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Theories of climate attribution in climate change litigation: Resolving the loss and damage causation dilemma

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Abstract: The causation conundrum in climate change litigation has long plagued the legal and scientific communities. This article explores the role of climate attribution theory in solving the loss and damage causation puzzle in climate change litigation. First, it describes the limitations of traditional causation theories in climate change litigation and analyzes the performance of emerging theories, such as the "substantial contribution" theory and the "market share" theory, in addressing this issue. The paper then evaluates the application of climate attribution theory in actual litigation through specific case studies and puts forward a series of policy recommendations. These include strengthening funding and support for climate attribution research, establishing a platform for interdisciplinary cooperation, developing a unified standard of proof, promoting public and judicial education, and promoting the improvement of the international legal framework. Finally, the paper points out the main problems and limitations in the application of climate attribution theory and proposes key directions for future research. The paper posits that by fostering continuous scientific research and enhancing the legal framework, climate attribution theory will assume a more prominent role in climate change litigation and facilitate the process of global climate governance.

Keywords: climate change litigation; causation; climate attribution theory; interdisciplinary cooperation; legal framework

1. Introduction

As the climate crisis intensifies and the responses of both the public and private sectors prove inadequate, an increasing number of individuals are seeking climate remedies in the courts. As documented in the Global Climate Litigation Report 2023: A Review of the Current State of Play, published in 2023 by the United Nations Environment Programme (UNEP) and the Sabin Center for Climate Change Law at Columbia University, indicates that since 2017, the total number of climate change court cases has more than doubled and continues to grow globally. This increase is characterised by the increasing number of cases involving a wider range of theories and across a wider geographic span. The Sabin Center for Climate Change Law's Climate Change Litigation Database indicates that there are 1934 cases in addition to the United States, with 2207 cases in the United States. The accelerated growth of climate change litigation serves to illustrate the growing reliance on legal avenues to address the complex and multifaceted climate crisis. One of the most significant legal challenges in such cases is the determination of causation. This specifically entails the challenge of linking specific adverse climate impacts to particular actions or omissions of defendants. The intricacy of this undertaking is compounded by the complex and interwoven nature of the climate system, as well as the multitude of actors involved in the emission of greenhouse gases. From a scientific perspective, the field of climate

attribution has emerged as a crucial tool for quantifying the impact of human activity on climate events. The objective of attribution science is to ascertain the extent to which human-induced climate change has contributed to specific extreme weather events or patterns. Nevertheless, while this scientific framework offers valuable evidence, translating scientific causation into legal causation presents unique challenges. In legal proceedings, the concept of causation entails not only the demonstration that the actions of the defendant resulted in a harmful outcome, but also the substantiation that this contribution meets the requisite legal thresholds, such as those pertaining to foreseeability and proximate cause. This legal manifestation of causation differs from the scientific approach, in which causation may be established through probabilistic models and statistical analyses. A study conducted by the University of Oxford, which evaluated the utilization handling of scientific evidence in 73 climate-related lawsuits. The objective was to assess the scientific and legal basis for determining causation. The study found that the evidence presented and cited in these cases lagged significantly behind the latest developments in climate science, namely the science of climate causation. This hindered the ability to substantiate causation claims (Stuart-Smith et al., 2021) Climate change attribution can serve to fill an evidentiary gap in climate litigation by quantifying human-induced climate change. In detail, climate attribution can bridge the gap identified by judges between the general recognition of the negative impacts of human-induced climate change and the provision of concrete evidence of the role of climate change in a particular location in relation to a particular extreme event that has led or will lead to losses (Peel, 2020). Consequently, the translation of attribution of causation in science into legal causation is possible. Nevertheless, while attributional science can provide a fact-based foundation for causation in climate change litigation, it is misguided to view it as a panacea. Furthermore, attributional science still has limitations (Burger et al., 2021). The question of how to respond to the opportunities and challenges that attribution science brings to climate change litigation is one that must be answered by all countries in response to climate change.

2. The causation dilemma in climate change litigation

In recent years, as the impacts of climate change on the global environment, economy, and society have become more pronounced, there has been a corresponding increase in the number of lawsuits filed involving loss and damage caused by climate change. The lawsuits are primarily aimed at holding governments, businesses, and other entities accountable for their actions. The plaintiffs are typically individuals, communities, or non-governmental organizations (NGOs) that have been affected by climate change (Oxford, 2023). One of the central issues in these litigation cases is the question of how to prove the causal link between climate change and specific loss and damage. However, due to the complexity of climate change and the intersection of multiple factors, proving this causal link presents significant legal challenges.

2.1. Traditional causation theories are difficult to apply to climate change litigation

In legal proceedings, proof of causation necessitates that the plaintiff demonstrates that the defendant's actions (e.g., greenhouse gas emissions) directly or indirectly resulted in a specific loss or damage (Briscoe, 2022). Traditional theories of causation necessitate a clear direct causal chain, i.e., that A behavior directly causes B outcomes. However, multiple chains of causation and indirect causation are often present in climate change issues, making traditional causation theories difficult to apply (Kaduk, 2021). For example, in a lawsuit filed by several cities and counties in California against major oil companies, the plaintiffs allege that the companies continued to produce and sell fossil fuels despite being aware that their products would have a significant impact on the climate, leading to rising sea levels and extreme weather events, causing significant economic losses and environmental damage to the coastal areas (Al-Nasser, 2023). In this case, plaintiffs would be required to demonstrate a clear causal relationship between the specific emissions behavior of these oil companies and the specific damages they have incurred. However, climate change is a global phenomenon influenced by a multitude of natural and anthropogenic factors, making it challenging to directly link emissions from a single individual or isolated act to a specific climate event (Carrico, 2021). For instance, sea level rise may be influenced by a multitude of emission sources on a global scale, and the contribution of any single source is challenging to discern and quantify (Sindelarova et al., 2023).

Similarly, in the Philippines, a group of typhoon victims sued 47 of the world's largest oil, gas, and coal companies, claiming that they were responsible for climate change because their large-scale greenhouse gas emissions had a significant impact on climate change, leading to catastrophic damage from Typhoon Haiyan (Driessen, 2018). The difficulty of proving causation in such cases is further compounded by the fact that plaintiffs must demonstrate the extent to which the companies' emissions increased the intensity and destructive power of the typhoon. However, causation in the context of climate change is often indirect and cumulative, making it challenging to prove it directly using traditional theories of causation.

2.2. Attempts and limitations of new theories

In response to the causation challenge in climate change litigation, the legal and scientific communities have jointly explored a number of new theories and approaches, including the "substantial contribution" theory, the "market share" theory, and other innovative approaches (Otto, 2022). These new theories attempt to provide a more flexible and applicable approach to proving causation in climate change litigation in the context of multiple factors and complex causal chains. While these theories offer more flexibility in proving causation, their practical applications remain fraught with challenges, and their limitations must be acknowledged.

The substantial contribution theory posits that a defendant can be held legally liable if their actions have contributed substantially to climate change and related losses to a certain extent (Otto, 2022). For instance, in Germany, Saul Luciano Lliuya, a Peruvian farmer, initiated legal proceedings against the German energy

conglomerate RWE, claiming that its emissions of greenhouse gases had contributed to the melting of glaciers in the Peruvian Andes, thereby increasing the risk of flooding and endangering his home and livelihood (Wedy, 2021). While this theory reduces the plaintiff's burden of proof by eliminating the requirement that the harmful event be the sole or primary cause, the standard of "substantiality" remains legally ambiguous. The courts have yet to establish a consistent threshold for what constitutes a substantial contribution, leading to varying interpretations. Furthermore, the causal connection between global emissions and localized harm, as seen in the Lliuya case, demonstrates the difficulty of applying this theory to complex global problems like climate change, where multiple sources of emissions are involved, and the individual contribution of a single defendant may appear marginal.

Similarly, the market share theory encounters difficulties in providing unambiguous legal outcomes in the context of climate litigation. This theory, which is based on the apportionment of liability according to a defendant's market share of emissions, was first proposed in the case of the City of New York v. ExxonMobil (Sokol, 2020). In this case, the city sought damages from the five largest oil companies for their contribution to sea-level rise and climate-related disasters. Although the theory has been successfully applied in drug liability cases, its use in climate litigation is hindered by significant scientific and evidentiary challenges. The precise quantification of a defendant's market share of emissions and the direct linkage of this figure to specific damages caused by climate change remains a highly speculative undertaking. Moreover, the theory assumes a direct correlation between market share and responsibility, which does not account for the complexities inherent in emissions from a multitude of sources across diverse sectors and regions.

Vicarious liability represents an additional innovative approach, though it is not without its own inherent challenges. By ascribing accountability to entities based on the aggregate impact of their actions, vicarious liability diverts attention from the concept of direct causation. This approach, exemplified by the Brazilian court ruling holding large meat companies responsible for deforestation in the Amazon, seeks to address the collective nature of climate harm (Otto, 2023). Nevertheless, this theory may potentially result in the dilution of individual responsibility by focusing on aggregate contributions, which could subsequently render the assignment of liability in a meaningful manner more challenging. Furthermore, this approach may prove challenging to enforce effectively, as it may extend traditional legal concepts of liability to their limits.

In contrast, the precautionary principle is a principle places an emphasis on prevention in the context of scientific uncertainty. Although this principle encourages action even in the absence of definitive scientific evidence of harm, its application in climate litigation, as evidenced by the Urgenda Foundation v. State of the Netherlands case, does not directly address the causation dilemma. In contrast, the precautionary principle shifts the focus from establishing proof of harm to advocating for preventative measures. Although the precautionary principle is widely accepted in international environmental law, its role in national courts remains constrained, as it cannot substitute for the necessity of concrete evidence of causation in legal proceedings (van et al., 2023).

In conclusion, while theories such as "substantial contribution", "market share", "vicarious liability", and the "precautionary principle" present potential solutions to the causation challenges in climate change litigation, they nevertheless remain subject to significant limitations. The practical application of these theories is constrained by issues of legal clarity, scientific uncertainty, and the difficulty of establishing precise causal links in complex, global problems like climate change. Furthermore, it is necessary to reconcile the emerging legal theories with the existing legal frameworks and doctrines that underpin causation in tort law.

In order to address these limitations, the scientific community has developed climate attribution methodologies with the objective of quantifying the impacts of human activity on specific climate events. These methodologies, which rely on climate modeling and statistical analysis, are designed to establish a causal link between extreme weather events and anthropogenic climate change (Bocchiola, 2023). For instance, in the Canadian litigation against oil and gas companies for "flood impacts", scientists employed attribution studies to demonstrate that climate change augmented the frequency and intensity of extreme rainfall events, thereby significantly enhancing the probability of flooding (Bocchiola, 2023). Nevertheless, despite the potential of attribution science to provide new evidentiary tools, its legal application remains uncertain, as courts continue to grapple with the integration of scientific data into legal causation frameworks.

3. Climate attribution theory: Concepts and applications

Climate attribution theory, which involves determining the extent to which human activities influence the probability and characterization of extreme weather events, is divided into three main areas (He, 2022; Lloyd, 2021) (**Figure 1**): climate change attribution, impact attribution, and source attribution. It can play a pivotal role in loss and damage research by elucidating the complex web of causality in the field of climate change impacts. Climate change attribution identifies the impact of human activities (e.g., fossil fuel combustion) on the global climate system (Bône, 2022). This is achieved by determining their contribution to global warming through the use of climate models and observational data. Impact attribution, in contrast, relates impacts to climate change. It also examines how changes in the global climate system affect other interconnected natural and human systems. Source attribution, finally, involves identifying the contribution of specific emission sources or behaviors to climate change. It also determines the extent to which different sectors, activities, and entities contribute to anthropogenic climate change (Perkins-Kirkpatrick, 2022).
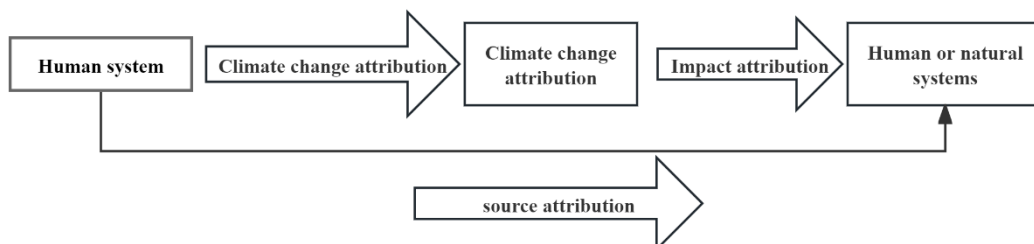

Figure 1. Climate attribution theory.

The three are frequently interdependent, with climate change attribution providing the underlying data and models that facilitate an understanding of the overall drivers of climate change. This information serves as the foundation for impact and source attribution. The research process typically begins with climate change attribution, which identifies the primary drivers of climate change. This is followed by impact attribution, which analyzes the impacts of climate change on specific events and damages. Finally, source attribution identifies specific sources of emissions and their responsibilities. These three elements complement each other to build a comprehensive framework for climate change analysis (Clarke, 2022). Climate change attribution provides the overall context, impact attribution refines the actual impacts, and source attribution clarifies the responsible parties and specific sources. The combination of these three aspects enables climate attribution theory to comprehensively and systematically analyze climate change and its impacts, provide a scientific basis for climate change litigation, and promote changes in policy and law (Colón-González, 2023).

3.1. How climate attribution theory addresses the causation dilemma

The development of climate science and attribution science as a scientific discipline has been instrumental in enabling the pursuit of compensation for losses caused by climate change. As stated by the Intergovernmental Panel on Climate Change (IPCC), the probability of attributing specific atmospheric occurrences to anthropogenic causes remains a certainty. As the science of attribution has evolved, it has become possible to statistically prove anthropogenic impacts on individual atmospheric events. This allows for not only the probability of an event occurring to be quantified, but also the magnitude of the impacts, thus providing significant support for proof of causation in legal proceedings (Nespor, 2024). The following section examines how climate attribution theory addresses the causation dilemma from a number of perspectives, with illustrative examples.

3.1.1. Quantifying impacts: Clarifying the contribution of human activities

The central tenet of climate attribution theory is the quantification of the impact of human activities on specific climate events through the application of modelling and data analysis techniques. This quantification not only provides concrete data support but also clarifies the contribution of human activities in climate change, thus providing strong evidence for proof of causation in legal proceedings. For instance, the 2003 heat wave in Europe resulted in tens of thousands of deaths and became a pivotal case study in climate attribution research (Beck et al., 2023). Through the application of climate modeling, researchers have demonstrated that the emissions of greenhouse gases resulting from human activity have made the occurrence of extreme heat waves at least two times more probable (Stott, 2004). Specifically, the attribution analysis demonstrated that heat waves of this intensity would occur once every thousand years in the absence of anthropogenic impacts, whereas the probability of occurrence increased to once every few decades due to human activity (Philip, 2022). This quantitative result elucidates the contribution of human activities to extreme weather events and furnishes a concrete scientific basis for the legal proof of causation. Moreover, it furnishes the court with unambiguous scientific evidence and enables

plaintiffs to illustrate the particular impact of the defendant's actions, thereby augmenting the persuasive force of the lawsuit. Nevertheless, the intricate and specialized nature of attribution studies necessitates a certain degree of scientific comprehension on the part of the court in order to accurately interpret and apply such evidence.

3.1.2. Scientific evidence: Enhancing the persuasiveness of legal proceedings

Climate attribution research provides compelling evidence through the scientific method to assist plaintiffs in establishing a causal link between a defendant's actions and climate events in court (Otto, 2023). This scientific evidence can be crucially persuasive in legal proceedings, reinforcing plaintiffs' arguments. In 2017, several California cities and counties filed a lawsuit against major oil companies, claiming that they are responsible for climate change-induced sea level rise and extreme weather events (Gunderson, 2021). The climate attribution studies provided key evidence in this lawsuit, demonstrating that the emissions practices of these oil companies significantly increase the rate and frequency of sea level rise, thereby increasing the risk of flooding for coastal cities (Craig, 2018). By means of specific attribution analyses, the plaintiffs were able to demonstrate with clarity the impact of these companies' emissions on specific climate events, thus facilitating the court's understanding and acceptance of the proof of causation. This type of scientific evidence is of particular importance in legal proceedings, as it can clarify the complex issue of climate change and assist courts in understanding the nuances of causation. However, the often-probabilistic nature of the results of attribution studies necessitates a careful balancing act between scientific evidence and legal standards to ensure that judgments are fair and reasonable (James, 2019).

3.1.3. Clarifying responsibility: Clarifying complex causal chains

The theory of climate attribution provides a means of clarifying the responsibility for a particular climate event by identifying specific emission sources or actors. This enables the legal profession to determine the extent of liability in the complex causal chain and to identify the behaviors that should be held legally responsible. In the Urgenda case in the Netherlands, the Urgenda Foundation, a non-governmental organization, and hundreds of citizens filed a lawsuit against the Dutch government for adopting more stringent emission reduction measures to combat climate change (De La Cámara, 2022). In 2015, the District Court of The Hague ruled that the Dutch government must reduce its greenhouse gas emissions by at least 25 percent by 2020 (Mikhailova, 2023). This ruling was based, in part, on climate attribution research, in which scientists provided evidence to support the plaintiffs' claims through modeling that demonstrated the significant contribution of Dutch greenhouse gas emissions to global climate change (Bergkamp, 2023). This case illustrates that the theory of climate attribution can not only assist in determining liability for specific events, but can also influence policy and legislation. There is not necessarily a straightforward correlation between an entity's GHG contribution and climate change-related damages. The extent of the contribution to the damage may depend on the timing of the GHG contribution, the type of emissions, and the type of damage. Nevertheless, in practical applications, it is essential to consider the limitations and uncertainties of attribution

studies and to establish an effective interface between scientific evidence and legal practice.

3.1.4. Supporting preventive measures: Promoting policy and behavioral change

The application of climate attribution theory is not limited to ex post facto accountability; it can also be utilized for ex ante prevention. By conducting attribution research, governments and enterprises can ascertain the impact of their own behavior on climate change. This enables them to implement corresponding emission reduction measures to prevent potential future losses and damages (Burger, 2021). For instance, the German government has extensively utilized the findings of climate attribution research in its energy transition policy (Edenhofer, 2017). Through attribution analysis, scientists have determined that Germany's greenhouse gas emissions have a significant impact on extreme weather events (e.g., heat waves, heavy rainfall, etc.) in the European region. These findings have prompted the German government to implement a series of rigorous emission reduction measures, including the phase-out of coal energy and an increase in the use of renewable energy, in order to mitigate the risks posed by future climate change. Such precautionary measures illustrate the potential of climate attribution theory in the context of policy-making. By understanding and assessing the impact of human activities on the climate in advance, governments and businesses can take more effective measures to mitigate the negative impacts of future climate change. Nevertheless, the results of attribution research must be properly interpreted and applied in policymaking in order to ensure the scientific validity and effectiveness of measures.

The field of attribution science is rapidly evolving, with each advancement in research increasing the relevance of findings in determining the responsibility of states, corporations, and businesses for climate change-related damages. The integration of legal expertise with climate science will facilitate the further alignment of these findings with legal frameworks, enabling the translation of scientific insights into legally applicable concepts, including the concept of causation. Nevertheless, the theory of climate attribution is not without its limitations.

3.2. Criticisms and limitations of climate attribution theory in the context of climate change litigation

Despite the contribution of climate attribution theory to the development of new tools and approaches for addressing the causation conundrum in climate change litigation, it remains subject to criticism and limitations in practice.

3.2.1. Apparent problem: Uncertainty in data and models

Climate attribution studies are highly dependent on climate models and historical data, which are inherently subject to some uncertainty (Bocchiola, 2023). This uncertainty arises from a number of sources, including the limitations of climate models and the limited availability of historical data (Schwarzwald, 2023). Climate models are mathematical descriptions of the interactions between the atmosphere, ocean, land, and snow and ice systems. Despite their development and validation over an extended period, these models continue to exhibit certain limitations, particularly in their ability to accurately simulate extreme climate events. It is possible that the

results produced by different models may differ, which could influence the conclusions of attribution studies. Climate attribution studies depend on a substantial quantity of historical climate data. However, the distribution of these data is not uniform in terms of temporal and spatial coverage (Smith, 2013). In particular, the meteorological data record may be incomplete or absent in some developing countries and remote areas. As a result, the results of attribution analysis may be susceptible to bias due to the absence of data, which in turn may limit its applicability in legal proceedings.

3.2.2. Mid-level problem: The gap between law and science

Although climate attribution research may yield relatively clear scientific conclusions, numerous challenges exist in applying these conclusions to legal proceedings (Otto, 2016). These challenges pertain to the divergence between the domains of law and science. Firstly, the legal standard of causation typically necessitates clear and direct evidence, whereas climate attribution research predominantly provides probabilistic and statistical evidence (Otto, 2023). For instance, attribution studies may demonstrate that the probability of a specific extreme weather event is tripled by human activity. However, this does not imply that the event was entirely caused by human activity. The translation of such probabilistic evidence into causation that meets legal standards represents a complex issue in legal proceedings. Secondly, it is not uncommon for courts to lack a comprehensive understanding of the intricacies of climate science when adjudicating cases pertaining to climate change. Such circumstances may result in misunderstanding or misapplication of climate attribution evidence. For instance, judges and juries may encounter challenges in comprehending the intricacies and inherent ambiguity of climate models, which could potentially influence the outcome of a case (Wentz, 2023). This necessitates the provision of comprehensive scientific clarification and instruction throughout the litigation process, which is frequently a protracted and intricate undertaking.

3.2.3. Deeper issues: The impact of political and economic factors

At a more fundamental level, the implementation of climate attribution research in legal proceedings is also influenced by political and economic factors that may further restrict its efficacy and impartiality. In terms of political pressures and conflicts of interest, the issue of climate change is highly politically sensitive, especially when large corporations and government agencies are involved (amarck, 2019). These stakeholders may exert influence over climate litigation through political and legal means, thereby impeding the application of climate attribution research. For example, major oil companies, which wield considerable political and economic influence, may actively seek to discredit or refute attribution studies that link their emissions to climate-related damage. This is frequently achieved through the use of corporate lobbying, substantial legal resources, and the exertion of influence over public discourse, which can ultimately influence the outcome of legal proceedings or delay litigation (Frumhoff, 2015). Furthermore, governments may encounter conflicts of interest, particularly when they have a financial stake in industries that are responsible for substantial greenhouse gas emissions. This can result in a reluctance to fully embrace climate attribution research in legal frameworks, as it may necessitate the

implementation of policies that could have a negative impact on the economy or on powerful corporate allies.

Economic factors also play a pivotal role. The production of high-quality climate attribution research necessitates substantial financial and technical resources, and litigating climate change claims often involves significant legal fees. For numerous communities and individuals affected by climate change, the financial burden of accessing such research or pursuing litigation can be prohibitive. This creates an uneven playing field, where wealthier corporations and entities with access to substantial resources have a greater ability to influence outcomes, while marginalized groups struggle to bring forward claims.

3.2.4. The essential problem: The essential difference between the scientific and legal systems

In essence, the constraints of climate attribution theory in climate change litigation mirror the intrinsic divergences between the scientific and legal systems. These discrepancies are evident in the following areas:

A. The Disparity Between Scientific Uncertainty and Legal Certainty The nature of scientific research is exploratory, and the results are therefore characterised by uncertainty and probability. In contrast, the legal system is oriented towards reaching clear and certain conclusions in order to make well-founded judgments. This discrepancy presents challenges in the application of climate attribution evidence within the legal system.

B. Evolutionary nature of science vs. stability of law: Scientific knowledge is in a constant state of evolution, with new research potentially overturning or revising previous conclusions. In contrast, the legal system places a premium on stability and consistency, and frequent changes may give rise to legal uncertainty and enforcement difficulties. This makes the use of the latest climate attribution findings in legal proceedings challenging when the pace of legal and scientific progress is not consistent.

In conclusion, the application of climate attribution theory in climate change litigation is beset by a multitude of challenges, encompassing surface data and modeling uncertainty, mid-level legal and scientific gaps, and deeper political economy factors that ultimately reflect the fundamental differences between the scientific and legal systems. These issues must be addressed through a multifaceted approach involving interdisciplinary collaboration, science education, and legal system reform in order to enhance the application of climate attribution theory in legal proceedings.

4. Policy recommendations and future research directions

4.1. Policy recommendations

The potential of climate attribution theory in the context of climate change litigation has been demonstrated, yet its practical application continues to present significant challenges. In order to address the causation challenges in loss and damage cases, the following policy recommendations are proposed. These recommendations

not only focus on legal practice but also consider how climate attribution theory can be utilized more effectively through legal means.

4.1.1 Enhance funding and support for climate attribution research

A significant obstacle to the efficacy of climate litigation has been the dearth of robust scientific evidence, as evidenced by cases such as Massachusetts v. EPA and Lliuya v. RWE. In these cases, the lack of scientific certainty constituted a significant obstacle to establishing a causal link (Stuart-Smith, 2021). To enhance the caliber and dependability of climate attribution research, it is imperative that governments and international organizations augment funding for such research and facilitate the advancement of climate models and data analysis technology (Bocchiola, 2023). For example, the International Panel on Climate Change (IPCC) has been instrumental in producing comprehensive scientific reports that are utilized in litigation. However, the scope and precision of these studies could be significantly enhanced with the allocation of additional resources. It would be beneficial to establish a dedicated research fund to support interdisciplinary projects focused on improving the precision and dependability of attribution models. It is incumbent upon legal professionals to advocate for more robust scientific research, so that future cases may rely on solid, high-quality evidence.

4.1.2. Establishment of interdisciplinary collaborative platforms

In order to effectively address the challenges of climate litigation, it is imperative that climate scientists, legal experts, and policymakers collaborate on interdisciplinary platforms. These platforms facilitate the integration of scientific research and legal practice, thereby helping to bridge the gap between complex climate science and legal standards. A case in point is the Urgenda Foundation v. State of the Netherlands litigation. In this landmark case, the Dutch court accepted the climate science presented by both legal professionals and scientists to establish the state's responsibility for emissions reduction (Lando, 2022). This success was largely attributable to the close collaboration between climate experts and legal practitioners, which enabled the court to comprehend and utilize scientific evidence in its judgment. Another illustrative example is the Lliuya v. RWE AG case in Germany, in which a Peruvian farmer initiated legal proceedings against a major utility company for its role in contributing to climate change. The case was made possible by scientists and lawyers working in close collaboration to model the specific impacts of RWE's emissions on glacier melt in the Andes (van, 2022). This interdisciplinary collaboration facilitated the advancement of the case through the German courts, thereby demonstrating the potential of such efforts.

In order to achieve such success in different jurisdictions, it is essential to establish platforms that facilitate regular seminars, workshops, and training courses where climate scientists, legal professionals, and policymakers can interact. For example, initiatives such as the Oxford Martin School's Climate Litigation Network have demonstrated the efficacy of regular interdisciplinary meetings in fostering ongoing collaboration. These platforms should prioritize the sharing of knowledge and the enhancement of professional skills, thereby enabling legal professionals to more effectively assess scientific evidence while also facilitating scientists' comprehension of the legal standards necessary for their research to be admissible in court. By

fostering such interactions, these collaborations can be tailored to the specific requirements of different legal systems and jurisdictions, thereby enhancing the role of science in climate litigation on a global scale.

4.1.3. Developing uniform standards of evidence

The uniformity and transparency of evidentiary standards are of paramount importance in legal practice. In instances of transnational litigation, such as the case of Saúl Luciano Lliuya v. RWE AG, the absence of standardized rules governing the admissibility of climate attribution evidence has resulted in procedural complexities (Tigre, 2023). The establishment of clear evidentiary standards has the potential to alleviate the court's reservations regarding the admissibility of evidence pertaining to climate attribution, thereby enhancing its acceptance (Wang, 2023). This not only enhances the fairness of litigation, but also reduces the number of legal disputes that arise from inconsistent evidentiary standards, thereby enhancing judicial efficiency. It is recommended that, at the international and national levels, uniform evidentiary standards be developed and promoted as applicable to climate change litigation (Lewellen, 2023). It is essential that these standards provide a clear definition of the criteria for the acceptance and evaluation of climate attribution evidence, thus ensuring that courts have a consistent reference basis for considering relevant cases. The clarification of the status and role of climate attribution research in legal proceedings through the enactment of laws and regulations can enhance transparency and consistency in the process.

4.1.4. Promoting public and judicial education

The objective is to enhance climate science education for the general public and for those involved in the justice system, with a particular focus on judges, lawyers, and jurors (Banda, 2020). This will entail an examination of the fundamental concepts, methodologies, and applications of climate attribution theory, with the aim of facilitating a more nuanced understanding and evaluation of scientific evidence in climate litigation. To institutionalize this educational initiative, it is essential to develop specific programs and partnerships. For example, universities could collaborate with judicial training centers to develop certification programs or specialized courses that focus on climate science for legal professionals. It would be beneficial for programs such as the Judicial Studies Program at universities to integrate climate science modules, while bar associations could offer continuous legal education (CLE) courses in climate attribution. Moreover, collaborations between entities such as the National Judicial College and environmental research organizations could facilitate the delivery of workshops and seminars tailored to judges and attorneys who are involved in cases pertaining to climate change. These practical measures would foster greater awareness of climate change among legal professionals and equip them with the requisite skills to interpret and evaluate climate attribution evidence effectively. By promoting such systematic education and training, the legal profession can enhance the scientific and rational nature of the litigation process and ensure the accuracy and fairness of judicial decisions.

4.1.5. Promoting the improvement of the international legal framework

At the international level, it is recommended that efforts be made to improve and harmonize climate change-related legal frameworks, with a particular focus on legal rules and procedures for transnational climate litigation. Transnational litigation encompasses the legal systems and judicial procedures of disparate countries. A unified international legal framework can mitigate legal conflicts and enhance the efficiency and fairness of transnational climate litigation. It is recommended that international legal institutions formulate clear rules to clarify the status of evidence in climate attribution research in transnational litigation and standardize the application of climate attribution research in transnational litigation. This would provide stronger legal support for international climate litigation and promote global climate governance (Otto, 2023).

4.2. Areas for further research

Despite the progress made in climate attribution theory in climate change litigation, there are still many areas that require further research and exploration to improve its application. First, improving the accuracy and reliability of climate models is essential. Current climate models still have uncertainties in modeling and predicting climate change and its impacts. Future research should be devoted to improving these models to increase their accuracy and reliability at different time and space scales to provide a more solid scientific basis for attribution studies (Sanford, 2023). Second, develop event-specific attribution methods and multi-factor attribution analysis. Existing attribution studies have primarily focused on large-scale climate events and long-term climate trends. However, the attribution analysis of specific events, such as single extreme weather events, still requires further development (Zaninelli, 2023). It is imperative that research be conducted to identify new methods and techniques that will enable more accurate quantification of the impact of human activities on single extreme events. Furthermore, the causes of climate change are complex, typically resulting from a combination of factors. Future research should investigate methods of multi-factor attribution analysis, which would take into account the combined effects of natural and anthropogenic factors. This would provide a more comprehensive and in-depth analysis of causality. Moreover, an assessment of the applicability of attribution research in legal practice necessitates a systematic examination of the applicability of climate attribution research in legal practice. This entails an evaluation of the acceptability and validity of different types of attribution evidence in various legal contexts. This will facilitate the development of more reasonable legal evidence standards and enhance the efficacy of attribution research in litigation. In conclusion, it is imperative to reinforce international collaboration and the dissemination of information. Given the global nature of climate change, international cooperation and information sharing are of paramount importance. It is recommended that research institutions and governments enhance international collaboration, create a platform for disseminating global climate data and research outcomes, and advance climate attribution research and its implementation on a global scale. These efforts will serve to enhance the scientific basis of global climate governance and promote the fairness and effectiveness of climate change litigation.

5. Conclusion

This paper presents a comprehensive investigation into the causation dilemma in climate change litigation. It offers a detailed analysis of the role of climate attribution theory in addressing this complex issue and presents a series of policy recommendations and future research directions. The research and analysis of specific cases has yielded the following main ideas and conclusions. Firstly, climate attribution theory provides a scientific basis for resolving the causation dilemma in climate change litigation. By quantifying the impact of human activities on climate change, attribution research provides crucial evidence for legal proceedings. However, traditional theories of causation are inadequate in addressing the complexities of climate change and are unable to meet the needs of modern climate litigation. The nascent "substantial contribution" and "market share" theories have, to some extent, alleviated this problem, but they still have many limitations. Secondly, the implementation of the policy recommendations could assist in further addressing the causation dilemma. To enhance the scientific rigour and fairness of climate litigation, it is essential to reinforce funding and support for climate attribution research, establish an interdisciplinary collaboration platform, develop unified standards of evidence, promote public and judicial education, and advocate for the improvement of the international legal framework. The collaboration between the legal and scientific communities, along with the support of governments and international organizations, can provide a more robust foundation for climate litigation. Finally, future research must address a number of additional areas. Future research should prioritize improvements in the accuracy and reliability of climate models, the development of event-specific attribution methods and multifactor attribution analysis, the assessment of the applicability of attribution research in legal practice, and the enhancement of international cooperation and information sharing. It is only with further progress in these areas that climate attribution theory will be able to play a greater role in climate litigation. Furthermore, the complex matter of causation in climate change litigation is not solely a legal concern, but rather an interdisciplinary challenge. It is imperative that the legal profession remains abreast of developments in climate science, ensuring that its theories and practices are continually updated and adapted to reflect the latest insights from this field. Through continued practice and reflection, a set of effective legal systems can be gradually established to ensure the fairness and scientific rigour of climate change litigation.

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