

Filling the evidentiary gap in climate litigation

Rupert F. Stuart-Smith^{1,2,3}, Friederike E.L. Otto^{1,2}, Aisha I. Saad^{1,4}, Gaia Lisi^{1,5}, Petra Minnerop⁶, Kristian Cedervall Lauta⁷, Kristin van Zwieten^{1,5}, & Thom Wetzer^{1,3,5}

¹ Oxford Sustainable Law Programme, University of Oxford, Oxford, OX1 3QY, UK

² Environmental Change Institute, University of Oxford, Oxford, OX1 3QY, UK

³ Institute for New Economic Thinking at the Oxford Martin School, University of Oxford, Oxford, OX1 3UQ, UK

⁴ Harvard Law School, Cambridge, MA, 02138, USA

⁵ Faculty of Law, University of Oxford, Oxford, OX1 3UL, UK

⁶ Durham Law School, Durham University, Durham, DH1 3LE, UK

⁷ Faculty of Law, University of Copenhagen, Copenhagen, DK-2300, Denmark

Lawsuits concerning the impacts of climate change make causal claims about the effect of defendants' greenhouse gas (GHG) emissions on plaintiffs and have proliferated around the world. Plaintiffs have sought, *inter alia*, compensation for climate-related losses and to compel governments to reduce their GHG emissions. To date, most of these claims have been unsuccessful. Here, we assess the scientific and legal bases for establishing causation and evaluate judicial treatment of scientific evidence in 73 lawsuits. We find that the evidence submitted and referenced in these cases lags considerably behind the state-of-the-art in climate science, impeding causation claims. We conclude that greater appreciation and exploitation of existing methodologies in attribution science could address obstacles to causation and improve the prospects of litigation as a route to compensation for losses, regulatory action, and emission reductions by defendants seeking to limit legal liability.

Plaintiffs have brought over 1,500 climate-related lawsuits worldwide, and the number of claims filed continues to increase¹. Without effective non-judicial mechanisms providing compensation for climate-related loss and damage, plaintiffs have filed lawsuits seeking financial remedies from high-emitting corporations for losses suffered due to climate change². Robust scientific evidence is critical to the success of such claims³⁻⁵. For example, claims for compensatory damages must demonstrate a causal link between the defendant's behaviour and the plaintiff's injury. Recognising this, recent literature has drawn on analogous categories of case, such as toxic torts, in which modified causation tests reconcile legal causal analysis with scientific evidence that demonstrates multiple entities' contribution to the risk of harm⁵. However, despite developments in scientific⁶ and legal theory⁵ on causation and attribution of climate change damages, compensatory-damages claims have been unsuccessful. Other lawsuits challenge inadequate state and corporate climate change mitigation targets and policies⁷. To establish admissibility, these claims may also rely on courts finding that emissions resulting from defendants' policies led to impacts affecting the plaintiffs.

A claim must first meet procedural requirements that render it admissible, including 'standing', which establishes that plaintiffs have legally protected interests that entitle them to bring the claim. Demonstrating a connection between defendants' actions and plaintiffs' injuries may contribute to meeting the standing requirement. To date, admissibility has been the primary outcome-determinative obstacle for climate litigation⁸. If claims pass procedural hurdles, more stringent causation standards for attributing losses to defendants' actions are applied to determine plaintiffs' entitlement to relief (remedies).

40 To establish causation, the court needs to receive scientific evidence, including through expert witness
testimony, bounded by rules on the expert's independence and duties to the court, and amicus briefs submitted
by third parties. Courts interpret this evidence through the lens of legal reasoning⁵. Such legal rules,
encompassing both "normative correctives" applied to evidence⁵ and the standard of proof, vary between
jurisdictions (Supplementary Information, 'Standards of proof in law'). Across jurisdictions, however, courts
45 ascribe value to authoritative sources of evidence such as Intergovernmental Panel on Climate Change reports
or peer-reviewed publications⁹. The *a priori* question motivating this research is whether the scientific evidence
courts were provided and have access to reflects the 'state of the art'.

Challenges to scientifically demonstrating causation

The fields of event attribution and trend detection and attribution evaluate the causal relationships at issue in
climate litigation. Attribution science comprises methods which generally use counterfactual inquiry to link
50 observed trends or changes in probability or intensity of climate-related events to human influence. Existing
methods can quantify the contribution of GHG emissions to specific events, including (1) extreme events,
including storms¹⁰, droughts¹¹, heatwaves¹², or floods¹³, (2) long-term trends in glacier lengths¹⁴ or sea levels,
and (3) persistent changes, for instance in mean temperatures or precipitation¹⁵. Despite the clear relevance of
attribution-science evidence, there is limited precedent for courts to base findings of causation on such
55 evidence, partly due to its relative novelty. In common with most forms of scientific evidence, including
regarding the health consequences of exposure to pharmaceutical substances, courts' use of climate-change
attribution evidence to assess causation is subject to several considerations.

First, GHG emissions are fungible and climate-change impacts result from the cumulative emissions of multiple
parties. This underlies use of 'market share theory'⁵, an approach which, following precedent in pharmaceutical
60 and tobacco litigation, allocates damages among defendants according to the portion of emissions for which
they are responsible³. Market share theory has been used to allocate damages in cases where losses derive
linearly or non-linearly from multiple entities' actions, to reduce evidentiary challenges in calculating
defendants' exact contributions to losses. It is recognised that this simplistic allocation basis may not exactly
reflect defendants' contributions to losses. Attribution-science evidence quantifying individual defendants'
65 contributions to plaintiffs' losses directly could be used instead of the market-share approach. This may be
helpful for impacts with non-linear emissions-impact relationships¹⁶.

Second, extreme weather events generally occur due to the combination of human influence and the underlying
chance that they would occur naturally. Climate lawsuits aim to follow past science-based tort litigation such as
product liability cases, which sought compensation for medical conditions arising from exposure to
70 pharmaceutical substances, tobacco smoke and asbestos³. Such conditions may have occurred in the absence
of this exposure. Similarly, climate change may increase the likelihood or intensity of an extreme event so
attribution statements are typically probabilistic. Legal frameworks exist for holding defendants responsible for
changes in an event's probability even if they make only a partial contribution to this change^{3,5}. Standards of

75 legal proof for probabilistic evidence may differ from the likelihoods evaluated in scientific assessments³ (Supplementary Information, 'Standards of proof in law').

Finally, in common with many types of expert evidence, attribution findings are question-dependant¹⁷ and influenced by the event definition. Contrasting approaches to framing attribution questions produce quantitatively differing results, while remaining scientifically valid¹⁸. These approaches vary in their alignment with the logic of legal causation (Supplementary Information, 'Approaches to conducting attribution studies').
80 Further, attribution assessments apply statistical methods to assess confidence and uncertainty in results¹⁹. Sources of uncertainty include limitations in model representations of the climate system and climatic observations for model evaluation. Uncertainty is assessed based on physical understanding of atmospheric processes and their representation in models, agreement between models and observations, and the quality of available evidence¹⁷.

85 **Climate science evidence in past litigation**

How well does the evidence submitted to climate-related lawsuits compare to the state-of-the-art in climate science? A growing body of literature explores the role attribution science can play in climate-related litigation, from legal and scientific perspectives^{3,5,20,21}. This is the first global study of the use and interpretation of climate-science evidence in lawsuits. We identify the scientific evidence needed to make successful causal arguments
90 and analyse the evidence provided by plaintiffs and defendants in 73 cases across 14 jurisdictions (Methods, Table 1, listed in full in Supplementary Table 1).

We consider cases that advance claims that defendants' GHG emissions impacted plaintiffs (Methods). Our analysis finds that most cases did not quantify the extent to which alleged impacts are attributable to climate change and fewer still provided quantitative evidence linking defendants' emissions and plaintiffs' injuries.
95 Although some recently-filed cases provided stronger evidence, e.g., refs. ²²⁻²⁴, 73% of cases did not refer to peer-reviewed attribution studies. Most of the cases that referred to attribution findings did so to establish general links between emissions and certain types of climate-change impacts, rather than to attribute losses sustained by plaintiffs. Moreover, despite substantial evidence that climate change increases the probability and intensity of a range of events, not all climate-related hazards are affected by climate change¹⁷. This
100 underlines the importance of providing evidence specific to the impact for which a causal link is alleged^{3,5}.

54 cases cited meteorological extremes as the cause of alleged impacts (Supplementary Table 2). Of these cases, 26 claimed that weather events occurred due to climate change, without providing evidence. A further 6 provided no quantitative estimate of the influence of climate change on the event's magnitude or probability. Losses stemming from extreme weather events cannot be presumed attributable to climate change *a priori*²⁵.
105 Even for events where climate change plays a substantial role, GHG emissions will increase the event's likelihood or intensity, rather than being its sole cause²⁶. Further, many legal claims concerned events, such as tropical cyclones, for which evidence of human influence is limited²⁷, or for which technical obstacles to conducting attribution assessments exist¹⁰. However, climate change substantially influences other events with

110 considerable humanitarian consequences, such as heatwaves and some droughts²⁸. Establishing causation is
easiest for events where the influence of climate change is greatest: these are logical subjects of climate
lawsuits.

38 cases made causal allegations related to sea-level-rise impacts. Human influence is very likely the dominant
cause of global-mean sea-level change since 1970²⁹. However, regional sea levels may differ due to natural and
human-influenced processes, modifying the anthropogenic contribution to impacts. These processes include
115 regional variation in thermal expansion and ocean and atmospheric circulation, glacial-isostatic adjustment,
and land subsidence²⁹. Factors such as subsidence outweigh the effect of human-induced climate change in
some regions³⁰. 12 cases concern impacts of glacier retreat (Supplementary Table 2), an established
consequence of climate change¹⁴. However, individual glaciers' response to climate change depends on their
geographic and climatic settings³¹. Linking emissions to glacial and sea-level-rise impacts at the appropriate
120 level of specificity for establishing legal causation may require evidence on these local factors (Box 1). This is
uncommon in the cases analysed.

The evidence needed for legal causation

Many of the lawsuits assessed here are at the early stages of adjudication or were dismissed before substantive
consideration of causation arguments. Our analysis of courts' interpretation of scientific evidence considers all
125 lawsuits in which courts evaluate this evidence, including cases that were ultimately dismissed for reasons
unrelated to issues of causation.

Courts evaluate scientific evidence by applying tests which set evidentiary thresholds for establishing causation.
Across jurisdictions, causal analyses focus on the relationship between defendants' conduct and plaintiffs'
losses, but the tests and standards of proof applied vary (Supplementary Information, 'Causation tests used in
130 climate litigation'). Our analysis finds that some courts required defendants to be the sole or material
contributor to the alleged harms^{32,33}; others have applied causality tests more flexibly. However, plaintiffs have
been unable to overcome even the more flexible causation tests applied in several jurisdictions which ask if
damages are 'fairly traceable' to defendants' actions³⁴⁻³⁶. This is typically due to courts' finding that the
evidence provided does not substantiate the connection between individual emitters' actions and plaintiffs'
135 losses. In our view, in most cases concerning impacts for which the causal link to climate change does exist,
existing scientific methodologies could fill the evidentiary gaps identified by courts.

Our analysis shows that when courts considered evidence on causation, they typically found that plaintiffs failed
to demonstrate that defendants' emissions caused the alleged impacts. Plaintiffs have claimed, with or without
supporting evidence, that climate change caused certain harms and therefore that defendants' GHG emissions
140 render them liable for a portion of these losses. In claims seeking compensation for climate-change impacts
brought in the US, Germany and New Zealand, courts found that plaintiffs failed to demonstrate that their
injuries would not have occurred in the absence of defendants' emissions. These findings were due to
defendants' small contribution to climate change³⁷, the high number of emitters responsible³³, the absence of

145 a method for discerning entities responsible for impacts³⁸, and the lack of a direct causal link between
defendants' actions and losses^{32,34,35,39-41}. In some cases, courts have incorrectly stated the infeasibility of
attributing climate impacts to individual emitters³³. Similarly, in claims seeking emission reductions, courts
found that plaintiffs failed to demonstrate how a positive judgement would reduce climate-change impacts³³.

150 In our view, these findings are not a product of technical limitations preventing the production of required
evidence. Scientific evidence on the influence of individual actors' GHG emissions is available for existing⁴²⁻⁴⁴
and projected impacts⁴⁵.

Despite inter-jurisdictional variation in the standards of proof for causation, there are shared characteristics of
evidence needed to support claims. Cases seeking compensation for adaptation costs must demonstrate that
(1) risk mitigation measures are required, and (2) the cost sought is a consequence of climate change resulting,
in part, from defendants' actions. Evidence submitted in cases of this type generally demonstrated that the
155 hazards threatening plaintiffs' property and wellbeing were substantial and required hazard-mitigation
measures. However, the evidence for causation was typically much weaker, despite availability of the scientific
methodologies needed to generate it (see above). Cases claiming that adaptation policies are inadequate may
argue that losses were foreseeable due to climate change (e.g., ref. ⁴⁶) which may in turn be supported by
attribution-science evidence.

160 Lawsuits seeking emission reductions considered in this analysis (Methods) make causal claims about the
impact of a positive judgment on projected impacts, usually to establish legal standing. Our analysis shows that
a case was dismissed by a court in the U.S.⁴⁷ partly due to plaintiffs' failure to establish standing because they
did not demonstrate that emission reductions would reduce the impacts they experience. Scientific evidence
linking defendants' GHG emissions to future impacts would address this finding.

165 **The evidence gap in climate litigation**

The existing literature suggests that there are real challenges to satisfying causation tests in climate-related
litigation^{3,5}. In our view, at least some of these challenges can be addressed by better exploiting scientific
developments, particularly in the field of climate-change attribution. It is therefore crucial that plaintiffs have
access to this science, and that this evidence is brought to the attention of courts. Our analysis identifies three
170 areas where scientific research could address existing evidentiary shortfalls: (1) attribution of climate-change
impacts to individual emitters of GHGs⁴²⁻⁴⁵ (possible using existing attribution-science methods), (2) research
on the foreseeability of climate-change impacts resulting from future emissions, and (3) research disentangling
the legally-relevant social and physical drivers of climate risks and impacts. The latter recommendation is the
most methodologically challenging, due to challenges in quantifying non-climatic contributions to impacts.

175 Establishing a defendant's contribution to plaintiffs' losses has presented a key challenge in cases in which
causal claims have been adjudicated. However, current scientific methodologies enable quantifying individual
emitters' marginal contributions to extreme weather events and slow-onset changes⁴²⁻⁴⁴. Methods for
modelling the response of the climate system to excluding certain GHG emissions exist⁴⁸ and have been applied

to evaluate the contribution of countries' emissions to extreme-weather probabilities⁴². Evidence of this type
180 appears capable of plugging evidentiary gaps identified in some prior cases^{32,34,35,37-41}. In some lawsuits seeking
emission reductions, plaintiffs argued that implementing emission-reduction measures would reduce otherwise
anticipated impacts, typically to establish standing. In one case, the court found that defendants had not
breached legal duties as plaintiffs failed to demonstrate how requested emission reductions would affect the
magnitude of climate-change impacts⁴⁷. Counterfactual analyses could support these claims by assessing
185 individual emitters' contributions to projected changes in impacts under future climate change (e.g., ref. ⁴⁵).

Our analysis also suggests that there is scope to develop evidence which provides a more complete assessment
of the drivers of losses on which claims are based. Climate-related losses result from physical events, about
which attribution science provides evidence, mediated by communities' exposure and vulnerability to these
hazards⁴⁹. Research that evaluates the relative importance of different drivers and which of these factors
190 constitute the legally relevant cause(s) of losses may support establishing defendants' liability for climate
impacts.

Finally, although most attribution findings are presented in terms of changing event probability, 48% of cases
analysed made claims about the impact of climate change on the magnitude, rather than probability, of events.
Attribution evidence on event intensities can be provided using existing methods (e.g., refs. ^{10,12}) and may be
195 more informative for some impacts, like adverse effects on human health⁵⁰. Such evidence may also strengthen
legal claims by providing an evidentiary basis for asserting that a defendant's conduct has made a plaintiff worse
off. Attributing changes in event intensity to a defendant aligns with the logic of the 'but-for' test in law and
may satisfy causation tests by showing how the magnitude of a harm was altered by an individual defendant's
conduct. Future research could determine whether probability or intensity-based attribution metrics best
200 assess the contribution of climate change to different types of losses.

Individuals, communities and activist non-governmental organisations have increasingly turned to the courts
for relief for costs associated with present-day climate change impacts, or to avoid future impacts. While the
cases we examined may not have been dismissed solely on evidentiary grounds, existing case law provides
insight into the challenges that need to be addressed if future climate-related lawsuits are to succeed. As
205 plaintiffs overcome initial procedural hurdles, such as standing, evidence on causation will become more
determinative of case outcomes. Attribution science is a fundamental source of evidence for informing and
substantiating causal claims about climate-change impacts, hitherto underutilised in law²¹.

Our analysis of 73 cases from 14 jurisdictions finds that, in contrast to previous interpretations⁸, limitations in
the scientific evidence provided to past lawsuits may have hindered the making of findings of causation. This
210 conclusion is based on the finding that such evidence lags significantly behind the state-of-the-art in climate
science. To maximise the chances of establishing causation in the courts, plaintiffs should ensure that (1) cases
filed concern impacts that are demonstrably attributable to climate change, and (2) that evidence submitted to
the courts clearly substantiates the alleged relationship between defendants' emissions and plaintiffs' losses.

Across jurisdictions, courts have found insufficient links between defendants' emissions and plaintiffs' injuries. In some cases courts have explicitly, and incorrectly, stated the infeasibility of scientifically attributing climate impacts to individual emitters^{33,34}. This underlines the importance of dialogue between the legal and scientific communities on the factual basis for causal claims. Better dialogue would ensure that lawyers are aware of, and able to request, evidence that can be used to robustly evaluate causal claims. This could be achieved through selection of independent experts with relevant scientific expertise, such as Intergovernmental Panel on Climate Change authors, as well as (outside the context of any particular case) funding to support the continuing development of the science in this field. Effective use of climate-science evidence in the courts could overcome existing obstacles to causality, set precedent for demonstrating legal causality with climate-science evidence, and make successful litigation on climate-change impacts feasible.

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Author contributions

All authors planned the analyses which R.S.-S., A.S., and G.L. performed. All authors contributed to the interpretation of the results and to writing the manuscript.

320 Competing interests

The authors declare no competing financial or non-financial interests.

Box 1: Scientific evidence in past lawsuits

Case study 1: Lliuya v. RWE AG

In 2015, Saúl Luciano Lliuya filed a case against a German energy company, RWE, seeking compensation for the pro rata cost of measures taken to protect his property against climate change impacts, based on Article 1004 of the German Civil Code. This article applies the ‘conditio sine qua non’ test for causality: the plaintiff’s injury would not have occurred fully or partially if not for the defendant’s activity. The District Court of Essen dismissed the case, reasoning that RWE would not qualify as “disturber by conduct” under Section 1004 of the German Civil Code given that the number of contributors to climate change render attributing individual damages to specific actors impossible. On appeal, the Higher Regional Court of Hamm accepted that the case has been conclusively argued and initiated an evidentiary phase. The first stage of the evidentiary phase assesses whether the claimant’s property is indeed seriously threatened by a potential glacial lake outburst flood, including a court visit to Peru. Subsequently, the court will assess evidence around whether the heightened flood risk is attributable to RWE, and finally whether the damage contributed by the defendant is measurable and can be calculated.

Recent research has demonstrated that it is indeed possible to provide an attribution assessment spanning the full causal chain in this setting¹⁴.

Case study 2: Native Village of Kivalina v. ExxonMobil Corp.

In 2008, the Alaskan village of Kivalina filed a public nuisance claim seeking to hold 24 energy companies liable for coastal erosion, alleged to be due to climate change, which threatened the village, requiring it to be relocated inland. The Court applied the ‘fair traceability’ test, which requires the plaintiff to demonstrate a substantial likelihood that the defendant’s conduct (emissions) was the seed of the plaintiff’s injury. The U.S. Court of Appeals for the Ninth Circuit dismissed the lawsuit, in part due to the plaintiff’s failure to establish standing through demonstrating causation. The Court ruled that the causal link between the defendant’s activities and the plaintiff’s damage was too indirect since “it is not plausible to state which emissions – emitted by whom ... and at what place in the world – ‘caused’ Plaintiffs’ alleged global-warming related injuries [because there are] a multitude of ‘alternative culprit[s]’ allegedly responsible for the various chain [sic] of events allegedly leading to the erosion of Kivalina”³⁴.

While attribution-science research specifically addressing the causal link alleged in this case (i.e., specific to the impacts at this location) does not yet exist, it would be scientifically possible to conduct a study to determine the extent to which defendants’ emissions led to the losses experienced by Kivalina.

Country	Number of cases	Successful	Dismissed	Pending
Australia	3	0	1	2
Belgium	1	0	0	1
Canada	3	0	0	3
Colombia	1	1	0	0
Germany	2	0	1	1
Ireland	1	1	0	0
Netherlands	2	1	0	1
New Zealand	4	1	2	1
Pakistan	2	1	0	1
Philippines	1	0	0	1
South Korea	1	0	0	1
Switzerland	1	0	1	0
Uganda	1	0	0	1
USA	45	3	21	21
International jurisdictions	5	0	2	3

Table 1: Number of cases and case outcome (as of November 2020) for lawsuits considered in this analysis, categorised by jurisdiction. Cases are listed in full in Supplementary Table 1.

Methods

Scope of case-law analysis

330 Our case law analysis covers cases that make claims about the past, present and future impacts of climate change and the relationship between GHG emissions and these impacts. We sought to analyse all lawsuits, brought using a variety of legal bases, where courts considered scientific evidence on causation. Cases were selected through a systematic review of the Sabin Center for Climate Change Law at Columbia Law School's climate litigation database (<http://climatecasechart.com/>) conducted in May 2020. The database categorises cases according to criteria such as the case objective (for instance, 'actions seeking adaptation measures) or the principal laws under which the claim was brought. Cases within relevant 'case categories' were identified and assessed for alignment with the project scope, including by searching for the presence of keywords pertaining to climate-change impacts in complaints. Claims in the following categories of the Sabin Center database were assessed for their relevance to the project scope: Adaptation (including 'Actions seeking money damages for losses'), Public Trust Claims, Common Law Claims, Climate Change Protestors and Scientists, and claims brought under the National Environmental Policy Act (U.S.); Suits against Corporations, Public Trust, Human Rights, GHG Emissions Reduction and Trading, Climate Adaptation (non-U.S.). The review of the Sabin Center database was supplemented by a review of cases cited in relevant academic literature, e.g., refs. ^{3,8,51}. A review of news articles was used to identify cases filed during the period over which we conducted the analysis, in September 2020.

345 We identified a list of 73 cases from 14 national jurisdictions which either refer directly to attribution science or use evidence to claim that climate change is or will become responsible for particular damages. The cases determined to be within the project scope do not include those that refer only to general impacts of climate

change. Rather, we only consider cases that make causal claims about impacts in specific locations, for which attribution-science evidence is relevant.

350 Cases identified within this scope fell into the categories of tort, human rights, public trust, takings, contract, judicial review, and federal statutory claims. The tort and human rights claims typically sought remedies in the form of financial compensation for climate change impacts or emission reductions. All ‘damage liability’ suits that were filed relied on causal argumentation about the relationship between emissions and impacts. By contrast, only a subset of pro-regulatory claims for emission reductions - typically brought as human rights
355 claims, or, for U.S. cases, under the public trust doctrine – have sought to link the actions of defendants to specific climate-related losses. Those that did were included within the project scope (Supplementary Table 1). Similar lawsuits that did not make claims that defendant emissions caused specific climate-related losses were excluded from the analysis as attribution science evidence was not relevant to the legal arguments made in these cases. We note that, in future, attribution-science evidence may be used by a wider range of lawsuits^{3,21}.

360 In our evaluation of the scientific evidence provided by parties to the case, we considered for inclusion publicly available case documents submitted by plaintiffs, defendants, and other parties. Such documents included complaints, petitions, responses, motions, and amicus briefs. A list of key documents which were used to inform our findings, for each case, is included in Supplementary Table 1. We included cases in early stages of litigation (for instance, for which only the complaint was available) but excluded two cases believed to be within the
365 scope of the research for which either no court documents were available (Petition of Torres Strait Islanders to the United Nations Human Rights Committee), or for which court documents, or high-quality translations of them, were only available in languages not spoken by the research team (*Federal Environmental Agency (IBAMA) v. Siderúrgica São Luiz Ltd. and Martins*). Documents in English, Spanish, and French were included. In a small number of cases, such as *Friends of the Irish Environment v. Ireland*, the Petition or complaint could not
370 be made public and so only the legal analysis of the judgement and appeal was possible.

We then identified court documents which introduced evidence or claims regarding the potential causal relationship between greenhouse-gas emissions and climate change impacts. As far as possible this was approached systematically through the use of a series of relevant search terms. We reviewed non-searchable documents manually.

375 Regarding the judicial assessment of the scientific evidence provided to cases, we considered final decisions and opinions, as well as court documents released during the pre-trial stage, such as orders to grant or dismiss motions to remand, orders to accept amicus briefs, or questions directed to expert witnesses.

Scientific analysis

The scientific analysis seeks to understand the nature of the attribution-science evidence used in climate-related legal cases. We identify key components of the evidence in each case within the project scope, through
380 a review of complaints, expert testimony, and defendants’ responses. These factors include (i) the type of attribution evidence provided in the case, (ii) the strength of attribution evidence as presented in the case (and

as compared with that available in the published literature), (iii) the methodologies used to quantify attributable damages, and (iv) the content of expert testimony.

385 For each lawsuit, we evaluated the type of evidence provided on causation according to the source of the evidence used for alleging the existence of a causal link between GHG emissions and impacts. Evidence from Intergovernmental Panel on Climate Change (IPCC) reports has commonly been submitted by plaintiffs to substantiate claims, including in unsuccessful cases. IPCC attribution assessments of climate change impacts are typically regional or global in scale, and therefore do not provide evidence specific to damages alleged in
390 most cases. To understand how different forms of attribution knowledge affect legal interpretation, we differentiate between cases that extrapolate from regional / global attribution statements, those where attribution is presumed based on consistency of impacts with published and peer-reviewed climate projections, those for which attribution is presumed with no supporting evidence, and those that use an attribution study into the causes of the impacts sustained by plaintiffs, and whether or not it has been peer-reviewed.

395 Further to our assessment of cited attribution evidence, where relevant, our analysis considers the expert testimony admitted to cases. This includes considering which experts are called upon and whether they have published in the field of attribution science.

Our analysis of the strength of attribution evidence used in within-scope cases considers the magnitude of human influence on the climatic event relevant to the litigation, and the confidence in and uncertainty associated with these findings. We can therefore assess the extent to which the magnitude of human influence
400 found affects the legal determination of causality, in the context of jurisdiction-specific standards, such as the ‘doubling of the risk’ test in England and Wales³. Further, we considered any evidence provided about plaintiffs’ pre-existing (independent of climate change) vulnerability to climate impacts, including defendants’ use of pre-existing vulnerabilities to counter plaintiffs’ arguments that there is a causal link between GHG emissions, and
405 the impacts experienced.

Finally, we consider how assessment of the attribution of physical impacts corresponds to the damages sought in the case. For each lawsuit, we identify whether plaintiffs sought to claim that the entire cost of the damages was attributable to anthropogenic GHG emissions, or whether damages were quantified according to attributable changes in event intensity or probability. We also consider whether economic and/or non-
410 economic losses are quantified, what relief was requested, and how a defendant’s contribution to losses was quantified in determining the requested relief.

Our assessment of the scientific evidence provided in the cases analysed includes the collection of qualitative – such as whether the type of evidence provided on causation was a peer-reviewed attribution study or a regional attribution statement from an IPCC report – and quantitative – for instance on the magnitude of economic relief
415 requested – data, supplemented by expert judgements.

Legal analysis

For each lawsuit within the scope of the analysis, for which courts' opinions, decisions, orders, or judgements were available (Supplementary Table 1), we evaluated how the courts have assessed and interpreted the scientific evidence on causation brought before them. The immediate obstacles to the success of litigation have largely been on admissibility and procedural grounds⁸, with causation evidence generally not being outcome determinative. Our analysis, therefore, evaluates judicial opinion on causal arguments irrespective of the immediate reason for the case outcome and identifies how attribution science evidence can best support litigation if non-evidentiary, procedural obstacles are overcome. We identify trends across jurisdictions and time in how attribution science has been used by litigants and interpreted by courts to overcome procedural and evidentiary hurdles to successful litigation.

Our legal analysis considers courts' use of scientific evidence in establishing the admissibility of a case (as used under English law: whether a court has jurisdiction to adjudicate on a matter) or in satisfying procedural and substantial requirements of the law. For a case to be admissible, plaintiffs must have standing to bring the lawsuit, and defendants must have legal duties to plaintiffs which they may have breached. We consider whether a court finds that a sufficient link exists between the losses experienced by plaintiffs and climate change, as well as the link between defendants' emissions and these losses. We also assess the extent to which courts find that plaintiffs' losses were foreseeable to defendants, and the admissibility of expert testimony. We further identify whether courts find defendants to be liable for losses. Our analysis focuses on the extent to which deficits in scientific evidence played a role in a courts' assessments of these issues. We also consider the approaches courts have taken in responding to scientific arguments concerning defendants' contributions to alleged impacts, including the apportioning of liability based on market share of emissions or on defendants' marginal contribution to impacts.

In cases in which courts have directly engaged with causation arguments, we identify the tests applied by the courts, how these have varied between jurisdictions and over time, and the differences between these tests. We then consider the implications of these causation tests for the courts' evaluation of scientific evidence and the standards of proof that plaintiffs need to meet to bring successful climate change lawsuits.

Finally, we provide an overall assessment of the role of science in case outcomes and an analysis of the required changes in scientific evidence that would improve the likelihood of establishing causation in future cases. We contextualise this analysis in the challenges faced when applying existing legal concepts to novel, global challenges for which they may not be well suited⁵².

Data availability: Case documents were sourced primarily from the Sabin Center for Climate Change Law at Columbia Law School's Climate Change Litigation database (<http://climatecasechart.com/>). Where relevant case documents were unavailable on this database, they were sourced from individual courts' public databases or from Westlaw.

References

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52. Fisher, E., Scotford, E. & Barritt, E. The Legally Disruptive Nature of Climate Change. *Mod. Law Rev.* **80**, 173–201 (2017).