relevant scientific literature or to identify and engage scientists with relevant expertise as expert witnesses or in other advisory roles. Scientists, in turn, may not understand what kinds of expertise are needed to inform climate litigation and how to identify and weigh opportunities to contribute.

Multiple initiatives are working to fill this gap. The Climate Science Legal Defense Fund, for example, publishes a "pocket guide" that advises scientists on what to expect and what to safeguard against when asked to serve as expert witnesses. Through its Climate Judiciary Project, the Environmental Law Institute is working to educate

Box 1: Why Climate Litigation is On the Rise

People are increasingly turning to courts for climate remedies due to the mounting severity of the climate crisis and the striking inadequacy of public and private sector responses. Many of these cases are strategic lawsuits aimed at achieving broad social impacts beyond protecting the interests of individual claimants (Ramsden & Gledhill, 2019; Setzer & Higham, 2021). Some seek to establish government obligations to control GHG emissions, consistent with constitutional, statutory, or human rights laws related to the protection of public health and welfare. Others are aimed at changing corporate behavior or recovering monetary damages from corporations that bear significant responsibility for climate change. The opportunities and prospects for such lawsuits have improved as researchers have generated new evidence on the harmful effects of climate change, the emissions contributions of government and corporate entities, and the scope of efforts undertaken by bad faith actors to sow doubt about climate science and delay climate action. Such evidence can be used to establish that: (a) the plaintiff was injured due to climate change, (b) the defendant contributed to that injury through its contribution to climate change, and (c) the defendant knew or had reason to know that it would cause harm by contributing to climate change. This information is used to establish both causation and fault in lawsuits involving claims about legal responsibility for climate change-related injuries (Burger et al., 2020).

To be sure, climate lawsuits offer no quick fixes; they take time to move through the judicial system. Nor do they offer certain outcomes; the jury is out over how influential climate litigation will prove to be. But recent court decisions suggest that climate lawsuits may have a major role to play. In 2019, the Dutch Supreme Court held in *Urgenda Foundation v. The Netherlands* that the Netherlands' inadequate action on climate change had violated the constitutional and human rights of Dutch citizens, and issued an order requiring the government to reduce emissions by at least 25% from 1990 levels by the end of 2020. Since then, other courts have recognized that national governments have legal obligations to protect citizens from climate change-related harms (Commune de Grande-Synthe v. France, 2021; Friends of the Irish Environment v. Ireland, 2020; Neubauer v. Germany, 2021; Notre Affaire à Tous v. France, 2021; VZW Klimaatzaak v. Kingdom of Belgium & Others, 2021).

Courts are also beginning to weigh in on corporate climate obligations. In 2021, The Hague District Court built on *Urgenda* to require Royal Dutch Shell to align with the goals of the Paris Agreement and reduce emissions across the company's supply chain, including from its products, by 45% below 2019 levels by 2030 (Milieudefensie et al. v. Royal Dutch Shell, 2021). If the decision is upheld on appeal, it could have major implications for companies worldwide (Text S.2.1 in Supporting Information S1).

The importance of litigation goes beyond final court decisions. In the 1990s, for example, U.S. public opinion turned against major tobacco companies, diminishing their political power to avoid regulations on the marketing of cigarettes. This came after lawsuits led to the discovery of documents revealing that multiple companies had misled the public about their extensive knowledge of the health harms of smoking, and courts issued injunctions compelling tobacco companies to cease fraudulent communications and issue corrective statements (see, e.g., *State ex rel. Humphrey v. Philip Morris Inc.*, 1996; *United States v. Philip Morris USA Inc.*, 2009). As with tobacco litigation, climate litigation can provide a pathway for uncovering information about corporate responsibility for climate change, affecting corporate reputations in the court of public opinion and hence, their "social license" to operate in ways that harm public health and the environment.

judges on the basic tenets of climate science. Columbia University's Sabin Center for Climate Change Law and Lamont-Doherty Observatory are providing the legal community and others with access to a rich database of litigation-relevant research on various dimensions of climate attribution science (Sabin Center for Climate Change Law, 2022a, 2022b). The New York University School of Law recently established a Climate Litigation Accelerator to serve as a collaborative hub for research and advocacy to support litigation in the global south and elsewhere. The Sustainable Law Program at the University of Oxford and the Grantham Research Institute on Climate Change and the Environment at the London School of Economics are also conducting litigation-relevant

research. And the Union of Concerned Scientists is running a “Science Hub for Climate Litigation” to help connect scientists with relevant expertise to legal teams, catalyze litigation-relevant research and foster a community of practice among scientific experts, legal scholars, and practitioners working at the nexus of science and climate litigation.

Here, we draw upon our work in this field and a recent survey of legal scholars and practitioners to characterize three priority areas for research to inform climate litigation (Burger et al., 2020; Franta, 2018, 2021b; Merner et al., 2022). Many of the research needs related to climate litigation are evolving as legal strategies continue to develop (e.g., as human rights arguments become more prominent in the climate litigation space). Our aim is to synthesize these trends and bring broader attention to the significant need and opportunity for researchers across climate-related disciplines to contribute to the legal discourse. We focus on research related to lawsuits involving government and corporate obligations with respect to GHG emissions and climate damages, encompassing a variety of legal actions arising under environmental law, human and constitutional rights, and products liability. At the same time, given the current and growing diversity of climate change litigation around the world, we see numerous opportunities for expanding this work. Details of our methodological approach, including interviews of climate litigation practitioners, are given in Supporting Information S1 (S.1).

2. Priority Research Areas

2.1. Climate Change Detection and Attribution

When courts are interpreting legal obligations related to GHG emissions and climate damages, they frequently confront questions about causation: specifically, whether and to what extent a defendant's allegedly unlawful acts or omissions contributed to climate change, and whether that contribution can be fairly traced to injuries experienced by plaintiffs or the public. In cases involving government defendants, the contribution to climate change-related injuries may arise from regulatory failures, affirmative policies such as fossil fuel subsidies, and permitting decisions. In cases involving corporate defendants, the contribution may include emissions from direct business operations, products marketed and sold by the defendants, or activities related to climate obstruction (Section 2.2).

Climate change detection and attribution science plays a critical role in fleshing out the causal chain between a defendant's conduct and climate change-related injuries (Figure 2). This field encompasses a range of research aimed at understanding whether and how anthropogenic influence on the global climate system has contributed to observed phenomena such as sea level rise and extreme weather events (Easterling et al., 2016; Hegerl et al., 2010). Climate scientists often use the phrase “detection and attribution” to describe research linking observed impacts to human activities in the aggregate. Our definition includes the related field of *source attribution*, which examines and quantifies the relative GHG contributions of different actors. This is integral to the consideration of legal responsibility for climate change harms (Burger et al., 2020).

Source attribution data include national emissions inventories, sectoral emissions estimates, and corporate-oriented data such as Heede's carbon majors study. These are important to establish whether a defendant's emissions contribution is large enough, from a legal perspective, to be fairly traced to climatic changes and climate change-related injuries (Burger et al., 2020). Such data is also integral to estimating damages attributable to a defendant on the basis of GHG contributions. In addition, research on the GHG emissions from government policies and the consistency of those policies with emission reduction targets is relevant to ascertaining government responsibility for climate change (Climate Analytics & New Climate Institute, 2022).

Because responsibility for emissions can be divided up in multiple ways, litigation-relevant source attribution requires accounting schemes that fairly attribute emissions to defendants. For example, when looking at national governments, there is significant debate regarding the fair attribution of emissions associated with internationally traded goods (Jakob et al., 2021). Under the United Nations Framework Convention on Climate Change (UNFCCC) reporting requirements, emissions are attributed entirely to the producing (exporting) jurisdiction. But emissions can also be attributed to countries based on product consumption, fossil fuel extraction, or a hybrid accounting method which blends these approaches. Changes to attribution of emissions from internationally traded products would have large and potentially litigation-relevant implications for nations to align their emissions reductions obligations with the Paris Agreement's temperature goals (Section II C).

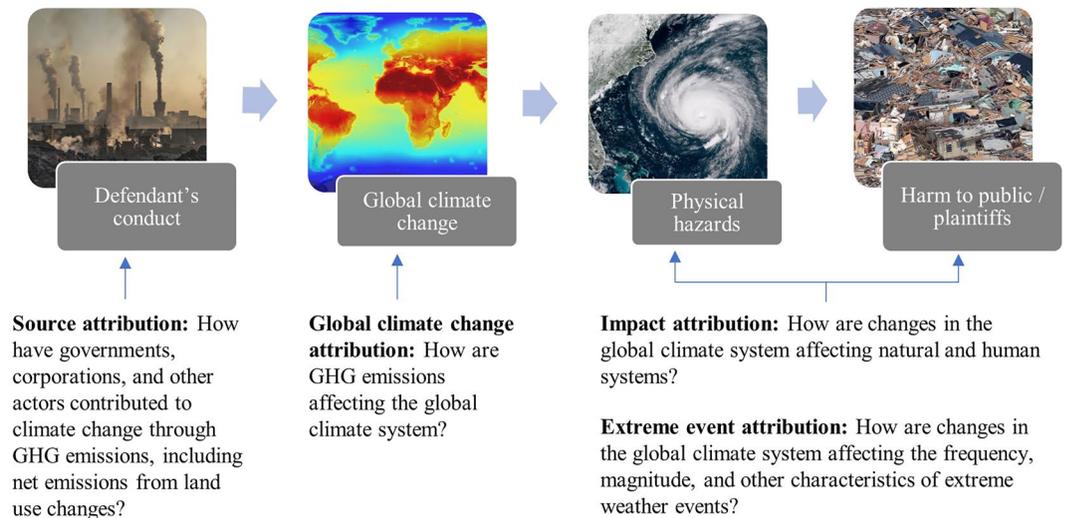


Figure 2. Establishing causation through detection and attribution research.

With regard to corporations, litigation-relevant questions may arise regarding the relative responsibility of various actors in the fossil fuel supply chain. Should ExxonMobil, for example, be held solely accountable for emissions and resulting climate harms from the combustion of the fossil fuels it produces and markets, or should these emissions be considered, at least in part, the responsibility of others in the oil and gas supply chain? Research on how fossil fuel companies intentionally obstructed climate action has bolstered the case for holding these companies liable for product-related emissions (Section 2.2) (Frumhoff et al., 2015). Prospective litigants may benefit from further research on the technical and ethical bases for attributing emissions to other entities, such as banks that finance oil and gas production, automakers, and agricultural and livestock producers.

Extreme event and impact attribution research can be used to demonstrate that alleged injuries are caused by anthropogenic climate change, and thus traced back, in part, to a defendant's GHG contribution. Scientists have made significant progress with extreme event and impact attribution, and there are now many studies linking specific events and phenomena to human-induced climate change (IPCC, 2021, 2022). Much of the existing research focuses on physical climate impacts, but there is a growing body of research on social, economic, and public health impacts (King & Harrington, 2018). The current evidence on impact attribution may be sufficient to support many of the climate change-related lawsuits that have been filed to date, but there are areas of additional research that could help strengthen existing claims and potentially expand opportunities for climate litigation (Banda, 2020; Burger et al., 2020).

First, legal practitioners would benefit from research that links the physical impacts of climate change to public or private harm with greater specificity (Perkins-Kirkpatrick et al., 2022). This could include, for example, additional research on how sea level rise and associated storm surge affect coastal communities, infrastructure, and property owners (Strauss et al., 2021); on how physical changes in marine systems affect fishery productivity, food security, and livelihoods; and on how, exacerbated by climate change, extreme events such as heat waves and wildfires affect public health and welfare (Mitchell et al., 2016). Impact attribution research can help with isolating the contribution of climate change to specific injuries such as increases in heat-related deaths or property losses from fire.

Second, in cases seeking monetary damages for climate change-related injuries, legal practitioners would benefit from additional research on costs attributable to climate change. This would include research quantifying financial impacts, such as those arising from property losses, as well as other costs, such as those arising from public health and ecological impacts. For example, recent research quantifying economic damages from Hurricane Sandy attributable to climate change could be expanded for a much broader range of impacts, injuries, and locations (Strauss et al., 2021). Researchers might focus on specific impacts and locales where litigation is being considered or is already underway. But there is also value in broadening the scope of research to provide evidentiary support for future cases, particularly in jurisdictions where historically marginalized communities are

harmed by climate change. Additional research on adaptation costs may also prove useful, as plaintiffs sometimes use adaptation costs as the basis for proposed monetary damages in lawsuits (Center for Climate Integrity, 2021).

Third, research that bridges the gap between source and impact attribution could help illustrate chains of causation. In cases involving responsibility for climate change-related damages, plaintiffs typically establish causation between the defendant's conduct and their injuries by relying on different studies and data sets to establish different links in the causal chain. For example, a hypothetical plaintiff could use: (a) emissions data to quantify the defendant's contribution to climate change, (b) IPCC reports to establish a link between rising GHG concentrations and anthropogenic climate change as a general matter, and (c) location-specific studies on climate change impacts to establish the link to their injury. This approach has worked in cases involving government obligations to control and regulate GHG emissions, where plaintiffs must demonstrate a link between government policies and public endangerment (see, e.g., *Massachusetts v. EPA*, 2007; *Urgenda Foundation v. State of the Netherlands*, 2019). However, there are pending and future cases that will involve more complex and specific causation inquiries—for example, whether a particular company's emissions can be traced to local damages in a specific municipality (Burger & Wentz, 2018).

To resolve more complex causation issues, courts and litigants may benefit from research that bridges the gap between source and impact attribution (i.e., studies that link specific entities, including governments and corporations, to specific injuries associated with climate change). Such research may be useful because there is not necessarily a linear relationship between an entity's GHG contributions and climate-change related harms—the contribution to the harm itself can depend on the timing of the GHG contribution, the type of emissions, and the type of harm.

Researchers have begun to bridge this gap by linking specific countries, major carbon producers, and emitters to physical impacts such as temperature increases, sea level rise, ocean acidification, and extreme weather (Beusch et al., 2022; Ekwurzel et al., 2017; Licker et al., 2019; Lott et al., 2021; Otto et al., 2017), and by developing metrics which can be used to estimate contributions to impacts based on emissions contributions (Frame et al., 2019). It would be useful to expand such studies to encompass a broader range of emitters and climate change impacts, including downscaled impacts (e.g., regional rather than global sea level rise). Such end-to-end attribution studies may not be necessary in most cases to prove causation; it should be sufficient for plaintiffs to rely on separate studies to flesh out different links in the causal chain (see, e.g., *Massachusetts v. EPA*, 2007; *Urgenda Foundation v. State of the Netherlands*, 2019). But this type of research could help demonstrate to judges that a sufficient causal nexus exists between the conduct of defendants and climate-related injuries.

Finally, there is a compelling need to expand the geographic scope of extreme event and impact research to inform prospective litigation in geographic areas that will experience the greatest climate change harms. There are very limited data about both the attribution and effects of extreme events in many highly vulnerable regions in the global south (Otto et al., 2020). This is in part due to a lack of good historical observations and well-verified climate models as well as a significant global north “bias in expertise” (Otto et al., 2020). Addressing these data gaps would help to inform not only litigation but also international discussions about loss and damage in the global south.

The evidence required to demonstrate causation will depend, in part, on the nature of claims raised in a case and the remedy sought. Plaintiffs challenging national policies may be able to use more generalized impact attribution data to show that the government's failure to adequately control GHG emissions poses a threat to public health and welfare in the aggregate, whereas plaintiffs seeking monetary damages for climate change-related injuries may need more specific and quantified impact attribution data to inform a damage award (Box 2).

Attribution researchers seeking to inform climate litigation should take into account the standards of evidence required. Decisions about standards of evidence inherently entail judgments as to the relative risk of type 1 errors (attributing causation where it is not warranted) versus type 2 errors (not attributing causation where it is warranted). Lloyd et al. (2021) point out that a standard of “more likely than not,” commonly characterized as greater than 50%, most closely approaches the legal standard often applied in civil climate litigation. They argue that scientists seeking to do litigation-relevant attribution research should avoid “setting the bar too high” by only reporting results with more traditional scientific standards of evidence such as greater than 95% probability.

Box 2: Examples of Evidentiary Requirements in Climate Cases

In *Urgenda Foundation v. State of the Netherlands*, the Supreme Court of the Netherlands held that the national government had a legal obligation to protect the human rights of its citizens against the harmful impacts of climate change, and as a result, the government must take steps to reduce carbon emissions consistent with limiting global warming to 1.5°C.

The Court found that GHG emissions under the direct influence of Dutch national policy (approximately 0.5% global emissions) were sufficiently substantial for adjudication, that climate change endangered the health and well-being of Dutch citizens in the aggregate, and that a causal nexus existed between national policy and those injuries based on information in IPCC assessments. It was not necessary for plaintiffs to prove that the Netherlands' national contribution to climate change had caused particularized harm to specific individuals or entities because Dutch law allows organizations to file lawsuits on behalf of collective interests.

Similarly, in *Milieudefensie et al. v. Royal Dutch Shell* (2021), The Hague District Court found that emissions under the direct influence of Royal Dutch Shell corporate policy (approximately 1%–2% global emissions) were sufficiently substantial for adjudication, that climate change endangered the health and well-being of Dutch citizens in the aggregate, and that a causal nexus existed between corporate policy and those injuries based on information in IPCC assessments. The Court also found that adjudication in the Netherlands was proper due to the presence of Royal Dutch Shell headquarters in the country. (The decision is being appealed by Royal Dutch Shell, and the company has relocated its headquarters to the United Kingdom.)

In *Lliuya v. RWE AG*, a Peruvian farmer sued the German utility RWE for its contribution to climate change, seeking compensation based on the costs of protecting his town from flood risk arising from glacier retreat. The plaintiff is seeking compensation for 0.47% of flood protection costs—the same percentage as RWE's estimated cumulative contribution to global GHG emissions from industrial sources (Heede, 2014).

The case was initially dismissed, in part because a German lower court determined that there was no “linear causal chain” linking the plaintiff's injury and RWE's emissions (*Lliuya v. RWE AG*, 2016). However, an appellate court reversed the dismissal and the case has now entered into the discovery stage.

To inform the court's analysis, climate scientists conducted a targeted attribution study on the extent to which the flood hazard could be traced back to human-induced glacier retreat (Stuart-Smith et al., 2021).

Other plaintiffs are also pursuing lawsuits to recover climate damages. More than two dozen governmental entities (cities, counties, and states) across the United States have sued fossil fuel producers seeking compensation for adaptation costs and/or civil penalties for allegedly unlawful conduct. The plaintiffs have asserted evidence of defendants' substantial contribution to climate change, allegedly unlawful conduct, and concrete injuries from climate change suffered by Plaintiffs. Evidentiary requirements in these cases are unfolding as they move closer to trial.

Box 3: Research Priorities for Climate Obstruction Lawsuits

Research on Conduct

- Research on disinformation and greenwashing activities across a broad range of actors
- Evaluating corporate marketing over time, including messaging, spending, target audiences (including youth), scale of impressions, and effects
- More detailed understanding of industry relationships to government and role in policymaking
- Characterizing lobbying activities, including to what degree lobbying communications have been false or misleading
- Identifying misleading communications to investors and the public regarding the viability or financial effects of a transition away from fossil fuels (so-called “transition risks”)

Research on Impact

- Describing the effects of climate obstruction in terms of measurable harms or damages, such as increases in GHG emissions or effects on specific policies
- Evaluating corporate and governmental pledges and advertisements in comparison to actual activities, such as investments in further fossil fuel production
- Determining industry influence over scientific processes, such as IPCC assessments
- Better understanding the detrimental effects of continued fossil fuel investments
- Demonstrating the feasibility of climate action and non-fossil energy economies in order to counteract misleading narratives about the efficacy or viability of climate action

There are also other factors which influence evidentiary requirements, such as jurisdictional standing requirements. For example, plaintiffs pursuing *Urgenda*-type claims in other jurisdictions may need to demonstrate that they, or a group they represent, have suffered or will imminently suffer particularized and concrete injury as a result of climate change in order to have standing to sue.

2.2. Obstruction of Climate Science and Action

Some climate lawsuits seek to impose liability on actors for unlawfully interfering with and impeding effective responses to the climate crisis. For example, in consumer and investor fraud cases filed against fossil fuel companies, plaintiffs have alleged that these companies have contributed to inaction and confusion on climate change through concealment, trivialization, disinformation campaigns, and greenwashing (Burger & Wentz, 2018; Center for Climate Integrity, 2021). Plaintiffs may also seek to hold government actors accountable for misleading the public and impeding climate action, for example, by deliberately concealing or distorting climate science, misrepresenting the costs and benefits of climate regulation, or otherwise undermining the public's understanding of the problem (Juliana v. United States, 2018).

Historians, social scientists, investigative journalists, and legal scholars have extensively documented that fossil fuel companies knew about the dangers of climate change decades ago but actively concealed and downplayed those dangers and coordinated to misinform the public and prevent policymakers from taking action to reduce fossil fuel production and use (Bjonberg et al., 2017; Franta, 2021b, 2021c; Grasso, 2019; Kaupa, 2021; McCright & Dunlap, 2000; Mulvey et al., 2015; Union of Concerned Scientists [UCS], 2007). Some research also examines how fossil fuel company campaigns influenced lawmakers (Jacques et al., 2008; Layzer, 2007; McCright & Dunlap, 2000, 2003; Perry, 2012; Wieners, 2014). Most of the current research focuses on oil and gas majors and their trade associations, as well as the U.S. policy context (Hicke et al., 2022), although there is some research covering the U.K. and other jurisdictions (Bellamy, 2020; Dupont, 2016; Kaupa, 2021; Sharman & Perkins, 2017). There is also some research on the extent to which government actors, particularly the U.S. federal government, have contributed to the climate crisis through actions above and beyond the failure to adequately regulate GHG emissions, for example, by coordinating with the fossil fuel industry to impede regulation and expand production and subsidies, and by intentionally concealing or misrepresenting climate science (Speth, 2021; Webb et al., 2020).

There is ample room for additional research on how the types of conduct described above have affected climate inaction and government policy. Research on the fossil fuel industry is most salient in current litigation, as fossil fuel companies are the defendants in most lawsuits involving these types of claims. Litigants and courts may benefit from additional information on how fossil fuel disinformation campaigns have contributed to outcomes such as public confusion, policy failures, or increased GHG emissions, as this would help flesh out the causal chain between climate disinformation and climate damages. Also valuable would be expanded research on: (a) the contributions to and effects of climate obstruction outside of the U.S.; (b) the conduct of a broader set of actors including state-owned fossil fuel companies, petrochemical companies, refiners, power utilities, automobile manufacturers, agricultural and livestock producers (Lazarus et al., 2021), public relations and advertising firms, consulting firms, think tanks, and trade associations implicated in the dissemination of false or misleading information about climate change; and (c) how conduct related to disinformation and greenwashing can be connected to supply chain (or “Scope 3”) emissions from fossil fuel companies and the other actors noted above.

Box 3 identifies specific research areas that would inform climate obstruction lawsuits across a broad range of jurisdictions and defendants.

2.3. Mitigation Obligations

Research on carbon budgets and emission reduction pathways at national, state and sectoral levels can contribute to the development of standards or norms for the equitable allocation of GHG mitigation obligations. These standards could inform judicial remedies as well as public policies regarding responsibility for climate change and may become increasingly important as forward-looking climate litigation, including litigation based on human rights arguments, becomes more prominent in some jurisdictions.

2.3.1. Government Obligations

There is a growing body of physical, social science, and legal scholarship on carbon budgets which can inform government obligations with respect to GHG mitigation. Much of this research is aimed at supporting UNFCCC negotiations on how countries should reduce emissions in accordance with their “common but differentiated”

responsibilities and capabilities. Courts have relied on both UNFCCC decision documents and carbon budget research when determining government obligations in cases like *Urgenda*. Courts are also beginning to encounter questions about the equitable framing of emission reduction targets (see, e.g., A Sud et al. v. Italy, 2021). For example, courts may be tasked with evaluating whether mitigation obligations should be defined in reference to (a) historical (cumulative), present, and/or future GHG emissions; (b) territorial, consumption, or production-based emissions; (c) total or per capita emissions; or (d) a hybrid approach which combines emissions accounting methods. Courts may also confront questions about how other considerations, such as per capita gross domestic product, may affect a jurisdiction's emission reduction responsibilities.

Government obligations can also be framed in reference to fossil fuel production horizons in addition to emission budgets. As with emissions, there are questions about how to account for fossil fuel production and/or consumption when defining baselines and reduction targets—for example, how to weigh historical fossil fuel use when defining fair share of production or consumption going forward. This approach to framing mitigation obligations is particularly relevant where litigants are challenging government approvals of fossil fuel production, transportation, and processing infrastructure.

Mitigation obligations can also be framed in reference to specific policies that a country must enact to address climate change. For example, a court could find that a government has an obligation to adopt certain types of regulations for the power sector or transportation sector based on the best available mitigation technology (Clean Air Act, 1963). Or a court could direct a government entity to adopt a GHG pricing scheme or other regulations comparable to that of other jurisdictions in order to ensure reciprocity in climate action.

Legal questions may also arise pertaining to the use of offsets and negative emissions in achieving the temperature goals of the Paris Agreement; whether net-zero emissions pledges may be misleading, for example, or whether unproven or temporary carbon removal methods constitute an appropriate remedy. And courts may also consider the unmet legal obligations under the UNFCCC for developed nations to support climate action in developing nations (Bos & Thwaites, 2022).

There is a wealth of empirical data and technical research to help decision-makers navigate these considerations, including data on historical and current emissions and projections of future emissions under different policy scenarios and carbon budgets (IPCC, 2021). There is also legal and social science research aimed at informing discussions about “fair share” obligations under the UNFCCC (Fuglestedt & Kallbekken, 2016; Skeie et al., 2017), including on how the remaining global carbon budget should be allocated equitably among nations (Climate Analytics & New Climate Institute, 2022). For example, Rajamani et al. (2021) evaluated national emission reduction commitments for compatibility with widely accepted principles of international environmental law, thus informing climate litigation in which the adequacy of emissions commitments is at issue. Strikingly, their analysis suggests that many developed nations have “fair share” Paris-aligned reduction obligations that are net-negative in 2030, far greater reductions than put forward in current national NDCs (Rajamani et al., 2021). Complementing the scholarship on mitigation obligations are detailed studies on the efficacy, cost, and viability of specific policy interventions to reduce emissions and decarbonize economies (Deep Decarbonization Pathways [DDP], 2022). However, the existing research on government “fair share” obligations is sometimes limited in geographic scope—the focus tends to be on large emitters such as the United States and other G20 countries.

To inform both climate litigation and the UNFCCC negotiations, it would be valuable to have further research on: (a) the effects on emissions of specific policy interventions across a broad range of countries, (b) how empirical data and normative principles should inform discussions about equity and fair share in national emission reductions, and developed country support for climate action in developing countries, (c) how land-use emissions might be incorporated into quantification of fair-share emissions reductions, and (d) how courts should consider “tipping points” and positive warming feedbacks when evaluating duties of care for limiting the risks of exceeding Paris-compliant remaining carbon budgets. Peer-reviewed research on these topics would be particularly useful (Text S.2.2 in Supporting Information S1).

There may be no single answer or one-size-fits-all approach to determining the mitigation responsibilities of individual countries. Nonetheless, further research on this topic would strengthen the foundation for establishing minimum requirements for government action and enable courts to ascertain when countries are failing to meet their mitigation obligations under national or international law. Moreover, scholarship may help countries move toward greater consensus on standards for mitigation obligations, the role of offsets and negative emissions in

achieving net zero or net-negative emissions and the responsibilities of developed nations to support climate action in developing countries (United Nations Framework Convention on Climate Change, 2022). Such research could also inform the discussion of corporate obligations, discussed below.

2.3.2. Corporate Obligations

Corporate actors also have legal duties to avoid causing harm through contributions to climate change, but there has been less discussion and research on how to frame their obligations. One approach is to define corporate obligations in reference to the Paris Agreement and international emission reduction targets, similar to governmental obligations. The Hague District Court adopted this approach when it ordered Royal Dutch Shell to reduce its supply chain CO₂ emissions, including from both its operations and products, by 45% below 2019 levels by 2030, consistent with corporate obligations to work toward the goal of net zero emissions by 2050 (Milieudefensie et al. v. Royal Dutch Shell, 2021). The court held that Shell could meet this obligation, at least in part, through emission capture technologies (Milieudefensie et al. v. Royal Dutch Shell, 2021). Petitioners have sought similar judgments in other jurisdictions (Notre Affaire à Tous et al. v. Total, 2019). Under this framework, fossil fuel producers would need to modify their operations substantially to comply with applicable duties of care.

Another approach is to define obligations more narrowly—for example, requiring carbon capture for certain industrial processes or power plants or shifting business plans toward less- or non-emitting products. A company's obligations could also be defined in reference to types of conduct discussed in Part III(B) above—for example, requiring fossil fuel companies to refrain from misleading communications regarding their products or climate change (Shue, 2017).

Much of the existing research relevant to corporate obligations examines the efficacy and cost of mitigation technologies for various sectors (Holappa, 2020). There is also some scholarship that deals with the responsibility of fossil fuel companies to mitigate the harms caused by their products as well as disinformation and lobbying campaigns (Shue, 2017). But courts would likely benefit from additional data as well as normative scholarship on these topics, including: (a) research on the impact of different mitigation technologies for sectors and companies that could continue to operate in a decarbonized society, and (b) research on how and whether companies that will no longer be viable in a decarbonized society could transition their corporate models. This second area of research could look at how other industries have adapted when courts or policymakers have determined that the harms of their products outweigh the benefits and that the manufacture and sale of such products is no longer legal (Svoboda, 1996).

3. Discussion

Robust scholarship is essential to help courts resolve questions regarding parties' responsibilities for climate harms from historic emissions, contributions to climate inaction, and obligations to avoid future harms. Discussions with legal scholars and practitioners have revealed substantial demand for additional research relevant to climate litigation (Merner et al., 2022).

Calls for more research should not be taken to imply that the existing body of climate research is insufficient to inform many of the cases that have been filed to date. In a review of 73 lawsuits, Stuart-Smith et al. point out that the attribution science presented in many cases actually lags behind the state-of-the-art and suggest that this gap might impede assessments of causation. However, the “evidentiary gap” they identify has not yet significantly affected case outcomes—the study identifies only two instances where lawsuits were dismissed on scientific grounds, both of which were lower court decisions that were modified or reversed on appeal (Kivalina v. Exxon-Mobil, 2009; Lliuya v. RWE AG, 2016). There have already been a number of important judicial decisions driving climate mitigation, and when cases have been dismissed, it has been most often due to legal barriers rather than evidentiary limitations (Banda, 2020; Burger et al., 2020; Setzer & Byrnes, 2020; United Nations Environment Programme, 2020). This suggests that litigants do not always need to rely on the latest, state-of-the-art research to prevail in their lawsuits. However, it is possible that research gaps like those we identify in this article, and the evidentiary gap discussed by Stuart-Smith et al., could impede some of the cases that are currently underway, particularly those seeking monetary damages for contributions to climate change, as well as future litigation.

Courts need to rely on high-quality research and typically consider peer-reviewed papers following well-established methods and published in reputable journals as more credible than unpublished white papers or other gray

literature. Courts also assign considerable weight to consensus documents such as IPCC reports, National Academies reports, and national climate assessments. Although these reports inevitably lag behind the “state of the art” research, they are an authoritative source of climate data to support findings of causation and responsibility for climate harms and GHG emissions (Massachusetts v. EPA., 2007; Milieudéfense et al. v. Royal Dutch Shell, 2021; Urgenda Foundation v. State of the Netherlands, 2019).

There are several other cross-cutting considerations relevant to the development of a research agenda for climate litigation:

There is a need for both foundational research with broad application and research that is focused on a particular jurisdiction or entity. Both have utility. More generalized research on the effects of climate change at large geographic and temporal scales has broader applicability, insofar as it can be used in lawsuits involving different types of plaintiffs, defendants, and legal claims. However, generalized research may not be sufficient to establish certain elements, such as particularized injury (where required of plaintiffs). Targeted research on issues relevant to a specific case can fill evidentiary gaps, strengthen legal arguments, and illustrate what is possible in other cases (Speth, 2021).

There are numerous opportunities to address information gaps so as to expand the scope of climate litigation going forward. One cross-cutting issue is the disparity in the geographic scope of current research, with significantly more information currently available to support lawsuits in the global north. Many legal practitioners have expressed concern that impacts and climate attribution research is currently focused on the global north, and extreme event studies often focus on events that make headlines. There are also data constraints which can make it more difficult to perform attribution research for some regions—for example, there are relatively fewer in situ measurements of essential climate variables in the global south (Otto et al., 2020). Satellite remote sensing data sets can be used to fill gaps in the in situ data, but there are issues associated with the duration and certainty of satellite data which can pose challenges for capturing long-term trends for many climate variables (Yang et al., 2013). This highlights the need for more data equity as well as creative research approaches in light of data constraints (Williams et al., 2022).

Discussions with legal scholars and practitioners have also highlighted the need for greater research coordination across multiple disciplines. Many of the evidentiary questions raised in climate litigation are inherently interdisciplinary—for example, estimating a corporate defendant's contribution to climate damages would involve looking at evidence from corporate records and other historical documents as well as various domains of climate change detection and attribution science.

The research priorities outlined above are not exhaustive. Some legal practitioners interviewed by Merner et al. (2022) also called for additional research on the responsibility of public and private lending institutions for climate damages arising from high-carbon activities they finance. Interdisciplinary research is needed to better understand the effects of financing decisions, both economy-wide and at the project level. Others highlighted the need for research on the practical effects of litigation and whether additional measures are needed to support compliance with judicial decisions. Some court orders provide significant flexibility as to how climate commitments are implemented and judicially mandated targets and timelines are not always met. Thus, the dialog between scientists and legal practitioners needs to continue even after cases are adjudicated.

4. Conclusion

We are at the early stage of building a time-sensitive research field and community of practice. Today, few researchers self-identify as doing climate litigation-relevant research or have opportunities to interact with and learn from other researchers and legal scholars about how to best work across the disciplinary divides, communicate findings to other scholars and practitioners and navigate the professional risks of conducting and communicating research relevant to lawsuits that seek to hold extremely powerful entities accountable for their outsized contributions to climate change.

The building of this field and community of practice would greatly benefit from dedicated forums where researchers and practitioners can regularly meet and discuss research gaps and priorities and through which litigation relevant research can be accelerated and applied. While confidentiality will be important with respect to individual

cases, the furthering of climate litigation relevant research, like all science, will benefit from open and transparent discussion and debate.

In conclusion, there are numerous opportunities for scholars across disciplines to conduct research to inform both litigation and broader public discussions about responsibility for climate change and its harmful effects. Through this article we have sought to outline a research agenda that is both impactful and equitable.

Data Availability Statement

This article does not use any new data, software, or other research products. A more detailed overview of the results of interviews conducted with legal practitioners is provided in Merner et al. (2022), https://www.cssn.org/wp-content/uploads/2022/04/CSSN-Research-Report-2022_2-Identifying-Gaps-in-Climate-Litigation-Relevant-Research_-An-Assessment-from-Interviews-with-Legal-Scholars-and-Practitioners.pdf.

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Erratum

The following errors were discovered in the Abstract after publication of this article: The first sentence of the Abstract read “This article characterizes key research gaps and opportunities for scientists across disciplines to do work that informs the rapidly growing number of climate lawsuits cases worldwide,” and the last sentence of the Abstract read “We also seek to help the research community see this as legitimate and important domain for timely, actionable scientific research.” The first sentence has been corrected to “This article characterizes key research gaps and opportunities for scientists across disciplines to do work that informs the rapidly growing number of climate lawsuits worldwide,” and the last sentence of the Abstract has been corrected to “We also seek to help the research community see this as a legitimate and important domain for timely, actionable scientific research.” This may be considered the authoritative version of record.