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Filling the evidentiary gap in climate litigation

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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. So far, 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 increase[1]. 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 change[2]. Robust scientific evidence is critical to the success of such claims[3–5]. For example, claims for compensatory damages must demonstrate a causal link between the defendant's behaviour and the plaintiff's injury. Recognizing 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' contributions to the risk of harm[5]. However, despite developments in scientific[6] and legal theory[5] 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 policies[7]. 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. So far, admissibility has been the primary outcome-determinative obstacle for climate litigation[8]. If claims pass procedural hurdles, more stringent causation standards for attributing losses to defendants' actions are applied to determine plaintiffs' entitlement to relief (remedies).

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 reasoning[5]. Such legal rules, encompassing both 'normative correctives' applied to evidence[5] and the standard of proof, vary between jurisdictions (Supplementary Information, 'Standards of proof in law'). Across jurisdictions, however, courts ascribe value to authoritative sources of evidence such as IPCC reports or peer-reviewed publications[9]. The a priori question motivating this research is whether the scientific evidence courts were provided with 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 that generally use counterfactual enquiry to link observed trends or changes in the 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 storms[10], droughts[11], heatwaves[12] or floods[13], (2) long-term trends in glacier lengths[14] or sea levels and (3) persistent changes, for instance in mean temperatures or precipitation[15]. Despite the clear relevance of attribution-science evidence, there is limited precedent for courts to base findings of causation on such 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 that, following precedent in pharmaceutical and tobacco litigation, allocates damages among defendants according to the portion of emissions for which they are responsible[3]. Market share theory has been used to allocate damages in cases where losses derive linearly or nonlinearly from multiple entities' actions, to reduce evidentiary challenges in calculating defendants' exact contributions to losses. It is recognized that this simplistic allocation basis may not exactly reflect defendants' contributions to losses. Attribution-science evidence that directly quantifies individual defendants' contributions to plaintiffs' losses could be used instead of the market share approach. This may be helpful for impacts with nonlinear emissions–impact relationships[16].

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Table 1 | Number of cases and case outcomes (as of November 2020) for lawsuits considered in this analysis, categorized by jurisdiction

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
the 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
United States of America	45	3	21	21
International jurisdictions	5	0	2	3

Cases are listed in full in Supplementary Table 1.

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 pharmaceutical substances, tobacco smoke and asbestos[3]. 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 legal proof for probabilistic evidence may differ from the likelihoods evaluated in scientific assessments[3] (Supplementary Information, 'Standards of proof in law').

Finally, in common with many types of expert evidence, attribution findings are question dependant[17] and influenced by the event definition. Contrasting approaches to framing attribution questions produce quantitatively differing results, while remaining scientifically valid[18]. These approaches vary in their alignment with the logic of legal causation (Supplementary Information, 'Approaches to conducting attribution studies'). Further, attribution assessments apply statistical methods to assess confidence and uncertainty in results[19]. 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 evidence[17].

Climate-science evidence in past litigation

How well does the evidence submitted to climate-related lawsuits compare with 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]. Here we present a global analysis of the use and interpretation of climate-science evidence in lawsuits. We identify the scientific evidence needed to make successful causal arguments and analyse the evidence provided by plaintiffs and defendants in 73 cases across 14 jurisdictions (Methods, Table 1 and 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. Although some recently filed cases provided stronger evidence, for example, 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 impact, 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 change[17]. This underlines the importance of providing evidence specific to the impact for which a causal link is alleged[3,5].

Meteorological extremes were cited by 54 cases 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 six 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]. 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 cause[26]. Further, many legal claims concerned events, such as tropical cyclones, for which evidence of human influence is limited[27], or for which technical obstacles to conducting attribution assessments exist[10]. However, climate change substantially influences other events with considerable humanitarian consequences, such as heatwaves and some droughts[28]. Establishing causation is easiest for events where the influence of climate change is greatest: these are logical subjects of climate lawsuits.

Causal allegations related to sea-level-rise impacts were made by 38 cases. Human influence is very likely the dominant cause of global-mean sea-level change since 1970[29]. However, regional sea levels may differ due to natural and human-influenced processes, modifying the anthropogenic contribution to impacts.

Box 1 | Scientific evidence in two past lawsuits

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 defendant's contribution to this risk 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 setting[14].

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 that threatened the village, alleged to be due to climate change and 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 (that is, 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.

These processes include regional variation in thermal expansion and ocean and atmospheric circulation, glacial-isostatic adjustment and land subsidence[29]. Factors such as subsidence outweigh the effect of human-induced climate change in some regions[30]. Twelve cases concern impacts of glacier retreat (Supplementary Table 2), an established consequence of climate change[14]. However, individual glaciers' response to climate change depends on their geographic and climatic settings[31]. Linking emissions to glacial and sea-level-rise impacts at the appropriate 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 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 that 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 climate litigation'). In some cases, claimants have had to show that the defendant's actions constituted material contributions to harm[32,33]; others applied causality tests more flexibly. However, plaintiffs have been unable to overcome even the more flexible causation tests applied in several jurisdictions that ask if damages are 'fairly traceable' to defendants' actions[34–36]. This is typically due to courts finding that the evidence provided does not substantiate the connection between individual emitters' actions and plaintiffs' 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 render them liable for a portion of these losses. In claims seeking compensation for climate change impacts brought in the United States, 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 change[37], the high number of emitters responsible[33], the absence of a method for discerning entities responsible for impacts[38] 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 emitters[33]. Similarly, in claims seeking emission reductions, courts found that plaintiffs failed to demonstrate how a positive judgement would reduce climate change impacts[33].

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 existing[42–44] and projected impacts[45].

Despite interjurisdictional 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 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 (for example, ref. [46]), which may in turn be supported by attribution-science evidence.

Lawsuits seeking emission reductions considered in this analysis (Methods) make causal claims about the impact of a positive judgement on projected impacts, usually to establish legal standing. Our analysis shows that a case was dismissed by a court in the United

States[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.

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 areas where scientific research could address existing evidentiary shortfalls: (1) attribution of climate change impacts to individual emitters of GHGs[42–45] (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.

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 changes[42–44]. Methods for modelling the response of the climate system to excluding certain GHG emissions exist[48] and have been applied to evaluate the contribution of countries' emissions to extreme weather probabilities[42]. Evidence of this type 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 impacts[47]. Counterfactual analyses could support these claims by assessing individual emitters' contributions to projected changes in impacts under future climate change (for example, ref. [45]).

Our analysis also suggests that there is scope to develop evidence that 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 hazards[49]. Research that evaluates the relative importance of different drivers and which of these factors 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 (for example, refs. [10,12]) and may be more informative for some impacts, such as adverse effects on human health[50]. 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 assess the contribution of climate change to different types of loss.

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 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 underutilized in law[21].

Our analysis of 73 cases from 14 jurisdictions finds that, in contrast to previous interpretations[8], limitations in the scientific evidence provided to past lawsuits may have hindered the making of findings of causation. This conclusion is based on the finding that such evidence lags substantially behind the state of the art in climate science. To maximize 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 IPCC 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.

Online content

Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41558-021-01086-7.

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Methods

Scope of case-law analysis. 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 categorizes 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 (United States); Suits against Corporations, Public Trust, Human Rights, GHG Emissions Reduction and Trading, Climate Adaptation (non-United States). The review of the Sabin Center database was supplemented by a review of cases cited in relevant academic literature, for example, 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.

We identified a list of 73 cases from 14 national jurisdictions that 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.

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 claims, or, for US 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 the future, attribution-science evidence may be used by a wider range of lawsuits[3,21].

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 for each case that were used to inform our findings is provided 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 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 be made public and so the legal analysis of only the judgement and appeal were possible.

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

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 pretrial 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 a review of complaints, expert testimony and defendants' responses. These factors include (1) the type of attribution evidence provided in the case, (2) the strength of attribution evidence as presented in the case (and as compared with that available in the published literature), (3) the methodologies used to quantify attributable damages and (4) the content of expert testimony.

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 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 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.

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 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 Wales[3]. 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 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-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 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 grounds[8], 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 that 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 contextualize this analysis in the challenges faced when applying existing legal concepts to novel, global challenges for which they may not be well suited[52].

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

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.

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Author contributions

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

Competing interests

The authors declare no competing interests.

Additional information

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Ecological, evolutionary & environmental sciences study design

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Study description	Analysis of 73 climate-related lawsuits from 14 jurisdictions, evaluates the scientific evidence provided to the courts and courts' interpretation of this evidence.
Research sample	73 legal cases
Sampling strategy	Systematic review of legal databases, selection of all cases within project scope.
Data collection	Paper authors RSS and GL followed a methodology developed by all authors and identified relevant components of case documents for analysis.
Timing and spatial scale	Data collected from case documents June - September 2020, all relevant court documents evaluated once.
Data exclusions	No data excluded from analysis
Reproducibility	Analysis methodology is stated in manuscript Methods section, efforts made to minimise subjective judgment in data collection during analysis of cases.
Randomization	Not relevant. No relevant experimental methods.
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