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SCIENCE ON TRIAL: BRIDGING SCIENTIFIC AND LEGAL EPISTEMOLOGIES IN STRATEGIC CLIMATE LITIGATION

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INTRODUCTION

How do courts grapple with complex climate science in an era of burgeoning climate litigation? This PhD thesis investigates the interaction between science and law in strategic climate change litigation, focusing on how scientific knowledge, especially climate science, is used, challenged, and evaluated within legal systems, and the epistemological tensions that arise in the process. The relevance of this inquiry is underscored by the rapid growth of climate litigation worldwide. In the past few years, the number of climate change cases has more than doubled, reaching over 2,100 cases across 65 jurisdictions by 2022.[1] Climate science has become a central feature of these lawsuits, providing evidence on issues ranging from emissions and global warming to impacts and attribution.[2] As communities and activists turn to courts as tools for climate accountability, judges increasingly find themselves adjudicating questions that hinge on scientific data and expert testimony. Yet, legal institutions are traditionally ill-equipped to handle the probabilistic and evolving nature of scientific knowledge. This thesis is motivated by a core question: How can legal reasoning and institutions accommodate the distinctive epistemology of climate science? In other words, how do (and should) courts integrate climate science into their fact-finding and decision-making, given that science's mode of knowing differs fundamentally from law's binary frameworks of proof and liability?

Addressing this question is both urgent and novel. Climate litigation is expanding not only in quantity but in scope and ambition. *Strategic* climate cases, such as those aiming to compel government action or hold corporations accountable, often explicitly rely on scientific findings (for example, carbon budgets or attribution studies) to establish harm or causation. High-profile examples in recent years illustrate

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[1] COLUMBIA SABIN CENTER FOR CLIMATE CHANGE LAW AND UN ENVIRONMENTAL PROGRAM, *Global Climate Litigation Report: 2023 Status Review*, 2023, https://scholarship.law.columbia.edu/sabin_climate_change/202/.

[2] A. HOLZHAUSEN, R. LUPORINI, *The Role of Science in Climate Change Litigation: International Workshop Report*, July 2021, https://www.biicl.org/publications/the-role-of-science-in-climate-change-litigation-international-workshop and https://www.santannapisa.it/en/event/role-science-climate-change-litigation.

this trend. The European Court of Human Rights (ECtHR) held its first-ever hearings on climate change in 2023, in a case brought by a group of Swiss senior women claiming that insufficient climate action violated their right to life and health. In a landmark advisory proceeding, the International Court of Justice (ICJ) has now clarified states' legal obligations on climate change, grounding its reasoning in the scientific consensus of the Intergovernmental Panel on Climate Change (IPCC) and thereby reinforcing the central role of science in shaping international law. National courts, too, are increasingly engaged: for instance, Italy's first climate lawsuit (the *"Giudizio Universale"* case of 2024) argued that the state's weak mitigation efforts breached fundamental rights and even contended that the legislature is bound by climate science evidence embodied in the Paris Agreement targets. These developments highlight the growing intersection of climatology and jurisprudence. However, they also expose a fundamental challenge: science and law are encountering each other in new ways, and their different ways of establishing "truth" can clash. This thesis seeks to explore those clashes, particularly the epistemological ones, and propose ways to navigate them. In doing so, the thesis positions itself at the crossroads of environmental law, evidence law, and the philosophy of science, aiming to contribute to an emerging discourse on *legal epistemology* in the context of climate change.

When climate science enters the courtroom, it brings with it a distinct epistemological character. It is crucial to recognize what kind of knowledge science produces, especially in contrast to the kind of answers the law typically seeks. From an epistemological perspective, science does not deal in certainties or final truths. Instead, science is best understood as a *method of inquiry*, iterative, empirical, and self-correcting. Knowledge in science is gained through systematic observation, experimentation (or in the case of climate science, simulation and modeling), and continuous revision of hypotheses. As the philosopher Karl Popper famously argued, a hallmark of true science is falsifiability: a scientific claim must be testable and capable of being proven wrong. No scientific theory is ever proven with absolute

finality; rather, the highest status it attains is *"not yet disproven"*.[3] Even long-established scientific laws remain subject to refinement or refutation if new evidence emerges. This means that scientific knowledge is inherently provisional and uncertain, always open to challenge by new data. Indeed, there is "no such thing as scientific 'proof'" in the sense of 100% conclusiveness, science exists in a continuous state of uncertainty, even as it produces increasingly robust understanding of phenomena.[4] Popper's insight underscores why scientists typically speak in terms of confidence levels, error bars, and probabilities rather than absolutes.

Beyond Popper's falsification principle, the nature of scientific knowledge is also illuminated by Thomas Kuhn's notion of paradigms. Kuhn taught us that science is influenced by prevailing paradigms, frameworks of theories and assumptions that guide research until enough anomalies accumulate to prompt a paradigm shift.[5] In climate science, for example, the paradigm of anthropogenic global warming emerged in the late 20th century as evidence mounted and earlier hypotheses (like mid-20th century speculations about global cooling) were overturned by new data.[6] Kuhn's perspective reminds us that scientific knowledge is contextual and evolving: it progresses not linearly toward an absolute truth, but through revolutions in understanding that reframe prior knowledge. Today's climate science is built on decades of observations and models, and it remains open to refinement, though it is firmly underpinned by a broad consensus on core facts (e.g. that greenhouse gas emissions from human activities are the dominant cause of recent warming).[7] In sum, science offers structured but probabilistic insights. Particularly in a field like climatology, scientists deal in likelihoods and ranges: for instance, projections of future warming or sea-level rise are expressed as ranges with confidence intervals,

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[3] K.R. POPPER, *The Logic of Scientific Discovery*, Berlin, 1934.

[4] R. LAWSON, *Climate Science & Falsifiability*, 2014, https://philosophynow.org/issues/104/Climate_Science_and_Falsifiability.

[5] T.S. KUHN, *The Structure of Scientific Revolutions*, Chicago, 1962.

[6] P.A. HANLE, M.D. MASTRANDREA, *How Climate Science Works*, January 2023, https://cjp.eli.org/curriculum/how-climate-science-works#:~:text=Politically%20polarized%20discussions%20used%20early,What%20might%20once%20have.

[7] See, e.g., *Obligations of States in respect of Climate Change*, Advisory Opinion, ICJ, July 23, 2025, [72–87], where the Court expressly relied on IPCC reports as the authoritative synthesis of climate science.

rather than a single guaranteed outcome. Climate models, the primary tools for forecasting climate futures, do not yield certainties but distributions of possible outcomes under different scenarios. They incorporate numerous uncertain factors (climate sensitivity, socio-economic developments, feedback effects) and produce results that are inherently probabilistic. As one judicial education resource notes, climate models represent unknown factors with probabilities and give us a spread of potential futures "rather than one determined outcome".[8] Crucially, though these insights are probabilistic, they are far from mere guesses: they are the product of rigorous methods, extensive peer review, and convergence of evidence from multiple lines of inquiry (atmospheric physics, paleoclimate data, observations, etc.). Climate science, in other words, is a robust body of knowledge, but not an absolute one. It yields nuanced answers ("X is very likely caused by Y" or "there is a 95% probability of Z under scenario A") where the degree of uncertainty is itself carefully quantified.

This inherently probabilistic and evolving nature of science can be *difficult to reconcile with legal reasoning*. Legal systems, especially in adjudication, often prefer more binary determinations: an event either legally *caused* harm or not; a defendant is either *liable* or not liable; proof either meets a threshold or it doesn't. Whereas science thrives in the grey zones of probability and acknowledges a perpetual "uncertainty margin," law operates in a forum where decisions must be definitive (at least within the case at hand). A court cannot generally say "the defendant is 95% likely responsible" and leave the matter at that: it must translate that into a yes or no judgment on liability. This binary imperative can clash with the way climate science conveys knowledge. As one commentator observed, legal reasoning tends to simplify complex scientific data to fit judicial binaries, but such simplification risks "eroding the integrity of the science".[9] Judges and juries may understandably crave clear answers (*Did climate change cause this flood? Is this company responsible for X% of the harm?*) while scientists would respond in terms of confidence levels or probabilistic

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[8] P.A. HANLE, M.D. MASTRANDREA, 19.

[9] J. REYES, N. PETKOV, N. WALKER-CRAWFORD, *Bridging Disciplines: Law, Science and The Emergence of Climate Attribution*, April 29, 2025, https://www.lse.ac.uk/granthaminstitute/news/bridging-disciplines-law-science-and-the-emergence-of-climate-attribution/#:~:text=challenge%20of%20conceptual%20translation%3A%20the,in%20court%20without%20becoming%20reductive.

attribution. The epistemological gap is evident: *science deals in degrees of certainty, while law often demands a threshold crossing*. Moreover, science is ever-open to new evidence, whereas legal judgments seek finality. This can create tension, for example, when opposing counsel exploit scientific caution by saying "the science isn't settled" in order to cast doubt, or when courts expect experts to present climate findings in unequivocal terms that science cannot honestly provide. The paradox of science in public discourse is that its very strength, *i.e.* rigorous uncertainty and nuance, can be perceived as weakness in a venue that values decisiveness.[10] Climate litigation exemplifies this dilemma. On the one hand, climate science provides an essential evidentiary foundation (demonstrating, say, the link between emissions and impacts); on the other hand, its conclusions are often couched in careful terms that legal fact-finders may find hard to interpret. Part of the challenge in strategic climate litigation, therefore, is epistemological: it requires creating a *space where law can engage with scientific knowledge on its own terms*. The law must find ways to absorb the powerful but probabilistic insights of climate science, rather than forcing science into a false dichotomy of certainty vs. uncertainty. As the introduction to this thesis will argue, meeting this challenge may require adjustments in how evidence is presented and evaluated, greater scientific literacy in legal contexts, and perhaps new legal doctrines that explicitly accommodate scientific uncertainty.

When scientific authority enters the courtroom, it can be, as one judge quipped, the "purgatory" of judges.[11] Judges typically lack the technical expertise that scientists have, yet they must rule on matters that may hinge on complex data or model-based inferences. This dynamic makes courts heavily reliant on experts to mediate between scientific knowledge and legal judgment. Expert witnesses become the translators of climate science for the court, explaining technical findings in a legally digestible way. However, this reliance raises further epistemological and practical dilemmas. An expert's role is to elucidate facts, but ultimately the court must decide how much weight to give their testimony and conclusions. There is an inherent tension in that

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10 R. LAWSON, 2014.

11 *Pulp Mills on the River Uruguay* (Argentina v. Uruguay), Judgment, ICJ Reports 14, [148] (Judge Cançado Trindade, Separate Opinion).

judges must not "abdicate" their decision-making to scientists, yet they also must avoid substituting scientific conclusions with legal intuition in areas where science truly has authority.[12] *How much deference to scientific experts is too much, and how little is too little?* If judges lean too heavily on experts, they risk letting the litigation outcome be dictated by those experts' views (effectively handing over the judicial function to non-judicial actors). But if judges discount or ignore scientific input, they risk decisions that flout reality and rationality, as well as eroding the legitimacy of the outcome. A balance must be struck where judges maintain what has been called "cognitive control" over scientific evidence, meaning they grasp the essential reasoning of the science, without pretending to be scientists themselves.[13]

A worrying scenario arises when scientific evidence is contested or distorted in court. In adversarial systems especially, each side may present its own experts, and courts face the task of determining credibility and validity. Here, *epistemological pitfalls* lurk. For example, it is possible for a scientifically unsound or biased position to nonetheless persuade a court if delivered by a confident expert witness in an intelligible manner.[14] Courts, after all, evaluate evidence based on legal standards (e.g. admissibility rules, burdens of proof) that do not automatically filter out junk science unless judges are proactive. Climate science has occasionally faced malign attacks in public forums, such as disinformation campaigns suggesting climate data were falsified, or the so-called "Climategate" episode where scientists' emails were taken out of context to allege misconduct. Although multiple investigations found no evidence that researchers like Dr. Michael Mann had fabricated data,[15] such controversies illustrate the political sensitivity of climate science. In court, one can imagine a well-prepared defense trying to cast doubt on mainstream climate findings by cherry-picking uncertainties or presenting fringe views as equivalent to consensus. Judges then must effectively assess scientific credibility. This entails a quasi-epistemological exercise: distinguishing robust science from pseudoscience,

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12 K. SULYOK, *Science, Epistemology and Legitimacy in Environmental Disputes – The Epistemically Legitimate Judicial Argumentative Space*, in *Leiden Journal of International Law*, 37(1), 2024, 145-147.

13 *Ibid*., 147-150.

14 *Ibid*.

15 M.L. BANDA, *Climate Science in the Courts: A Review of U.S. and International Judicial Pronouncements*, Washington, 2020, 30.

understanding the peer review status of studies cited, and perhaps even grasping statistical concepts, all within the confines of legal procedure. The thesis will delve into how courts approach this task and what principles could guide them to do it better.

Perhaps the toughest substantive challenge climate litigation poses is the problem of causation. Legal causation typically requires a showing that the defendant's conduct was a cause (in fact and often in law) of the harm suffered by the plaintiff. Climate change radically complicates this inquiry because of its diffuse, cumulative causation structure. Greenhouse gas emissions from innumerable sources worldwide together cause global warming, which in turn manifests in local harms (heatwaves, floods, sea-level rise, etc.). In an isolated tort case, one can often draw a direct line: e.g., a faulty product exploded and caused the plaintiff's injury. In climate cases, by contrast, any individual actor's contribution to the harm is by itself minuscule and often *indistinguishable* in the atmosphere. Courts have likened this to a "drop in the ocean" problem. For instance, an Australian court considering a coal development noted that given the small fraction of global emissions the project represented, any specific increase in global temperature or related impacts due to that project alone would not be identifiable.[16] This encapsulates the causation conundrum: scientifically, we know that *collectively* such projects contribute to climate change, but *legally*, pinning a particular climate impact on a particular emitter (or group of emitters) with certainty is exceedingly difficult. Traditional "but for" causation (but for this ton of CO_2, would this flood have occurred?) is nearly impossible to establish for climate harms. Courts in various jurisdictions have wrestled with this. Some have dismissed climate-related claims for failure to prove a direct causal link between the defendant's emissions and the plaintiff's specific injury. Others, however, are starting to innovate. For example, a German court in the *Lliuya v. RWE* case allowed a causation argument to proceed based on *proportional contribution*: a scientific study estimated RWE's historical emissions represented a certain percentage of global emissions, and the plaintiff seeks to hold the company liable for that same percentage of the costs of flood protection measures in his community. This reflects an attempt to reconceptualize

[16] L.A. OMUKO, *Applying the Precautionary Principle to Address the "Proof Problem" in Climate Change Litigation*, in *Tilburg Law Review*, 21, 2016, 57 ff.

causation in probabilistic or contributory terms, rather than all-or-nothing liability. The role of attribution science becomes crucial here. In recent years, climate scientists have developed methodologies to estimate the changed probability or magnitude of extreme events due to climate change ("fractional attribution" of events to climate change), and even to trace fractions of climate change to major emitters. The thesis will explore how courts treat such evidence: Do they accept statistical causation or risk-based causation as sufficient? Are doctrines like the precautionary principle invoked to lower the standard of proof when the harm is potentially catastrophic but uncertainty remains?[17] How do different legal systems (common law vs civil law, human rights law vs tort law) grapple with causality in this context?

In sum, the interaction of climate science and law raises deep questions about proof, uncertainty, and the standard of judicial reasoning. It is not only a legal or scientific challenge but an epistemological one, requiring reflection on what counts as knowledge in court. The remainder of this thesis introduction will outline how the research is structured to tackle these issues. The thesis is both analytical, mapping how courts currently handle (or struggle with) climate science, and normative, considering how they *should* handle it to achieve just and informed outcomes. The ultimate ambition is to contribute to developing legal epistemologies (or reasoning frameworks) that can better accommodate complex, interdisciplinary evidence like climate science, thereby improving the law's responsiveness to global challenges.

To address the research questions, the thesis is organized into three substantive chapters, in addition to this introduction and a conclusion. Below is a brief overview of each chapter's focus:

1. Chapter One – Science Meets Law: Concepts, Contexts, and Challenges *Analysis of Climate Science and Legal Frameworks.* This chapter lays the groundwork by examining the two domains at the heart of the study: climate science (climatology) and law. The first part of the chapter defines climatology as a scientific discipline, tracing a short history of how climate science

[17] *Ibid*.

developed and identifying its key characteristics. Here, the chapter distinguishes climatology from "harder" sciences such as classical physics. For example, it discusses how climatology relies on observational data and complex modeling of the Earth system, rather than repeatable laboratory experiments, which means it must grapple with profound complexity and inherent uncertainties. The chapter also notes that climate science has become politically sensitive, unlike, say, basic physics, climatology's findings directly inform policy and have stirred political controversy (e.g. organized climate denial campaigns). This underscores that climate science in court may face adversarial pushback not just on technical grounds but due to ideological resistance. The second part of Chapter One turns to the legal dimension of this interface, examining the frameworks and principles through which law incorporates science. At the international level, this is evident in the Paris Agreement and the Glasgow Climate Pact, both of which highlight the central role of "best available science" in shaping climate action. At the European level, the chapter examines how both EU law and the European Court of Human Rights embed scientific considerations into their legal reasoning. Article 191(3) of the Treaty on the Functioning of the European Union (TFEU) expressly requires the Union to take account of "available scientific and technical data" when shaping environmental policy. Similarly, the ECtHR has recognized that state measures must be monitored in light of evolving scientific and social developments. At the domestic level, with a focus on Italy, the chapter examines how legal sources and constitutional jurisprudence integrate scientific evidence into decision-making. The law establishing the National System for Environmental Protection (SNPA) provides that the scientific data it produces constitute binding references for public administrations. In parallel, the Constitutional Court has developed the principle of scientific reserve, under which regulatory choices must be grounded in qualified and institutionalized scientific knowledge, thereby setting substantive limits on both political discretion and judicial reasoning. Finally, Chapter One identifies the ethical dimensions of science-law integration, emphasizing the challenges that arise from the limits and self-referentiality of science. Drawing on the work of

scholars such as Mariachiara Tallacchini, it highlights how scientific advice can be prone to problems of reproducibility, conflicts of interest, and isolation from broader society, raising questions of accountability and legitimacy. The chapter therefore considers proposals for democratizing science through citizen participation as well as alternatives such as independent oversight bodies, both aimed at ensuring transparency, responsibility, and trust in the use of science for policymaking. By the end of Chapter One, the reader will have a clear understanding of the baseline: what climate science is and why it poses special challenges, and what legal tools exist (or are lacking) to bring scientific knowledge into the courtroom.

2. Chapter Two – Adjudicating Climate Science: A Comparative Analysis of Courts (ICJ, ECtHR, Italy)

Case Studies in Judicial Approaches. This chapter provides a comparative examination of how different courts and jurisdictions actually handle climate science in litigation. It zeroes in on three judicial contexts: the ICJ, the ECtHR, and domestic Italian courts. These were chosen to cover a spectrum from international to regional to national adjudication, each with distinct procedural rules and legal cultures. The chapter asks in each context: How does climate science enter the courtroom? How is it assessed? And how much influence does it exert on outcomes? For the ICJ, the analysis includes relevant cases like the *Pulp Mills* case (ICJ, 2010) and the *Whaling in the Antarctic* case (ICJ, 2014), where scientific evidence about environmental harm was central. In the Whaling case, for example, the ICJ had to decide if Japan's whaling program was "for purposes of scientific research," which led the Court to evaluate expert evidence and even formulate its own view on what genuine science entails. The ICJ's general practice regarding experts is examined, notably Article 50 of the ICJ Statute allows appointment of scientific experts by the Court, though this power is rarely used. The chapter also discusses the ICJ Advisory Opinion on Climate Change (delivered in 2025), which is unprecedented in its direct reliance on climate science within a legal proceeding at the world court. Moving to the ECtHR, Chapter Two reviews how this human rights court has begun to engage with climate science. The

ECtHR's climate cases (such as *KlimaSeniorinnen v. Switzerland* and others) involve claims that government inaction on climate change breaches the right to life and family life. Since these are positive-obligation cases, the science comes in as evidence of risk and causation: applicants bring reports (like IPCC assessments) to show the severity of threats to their health and life. The chapter analyzes the ECtHR's approach to evaluating such evidence. Does the court appoint its own experts or rely on party submissions? How does it decide whether a state's climate policy is within its "margin of appreciation" given scientific consensus on required actions? Preliminary indications (e.g., from questions judges asked at the 2023 hearing) suggest the ECtHR is cautious, but it has signalled awareness that climate science is robust and broadly accepted, citing IPCC reports as authoritative. Lastly, the chapter examines Italian courts through the lens of recent climate-related cases. The *Giudizio Universale* case in 2024 is instructive: although the case was dismissed on procedural grounds (separation of powers), the plaintiffs heavily relied on scientific evidence (emissions data, temperature pathways) and even argued that under international commitments the Italian government was obliged to heed specific scientific thresholds. Another notable case is a lawsuit filed against the energy company ENI in Italy, alleging that its greenhouse gas emissions contribute to climate harms; the Italian judiciary had to consider whether such claims are justiciable and what evidence could substantiate them.

By comparing these three venues, Chapter Two highlights common challenges that emerge. Two challenges stand out across the board: the role of expert evidence and the problem of causation. In each context, the chapter observes how courts struggle with expert testimony: for instance, the ICJ's reluctance to use independent experts, the ECtHR's dependence on written scientific briefs from third parties, or Italian courts' rules on when an expert *consulente tecnico* can be appointed. The comparative study also reveals different standards of judicial scrutiny: some courts take a hands-on approach in dissecting scientific claims, while others effectively defer to government assertions or broad consensus. With respect to causation, Chapter Two shows that international tribunals and domestic courts alike

wrestle with linking emissions to impacts. The ICJ in contentious cases may avoid causation questions by focusing on states' procedural duties (e.g., did a state conduct an environmental impact assessment), whereas national courts in tort cases must often confront causation directly. The ECtHR, dealing with state obligations, faces a nuanced task of connecting failure to cut emissions with risks to human rights, effectively a form of systemic causation argument. Through these case studies, Chapter Two not only documents how climate science is being treated by courts, but also identifies gaps and inconsistencies. For example, it notes if courts are inconsistent in what scientific reports they consider "authoritative" or how they handle conflicting expert opinions. The comparative insight sets the stage for the final analytical step: grappling with how to improve judicial engagement with climate science.

3. Chapter Three – Navigating Epistemological Tensions: Experts, Causation, and the Way Forward

Towards Reconciliation of Scientific and Legal Reasoning. Building on the findings of Chapter Two, the final substantive chapter addresses in depth the two recurring issues – expert evidence and causation – and considers possible approaches to mitigate the epistemological tensions they raise. It first examines expert evidence in climate litigation, showing how courts increasingly rely on experts to navigate the complexity of climate science and to establish causal links, particularly through probabilistic methods such as attribution studies. Unlike general scientific assessments (e.g., IPCC reports), expert testimony is case-specific and tailored to judicial needs, making it indispensable in climate litigation but also raising concerns about impartiality, reliability, and fairness. Drawing on case law, including the ECtHR's 2024 *Verein KlimaSeniorinnen Schweiz v. Switzerland* judgment, the chapter illustrates how courts combine broad scientific consensus with targeted expert input. At the same time, it underscores the challenges associated with both party-appointed and court-appointed experts: from the risk of bias and unequal resources to the lack of standardized procedures and the phenomenon of "phantom experts." The discussion highlights how these structural weaknesses complicate judicial reasoning and calls attention to the need for reforms aimed at enhancing

transparency, impartiality, and the effective use of expert testimony in climate cases.

The second half of Chapter Three turns to the causation dilemma. It explores doctrinal and evidentiary avenues to narrow the gap between the probabilistic nature of climate science and legal standards of liability, focusing on the growing role of attribution science and risk-based causal reasoning. Among the approaches discussed are the "necessary element of a sufficient set" (NESS) test and liability models that distribute responsibility among multiple contributors, such as proportional liability and market-share liability, reflecting the cumulative character of greenhouse-gas emissions. The chapter situates these developments within emerging case law (including *Urgenda*, *Neubauer*, and *Lliuya*), where courts have shown greater flexibility in linking contributions to risk and harm, and it highlights how human-rights and constitutional frameworks have begun to accommodate probabilistic evidence without demanding deterministic proof. In weighing these trends, the chapter considers the benefits of easing traditional causation hurdles to secure accountability and effective remedies, while cautioning that any recalibration must remain consistent with fairness to defendants and the rule of law.

Throughout Chapter Three, the analysis is both diagnostic and prescriptive. It shows how expert evidence and causation are tightly interlinked, with disagreements among experts, methodological uncertainty, and evidentiary standards (e.g., stricter Daubert-type thresholds versus more flexible acceptance of generally accepted methods) creating a feedback loop that shapes what courts can conclude. The chapter distinguishes general from specific causation and explains how probabilistic attribution science can support causal reasoning without demanding deterministic proof, as illustrated by evolving approaches in cases such as *Lliuya*. It then turns to fairness and effectiveness, emphasizing transparency in judicial reasoning, clearer criteria for evaluating scientific testimony, judicial education, and the contribution of specialized benches or courts. The upshot is a more adaptive toolbox for reasoning under

scientific uncertainty, one that acknowledges probabilistic evidence while preserving legal certainty and procedural fairness.

This thesis addresses a cutting-edge issue at the intersection of environmental law and the philosophy of science, one that has significant societal implications as the world confronts the climate crisis. The novelty of the research lies in its explicitly epistemological lens on climate litigation. While there is a growing body of literature on climate change litigation, much of it focuses on case outcomes, doctrinal developments, or political implications. This work instead zeroes in on *how courts know what they claim to know* in climate cases: how evidence is constructed, how scientific knowledge is translated or transformed by legal procedures, and what this reveals about the limits of current legal thought. By comparing the ICJ, ECtHR, and Italian courts, the thesis provides a multifaceted view that has not been extensively explored side-by-side. Each of these *fora* has a different way of interacting with science, and examining them in tandem sheds light on the universal versus context-specific aspects of the problem. The emphasis on experts and causation as the two pivotal challenges is likewise a novel synthesis: these issues are often discussed separately, but this thesis argues they both stem from the fundamental epistemological mismatch between science and law.

The practical significance of the study is considerable. As climate litigation continues to surge (with at least 230 new cases filed in 2023 alone[18] and new countries joining the trend), there is a pressing need for courts to handle scientific evidence adeptly and fairly. The risk of *epistemic failure* in climate litigation is real: if courts misunderstand climate science or apply inappropriate standards to it, they could either dismiss meritorious claims or conversely accept unsound arguments, thereby setting bad precedents. Enhancing the dialogue between science and law is essential for justice in the climate context, where so much is at stake for communities and for policy. Thus, the thesis has a normative goal: to suggest ways to build legal decision-making processes that are epistemologically robust. This might feed into guidelines

[18] J. SETZER, C. HIGHAM, *Global trends in climate change litigation: 2024 snapshot*, June 2024, https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2024/06/Global-trends-in-climate-change-litigation-2024-snapshot.pdf.

for judges, reforms in evidence law, or at least scholarly frameworks that future cases can draw on. Ultimately, engaging with the epistemology of climate science is part of a broader push to modernize legal systems for an age of complex, interdisciplinary problems. Climate change is not the only area where probabilistic science meets the courtroom (one can think of public health, pandemic responses, etc.), but it is perhaps the most globally urgent and politically charged example. Solving the law-science puzzle here could have ripple effects in how courts treat scientific expertise in other domains as well.

The case studies chosen – ICJ, ECtHR, and Italy – each carry strategic importance. The ICJ's advisory opinion on climate obligations, delivered in 2025, may become a touchstone in international law, and it explicitly grapples with scientific findings at a judicial level. The ECtHR's impending judgments on climate cases could potentially revolutionize climate governance in Europe by judicializing states' scientific duties (e.g. duty to heed IPCC reports under human rights law). Meanwhile, the Italian context offers a view into how a domestic legal system with civil law traditions and recent constitutional amendments might integrate (or struggle to integrate) climate science; it also provides a microcosm of the challenges any national court faces, from questions of separation of powers to evidentiary hurdles. By reflecting on these, the thesis ensures its conclusions are not abstract, but grounded in real-world litigation experiences.

In conclusion, the introduction has framed the thesis's inquiry and demonstrated why it is both timely and needed. Science and law operate on different epistemic wavelengths: one probabilistic and evolving, the other normative and binary. *Strategic climate litigation* forces these wavelengths to overlap, creating friction but also an opportunity for innovation. The thesis, "Science on Trial: Bridging Scientific and Legal Epistemologies in Strategic Climate Litigation," aims to map this uncharted territory. It combines descriptive analysis of how courts have handled climate science with prescriptive ideas for how they might do so more effectively. The ultimate hope is that this research contributes to a better mutual understanding between the scientific and legal communities. As climate change litigation expands around the globe, developing a jurisprudence that can intelligently and fairly engage with climate

science is not just an academic exercise, it is part of building a justice system capable of responding to one of the most complex challenges of our time.

FIRST CHAPTER

SCIENCE MEETS LAW: CONCEPTS, CONTEXTS, AND CHALLENGES

Analysis of Climate Science and Legal Frameworks

1. The Intersection of Science and Law: Exploring Strategic Climate Litigation

Climate litigation has emerged as a powerful tool in the fight against climate change, where legal actions are brought against states, corporations, or other entities to challenge behaviors, decisions, or omissions that contribute to environmental degradation. These cases are not confined to a single area of law but span across civil, administrative, and constitutional or international courts, particularly those protecting human rights.[19] Plaintiffs seek to hold these actors accountable for their roles in exacerbating climate change, which often results in the violation of fundamental human rights or environmental standards. Climate litigation seeks not only the resolution of individual cases but also serves as a mechanism for influencing broader social and political change.

Strategic climate litigation, a growing phenomenon in recent years, represents a specific category of climate litigation that transcends the individual disputes in question. Unlike ordinary litigation, strategic cases are brought with the broader objective of shaping legal precedents, influencing policy reforms, and altering public opinion on climate-related issues. These legal actions are often part of larger campaigns driven by non-governmental organizations (NGOs), environmental groups,

[19] K. MCKENZIE, G. MEDICI-COLOMBO, L. WEGENER, F. SINDICO, *Climate change litigation: one definition to rule them all...?*, in *Research Handbook on Climate Change Litigation*, Cheltenham, 2024.

or concerned citizens, who seek to push the climate agenda forward where traditional political processes have stalled. Even when strategic litigation does not achieve a legal victory, it can still have a profound impact by generating public awareness, creating pressure on policymakers, and promoting regulatory changes.[20]

In other words, strategic litigation is characterized by a strong ideological motivation, with cases designed not only to win in court but also to serve as catalysts for broader legal and political transformations. These cases often aim to address systemic issues, such as inadequate environmental regulation, corporate accountability, or insufficient state action to meet international climate commitments. In this sense, even unsuccessful cases can achieve significant progress, as courts may adopt interpretations favorable to the climate movement or deliver rulings that inspire legislative reforms.

This form of litigation developed in the United States and Australia in the 1980s, initially focusing on specific environmental issues like pollution and industrial responsibility. It has since evolved and expanded globally, with Europe becoming a major hub of climate-related legal actions.[21] The increasing number of cases is partly attributed to the growing recognition of the catastrophic risks posed by climate change and the widespread political failure to address these risks effectively.[22] The Paris Agreement of 2015, which created binding international climate obligations, provided further impetus for a surge in strategic climate litigation.[23]

According to the United Nations Environment Programme (UNEP) and the Sabin Center for Climate Change Law, the number of strategic climate litigation cases has skyrocketed, more than doubling between 2017 and 2022.[24] The growth of such cases underscores the pressing need for legal systems to address climate issues in more

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20 S. VALAGUZZA, *Liti strategiche e cambiamento climatico*, in *Rivista Giuridica dell'Ambiente*, 2021; S. VALAGUZZA, *Liti strategiche: il contenzioso climatico salverà il pianeta?*, in *Diritto Processuale Amministrativo*, 2021, 293.

21 K. POUIKLI, *Editorial: a short history of the climate change litigation boom across Europe, in Journal of the Academy of European Law*, 22, 2021, 569-586.

22 J. SETZER, C. HIGHAM, A. JACKSON, J. SOLANA, *Climate change litigation and central banks*, in *European Central Bank Legal Working Paper Series*, 21, 2021, 3.

23 *Ibid.*, 3, 7.

24 U.N.E.P., *Global Climate Litigation Report: 2023 Status Review*, July 23, 2023, https://wedocs.unep.org/bitstream/handle/20.500.11822/43008/global_climate_litigation_report_2023.pdf?sequence=3.

effective ways. The rise in these cases also reflects a growing reliance on courts as arenas for environmental advocacy, as political processes and regulatory bodies often fail to implement necessary measures.

One of the most distinctive aspects of strategic climate litigation is its reliance on science. Strategic climate litigation serves as a crucial bridge between legal frameworks, political decision-making, and scientific evidence. In many cases, plaintiffs rely heavily on climate science to demonstrate the causal link between greenhouse gas emissions and environmental harm, often drawing on the authoritative assessments of organizations such as the IPCC. Scientific data is essential to substantiate claims related to climate impacts, and courts are increasingly being asked to evaluate complex technical evidence in determining liability and responsibility.

However, the role of science in these cases goes beyond the presentation of data; it becomes a critical factor in shaping legal outcomes. Judges are often tasked with interpreting scientific evidence, and their rulings can influence not only the immediate case but also the broader legal landscape. Courts may compel governments and corporations to adopt policies aimed at reducing emissions, implementing adaptation strategies, or compensating for damages caused by climate change. In this way, science informs the development of legal doctrines that have far-reaching implications for climate policy.

The integration of science into the legal system is not without challenges. Courts are often required to navigate the uncertainties inherent in scientific models and predictions, and they must balance scientific evidence with legal standards of proof. In some jurisdictions, such as the United States, courts have invoked the "political question doctrine" to avoid ruling on climate cases, arguing that climate change is too complex and far-reaching to be adjudicated within the judicial system.[25] Yet, in other contexts, courts have taken a more active role in enforcing climate obligations.

The aim of this thesis is to investigate the relationship between science and law in the context of strategic climate litigation, with a particular focus on how scientific knowledge is integrated into legal arguments and how courts balance the demands of

[25] A. THORPE, *Tort-based climate change litigation and the political question doctrine*, in *Juridical Land Use & Environmental Law*, 24, 2008, 79.

both disciplines. Climate change presents unprecedented challenges for legal systems, and understanding the interplay between law and science is crucial for developing effective legal responses to the climate crisis. This thesis seeks to explore how legal frameworks can be adapted to better incorporate scientific evidence and to address the procedural and substantive challenges that arise from this integration.

The first chapter will provide a detailed examination of the scientific basis of strategic climate litigation, exploring the role of climate science in shaping legal arguments and informing judicial decision-making. This chapter will focus on the development of climate science as an interdisciplinary field, incorporating data and theories from meteorology, oceanography, physics, and biology. It will also address the challenges associated with integrating scientific evidence into legal processes, particularly in relation to the uncertainty and complexity of climate models.

The concept of the "scientific reserve" will be discussed as a key legal principle that allows courts to rely on expert knowledge in climate cases. This concept, rooted in the Italian legal system, ensures that legal decisions are based on scientifically sound evidence and that courts can defer to scientific authorities when necessary. The chapter will analyze how this principle has been applied in strategic climate litigation and consider its potential for broader application.

2. Understanding Climate Science in the Scientific Community

This part of the chapter explores how the characteristics of climate science, particularly its holistic and interdisciplinary nature, influence its credibility and acceptance by both the scientific community and the general public compared to traditional hard sciences, which often focus on narrower, more specialized fields. Climatology combines data and theories from disciplines such as meteorology, oceanography, physics, chemistry, and biology, enabling it to model and predict global climate dynamics and address issues that no single scientific field could resolve. It is precisely this integrated approach that allows for a more comprehensive understanding of the interactions between the atmosphere, oceans, and Earth's surface.

However, the interdisciplinary nature of climate science also presents challenges for its acceptance. Traditional hard sciences are often grounded in well-established principles and methodologies that yield reproducible results and precise predictions. In contrast, climate science, relying on complex models and integrating diverse fields, can appear less definitive and more open to interpretation, sometimes provoking skepticism from researchers and the public accustomed to more deterministic sciences.

A recent survey by the Pew Research Center found that only one-third of U.S. citizens believe climatologists can accurately assess whether climate change is occurring, and even fewer – about a quarter – think they can determine its effects on extreme weather events, its causes, or the best ways to address it.[26] Despite these challenges, the urgency of climate issues necessitates extensive collaboration across disciplines to develop mitigation and adaptation strategies rooted in sound scientific knowledge. Growing awareness of climate change and its tangible impacts has increased the legitimacy of climate science, prompting scientific communities and governments to take its projections and warnings seriously.

The increasing recognition of global climate interdependence, both in terms of phenomena and solutions, highlights the importance of this field. Climate science challenges the traditional paradigm of sciences, emphasizing the need for collaborative, transdisciplinary research where credibility stems not only from methodological rigor but also from the ability to interpret and integrate complex, interconnected phenomena.

An emblematic example is the IPCC, the scientific body established by the United Nations in 1988, which unites thousands of scientists worldwide to assess climate-related information. The IPCC's reports, among the most authoritative sources on global climate, synthesize knowledge from meteorology, oceanography, atmospheric physics and chemistry, biology, ecology, and social sciences. This integration allows the IPCC to produce comprehensive, coherent assessments that

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[26] G. PASQUINI, B. KENNEDY, *Americans continue to have doubts about climate scientists' understanding of climate change*, Pew Research Center, October 25, 2023 https://www.pewresearch.org/short-reads/2023/10/25/americans-continue-to-have-doubts-about-climate-scientists-understanding-of-climate-change/.

significantly influence global climate policies. It demonstrates that, through effective organizational structures and collaborative commitment, it is possible to coordinate scientists from diverse nations and disciplines, despite the logistical and methodological challenges such cooperation entails.

The next three paragraphs will analyze climate science's history and methodology, compare it with hard sciences in terms of methodology, reproducibility, and precision, and examine public perception. Finally, they will explore how climatological findings influence public policies, shape societal views on climate phenomena, and underscore the need for sciences to present a unified front in addressing climate change and communicating complex scientific insights to the public.

2.1 *The Nature of Climate Science*

Climatology is defined as "*the scientific study of the behavior of the atmosphere – the thin gaseous layer surrounding Earth's surface – integrated over time.*" While this definition is technically accurate, it does not fully encompass the field's broader purpose and scope. A more comprehensive understanding of climatology positions it as a "*holistic science that incorporates data, ideas, and theories from all parts of the Earth-ocean-atmosphere system, including those influenced by humans, into an integrated whole to explain atmospheric properties.*"[27] This inherently interdisciplinary nature reflects a defining characteristic of climatology: its capacity to merge and synthesize diverse strands of knowledge to address complex problems that no single discipline can resolve independently.[28]

The interdisciplinary nature of climatology stems from the inherent complexity of the Earth-ocean-atmosphere system, which can be divided into distinct zones, each traditionally studied by separate scientific disciplines:

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27 R.V. RHOLI, A.J. VEGA, *Climatology*, Sudbury, 2018, 3.

28 S. WEART, *Rise of interdisciplinary research on climate*, in *Proceedings of the National Academy of Sciences*, 110(1), 2013, 3657-3660.

(i) The lithosphere: This zone comprises the Earth's crust and mantle and falls within the domain of geologists, geophysicists, and volcanologists. These experts examine the physical structure and processes of the solid Earth, which influence the climate through volcanic activity, tectonic shifts, and soil properties.

(ii) The hydrosphere: Including all liquid and solid water on the Earth's surface, it is studied by oceanographers, hydrologists, and glaciologists, among others. The solid component, known as the cryosphere, specifically engages glaciologists, whose work is crucial for understanding ice sheet dynamics and their role in sea-level changes.

(iii) The biosphere: Representing the regions of Earth occupied by living organisms, this zone is examined by biologists, physical geographers, and ecologists, who analyze the interactions between living systems and atmospheric processes, such as carbon and nitrogen cycles.

Climatology focuses on the atmosphere – the medium that interacts dynamically with these zones – producing various climatic phenomena. Fully understanding these interactions requires drawing insights from the specialized disciplines that study each zone, making interdisciplinarity a practical necessity for the advancement of climate science. The need for collaboration across fields highlights the importance of developing a unified approach to address the multifaceted nature of climate phenomena.[29]

Historically, climatology evolved from a data-centric approach that primarily involved compiling and analyzing statistics about regional weather conditions.[30] This work was crucial for practical applications such as agriculture and engineering, where knowledge of average temperatures, rainfall extremes, and other climatic patterns informed decisions. However, this approach treated the climate as a static system, emphasizing localized data over a global perspective. Until the mid-20th century, climatology remained a "backwater" field in the eyes of many scientists, with limited theoretical ambition and a narrow focus on descriptive statistics. In 1953, the U.S.

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29 R.V. RHOLI, A.J. VEGA, 4.

30 *Ibid*., 4.

Weather Bureau effectively described the work of climatologists at the time as primarily data compilation, with minimal funding or intellectual enthusiasm driving the field.[31]

A pivotal moment in the transformation of climatology into a true science came in 1941 with Helmut Landsberg's Physical Climatology. This manual introduced American students to climatology as an applied physical science grounded in statistical data.[32] Published during World War II, the manual coincided with a period when climatology and meteorology gained prominence due to their strategic military applications. This era witnessed the creation of university courses and research centers dedicated to these fields. A prime example is Carl-Gustaf Rossby, who founded a meteorology department at the University of Chicago in 1942, promoting a dynamic approach to climatology. This new perspective shifted the focus from static geographic factors to systemic analyses of meteorological phenomena.

Following World War II, geophysics, of which climatology was a component, solidified as a scientific discipline. Its postwar growth led to fragmentation into specialized fields such as astrophysics, geochemistry, and meteorology, each with distinct methodologies and data types, often at the expense of interdisciplinarity. Between the 1960s and 1970s, a series of adverse climatic events exposed the limitations of methods based solely on data collection and comparison for climate predictions. This realization drove the adoption of models and calculations derived from physics, necessitating collaboration across various Earth sciences.[33]

It was during this period that holistic investigation began to take root. While scientists often retained their distinct titles as oceanographers, meteorologists, or physicists, interdisciplinary conferences became increasingly common, fostering collaboration on climate-related topics. By the late 1970s, the first centers for climatology emerged, shifting their focus from regional climatic trends to the global climate. These centers developed the earliest climate models, marking a significant milestone in the evolution of the field.[34]

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31 S. WEART, 3657-3658.
32 H.E. LANDSBERG, *Physical Climatology*, Pennsylvania, 1941.
33 S. WEART, 3659-3661.
34 *Ibid.*, 3652-3663.

This gradual evolution gave rise to the climatology we know today – a holistic science that draws from various disciplines while maintaining its distinct identity. A common misconception is to conflate climatology with meteorology. While the two fields share similarities, they are not identical: meteorology focuses on atmospheric phenomena and their variations in specific places and times, whereas climatology examines atmospheric phenomena to understand their effects over extended periods.[35]

Climatology employs its own methods of analysis and sources of information, including historical records of temperatures and precipitation, data from weather stations, ocean buoys, and orbiting satellites – available only since the 1960s with the advent of weather satellites. It also relies on alternative sources, such as biological or chemical indicators (e.g., tree rings and lake sediments), historical and geographical records, and firsthand accounts from explorers, colonists, or missionaries.[36]

An interesting example is David Livingstone, the renowned Scottish missionary and explorer, whose detailed observations of southern and eastern Africa's climate have contributed significantly to understanding the region's historical climate patterns. Livingstone's diaries and letters documented phenomena such as the frequency of seasonal rains, droughts, and their effects on local populations and ecosystems. These accounts have proven invaluable for calibrating regional climate models and verifying reconstructions based on alternative sources like tree rings and lake sediments.[37]

To analyze climatic variations over time and space, climatologists employ several methods, including:

(i) Trend analysis, which estimates general climatic changes over a given period.

(ii) Spectral analysis, which examines the frequency of climatic phenomena over time.[38]

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35 R.V. RHOLI, A.J. VEGA, 5.

36 For further reading on the topic, see S.E. NICHOLSON, *Climatology: Methods*, Oxford Research Encyclopedias, African History, August 22, 2017, https://doi.org/10.1093/acrefore/9780190277734.013.27. While it primarily focuses on African climate, it clearly explains concepts related to the methodology of climate science that are universally applicable.

37 G.H. ENDFIELD, D.J. NASH, *Drought, Desiccation and Discourse: Missionary Correspondence and Nineteenth-Century Climate Change in Central Southern Africa,* in *The Geographical Journal*, 168(1), 2002.

38 H.E. LANDSBERG, J.M. MITCHELL JR., H.L. CRUTCHER, *Power spectrum analysis of climatological data for Woodstock College, Maryland*, in *Monthly Weather Review*, 87(8), 1959.

(iii) Wavelet analysis, which not only studies the frequency of climatic phenomena but also identifies their timing.[39]

Another cornerstone of modern climatology is the use of climate models—computational tools that simulate the physical processes of the atmosphere, oceans, Earth's surface, and ecosystems. These models rely on mathematical equations describing physical laws, such as air and water movement, heat transfer, solar radiation, cloud dynamics, and other factors influencing the global climate. They can be categorized into three main types:

(i) General Circulation Models (GCMs), the most complex and comprehensive, simulating all aspects of Earth's climate system.[40]

(ii) Regional models, which focus on specific areas or aspects of the climate system, such as climate impact models.

(iii) Earth System Models (ESMs), which integrate multiple components of Earth's systems, including biogeochemical cycles and their interactions.[41]

These models are crucial for predicting long-term climate changes under various greenhouse gas emission scenarios, understanding climate processes, and testing scientific hypotheses about the climate system.[42] A notable example is the 1997–1998 El Niño event, one of the strongest ever recorded, which caused severe global impacts, including floods, droughts, and heatwaves.

El Niño is characterized by an anomalous increase in the surface temperature of the eastern equatorial Pacific waters, significantly influencing global weather and climate patterns. In 1997, researchers, using global climate models, detected early signs of an intense El Niño. The National Oceanic and Atmospheric Administration (NOAA) operated one of the most effective models, utilizing data from ocean buoys, satellites, and other technologies to monitor water temperatures and ocean currents.

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39 S.E. NICHOLSON, 15-17.

40 I.P.C.C., *What is a GCM?*, IPCC Data Distribution Center, https://www.ipcc-data.org/guidelines/pages/gcm_guide.html.

41 N.G. HEAVENS, *Studying and Projecting Climate Change with Earth System Models*, in *Nature Education Knowledge*, 4(5), 2013.

42 S.H. SCHNEIDER, R.E. DICKINSON, *Climate modeling*, in *Review of Geophysics*, 12(3), 1974.

The model not only predicted the event's occurrence by year's end but also accurately forecasted its intensity.[43]

This early warning allowed governments and agencies to implement mitigation measures, underscoring the importance of climate models in preparing for and managing extreme climatic events. It also highlighted the value of investing in advanced technologies and a global network of climate observations to improve the accuracy of climate predictions further.

Looking to the future, several emerging technologies and research areas promise to further transform the field of climatology. Its evolution has always been closely tied to technological advances, which have enabled increasingly precise data collection, more sophisticated climate models, and more accurate predictions.

Artificial intelligence (AI) and machine learning are already revolutionizing climatology by allowing the analysis of vast amounts of climate data, the identification of complex patterns, and the generation of more accurate predictions. Neural networks, in particular, enable forecasting of extreme weather events such as hurricanes, droughts, and heatwaves, reducing response times and improving mitigation strategies.

Using techniques like downscaling or neural network models, climatologists can produce point forecasts – predictions for specific weather events in very narrow areas.[44] Neural networks also excel at uncovering non-linear relationships between predictors (climate-related variables) and a fixed target (specific climatic phenomena), enabling deeper insights into the causes of these phenomena.[45]

Supercomputers play a similarly critical role in climatology and are expected to become even more central in the future. These powerful machines enable highly detailed and complex climate simulations, processing enormous amounts of data in relatively short timeframes. A notable example is the Earth Simulator in Japan, which

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43 S.A. CHANGNON, *What Made El Niño 1997-1998 Famous?: The Key Events Associated with a Unique Climatic Event*, in S.A. CHANGNON (ed.), *El Niño, 1997-1998: The Climate Event of the Century*, New York, 2000.

44 See A. PASINI, V. PELINO, S. POTESTÀ, *A neural network model for visibility nowcasting from surface observations: Results and sensitivity to physical input variables*, in *Journal of Geophysical Research: Atmospheres*, 106(D14), 2001, 14951-14959, who have developed a model for predicting local visibility in Northern Italy.

45 S. AMENDOLA, *Neural-Network modelling for meteorological and climatological applications*, Rome, 2020.

conducts detailed simulations of the Earth's climate to predict future changes and study their impacts.[46]

Next-generation sensors and satellites further enhance climatology by providing high-resolution data on atmospheric, oceanic, and terrestrial variables, improving our understanding of climate systems. Meanwhile, the growing network of Internet of Things (IoT) devices offers real-time environmental data, delivering detailed and localized insights into climatic conditions.

In summary, technological innovations and future advancements hold tremendous potential for enhancing our ability to understand and address climate change. The integration of cutting-edge tools such as artificial intelligence, supercomputers, advanced sensors, and IoT devices, combined with an interdisciplinary and collaborative approach, will enable the development of more effective strategies to mitigate the impacts of climate change and adapt to an evolving world.

2.2 *Comparison with Hard Sciences*

In the previous subparagraph, climatology was presented through its essential characteristics: definition, history, and methodology. In this section, these features will be compared with those of the hard sciences, which, as previously noted, are characterized by narrower areas of expertise, rigorous methodologies, reproducibility of results, and the precision of both collected data and proposed solutions. This comparison will provide insight into how climate science is perceived by both the scientific community and the public, as well as how its findings are received within legislation and jurisprudence.

To begin, it is essential to briefly examine the concept of "hard sciences," their definition, and their significance within the scientific tradition. Hard sciences are those disciplines in which facts and theories can be measured, tested, and verified with

[46] The website https://www.jamstec.go.jp/es/en/ provides in-depth information about the Earth Simulator supercomputer, the projects it is employed in, and the results of its work.

certainty and precision. These include mathematics and logic – the so-called "exact sciences" – as well as biology, chemistry, and physics, which are considered "natural sciences." Their central role, particularly in addressing global challenges, derives from their reproducibility of results and their ability to formulate predictions based on universal physical laws. This ensures the validity of their findings and enables the progressive development of scientific knowledge built upon solid, "hard" foundations.[47]

Regarding the methodological foundations, the key traits of climatology have already been outlined in the previous subparagraph. For the "hard sciences," the defining characteristics are the reproducibility of experiments, the use of rigorous controls, and the reductionist approach.

The reproducibility of experiments is fundamental to the validity of any science that defines itself as empirical – where data are collected through experiments, systematic observations, and other forms of practical investigation – and nomological, which seeks to formulate general and universal laws to explain natural behaviors and events. Reproducibility is crucial for two main reasons. First, without it, the laws of nature could not be empirically tested and confirmed, as replication is necessary to validate experimental findings. Second, reproducibility ensures that scientific results are objective and verifiable, rather than subjective beliefs of individual researchers, which would otherwise remain unverifiable and inaccessible to others.[48]

The reductionist approach, on the other hand, is a methodological strategy that seeks to understand complex systems by breaking them down into their simplest, most fundamental components and analyzing these elements individually, as well as their interactions. This approach has been a powerful tool in achieving significant scientific advancements over time. However, reductionism also reveals its limitations when applied to extremely complex systems, such as ecological, biological, or social

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[47] For a deeper understanding of the history of the distinction between hard sciences and soft sciences, see S. SHAPLIN, *Hard science, soft science: A political history of a disciplinary array*, in *History of Science*, 60(3), 2022, 287-328.

[48] H. TETENS, *Reproducibility, Objectivity, Invariance*, in H. ATMANSPACHER, S. MAASEN (eds.), *Reproducibility: Principles, Problems, Practices, and Prospects*, Zurich, 2016.

systems. These systems often involve intricate interactions and emergent processes that cannot be fully understood solely through the analysis of individual components.[49]

Thus, even at the methodological level, the first differences between climatology and the hard sciences begin to emerge. The reductionist approach, for the reasons previously mentioned, is difficult to adopt in climatology. But this is not the only challenge. The replicability of studies and results, as well as the accuracy of predictions derived from climate models, present significant difficulties for climatology.

These challenges are primarily due to the long temporal scales and vast spatial dimensions that many climate studies must account for. A single study may require data spanning decades or even centuries. However, historical climate records are often incomplete or collected using non-standardized methods, which increases uncertainty and complicates efforts to replicate findings. Furthermore, climate is inherently a global phenomenon, exhibiting significant regional variations and shaped by complex interactions among the atmosphere, oceans, biosphere, and human activities on a planetary scale. These factors make it nearly impossible to replicate identical environmental and spatial conditions across different studies.[50]

The prediction of Asian monsoons serves as an emblematic example of the challenges climatology faces due to these temporal and spatial complexities. Temporally, monsoons are influenced by long-term climate cycles such as the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Oscillation (AMO), which vary on decadal timescales. In addition, global climate change introduces new variables and uncertainties, complicating predictions about how monsoon patterns may evolve in the coming decades. Spatially, Asian monsoons affect an immense region – including India, Southeast Asia, and parts of China –with diverse topographies ranging from open seas to mountain ranges, each exerting unique influences on precipitation and wind patterns. Monsoons are also shaped by global

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[49] M. HEYMANN, D. ACHERMANN, *From climatology to climate science in the twentieth century*, in S. WHITE, C. PFISTER, F. MAUELSHAGEN (eds.), *The Palgrave handbook of climate history*, Londra, 2018, 605-632.

[50] R. BUSH, A. DUTTON, M. EVANS, R. LOFT, G.A. SCHMIDT, *Perspectives on Data Reproducibility and Replicability in Paleoclimate and Climate Science*, in *Harvard Data Science Review*, 2(4), 2020.

climate phenomena such as El Niño and La Niña, which interact in complex ways with regional climatic systems. These factors, combined with incomplete data and the complexity of climate models, make precise climatic predictions extraordinarily challenging.[51]

These characteristics – long temporal scales, vast spatial dimensions, and the complexity of data stemming from the interdisciplinary nature of climatology –leave the field vulnerable to criticism. Skeptics argue that historical observations of climatic and meteorological phenomena are too uncertain and based on insufficiently robust data to definitively conclude that climate change is occurring or to ascertain the extent of human influence.[52] Such critiques reflect broader doubts about whether climatology can be considered a fully "consolidated" science.[53]

This brings us to another important theme in the comparison between hard sciences and climatology: the level of acceptance and trust that each enjoys. Hard sciences, due to their ability to produce concrete, reproducible, and predictable results demonstrable through controlled experiments, typically command a high level of trust and acceptance both within the scientific community and among the broader public. These characteristics bolster their credibility and reinforce the perception of objectivity, making these disciplines appear more rigorous and reliable.[54]

In contrast, climatology often finds itself at the center of political debates, particularly those concerning climate change. Its findings have direct implications for public policies, industrial practices, and commercial interests, leading to resistance and criticism, especially from stakeholders negatively impacted by its conclusions. This dynamic frequently results in the politicization of climatology, which can erode its

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51 P.J. WEBSTER, V.O. MAGANA, T. PALMER, J. SHUKLA, *Monsoons: Processes, predictability, and the prospects for prediction*, in *Journal of Geophysical Research Atmospheres*, 1031(C7), 1998, 14451-14510.

52 S.R. KOONIN, *Unsettled: What Climate Science Tells Us, What It Doesn't, and Why It Matters*, Dallas, 2021, but see also the op-ed by W. HAPPER, *Global warming models are wrong again*, Wall Street Journal, March 27, 2012 https://www.wsj.com/articles/SB10001424052702304636404577291352882984274; or the cover story on Freeman Dyson by N. DAWIDOFF, *The Civic Heretic*, New York Times Magazine, March 25, 2009 https://www.nytimes.com/2009/03/29/magazine/29Dyson-t.html, where the two physicists declared that climate change is not a serious problem.

53 *Ibid*.

54 V.H.M. VISSCHERS, *Public Perception of Uncertainties Within Climate Change Science*, in *Risk Analysis*, 38(1), 2018.

perceived objectivity and neutrality. Hard sciences, by comparison, are generally viewed as more detached from immediate political concerns.

A notable example is the 1997 decision by President Bill Clinton not to ratify the Kyoto Protocol – one of the first international agreements aimed at addressing climate change through reductions in greenhouse gas emissions – due to strong opposition from Congress. Even today, segments of the political spectrum express skepticism or outright denial of climate change, often challenging the validity of scientific research that attributes climate change to human activity. Such positions are frequently rooted in economic concerns, particularly regarding the potential negative impacts of climate mitigation policies on industries like fossil fuels and on national economic competitiveness.

Despite these challenges, trust in climate science is growing as models and data collection techniques continue to improve, enabling increasingly accurate predictions. Furthermore, the rising visibility of climate change impacts has heightened public awareness of the importance and reliability of climate science. Nevertheless, it is still viewed with greater skepticism compared to the hard sciences, requiring ongoing efforts in scientific communication and education to build and sustain public trust.

On this point, a final consideration is worth mentioning: the critical importance of effectively communicating climate science results and promoting climate science education for all.

Effective communication of climate research findings is essential to ensure that scientific information is not only understood but also accepted and utilized to inform public policies and individual decisions. Given the complexity of climate models and the global ramifications of climate change, it is crucial that research results are conveyed in a manner that is clear, precise, and accessible to diverse audiences, including policymakers, private sector stakeholders, and the general public.

Equally important is climate science education, which plays a fundamental role in fostering an informed and responsible society capable of addressing the challenges posed by climate change. A solid understanding of the scientific principles underpinning climate and climate change helps encourage sustainable behaviors, support effective environmental policies, and prepare future generations to navigate an evolving world.

For these reasons, these aspects – effective communication and education –will be explored in greater detail in the next subparagraph.

2.3 *The Impact of Climate Science on Public Policy and Perception*

The previous subparagraph highlighted that the findings of climatology are often met with skepticism, a reaction partly rooted in the discipline's distinct characteristics compared to other hard sciences. This skepticism is frequently exacerbated by the economic and political ramifications of climate science discoveries for certain stakeholders. The power of climate science to influence public policies and societal perceptions is not an inherent trait but a capacity it has gradually acquired over time, shaped by its growing role in addressing one of the most pressing global challenges of our era.[55]

The gradual process by which climate science has gained influence began in the 1960s and 1970s, as scientific research started providing concrete evidence of rising greenhouse gas concentrations in the atmosphere and their potential effects on global warming. Pioneering studies, such as those conducted by Charles David Keeling, documented the steady increase in atmospheric CO_2 levels, establishing a direct link between human activities, such as fossil fuel combustion, and global warming. These findings laid the foundation for a deeper scientific understanding of climate change and sparked growing concern among both the scientific community and the general public.[56]

In the post-war period, the relationship between science and policy became a site of debate between two opposing visions regarding the role of science in society – one liberal and the other democratic. On one side stood the document "*Science – The Endless Frontier*" (1945),[57] drafted by Vannevar Bush, an MIT engineer and head of the wartime Office of Scientific Research and Development. This report advanced a

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55 B. HAGEN, *Public Perception of Climate Change*, London, 2015.
56 M. HEIMANN, *Charles David Keeling 1928–2005*, in *Nature*, 437(331), 2005.
57 V. BUSH, *Science – The Endless Frontier: A Report to the President on a Program for Postwar Scientific Research*, Washington DC, 1945. Reprinted 1990.

liberal and conservative perspective, arguing for the independence of science from government interference. Bush famously asserted that "[s]*cientific progress on a broad front results from the free play of free intellects, working on subjects of their own choice, in the manner dictated by their curiosity for exploration of the unknown.*"[58]

On the other side, "*Science and Public Policy*" (1947),[59] drafted by Democrat John R. Steelman, presented an alternative view. Steelman contended that science, as a form of knowledge and power, must be regulated by guarantees consistent with democratic principles. According to Steelman, there is no inherent aspect of science that justifies derogating from the fundamental principles of the State.[60]

The 1980s and 1990s marked a turning point as scientific consensus on climate change began to solidify. The establishment of the IPCC in 1988 was pivotal in this process. The IPCC synthesized existing scientific knowledge, producing authoritative reports that provided policymakers and the public with a clear understanding of the risks posed by climate change. These reports increased global awareness and laid the groundwork for coordinated political actions.

Scientific discoveries began to have a direct impact on public policy. A landmark example was the Kyoto Protocol of 1997, which, despite its mixed results, represented a significant step forward in international cooperation to address climate change. More recently, the 2015 Paris Agreement, driven by robust scientific evidence and a strong international consensus on the urgency of action, galvanized global commitments to limit global temperature increases to well below 2°C above pre-industrial levels.[61]

Today, the influence of climate science extends beyond policy frameworks, catalyzing social movements and grassroots activism. Initiatives like Fridays for Future, led by Greta Thunberg, have mobilized millions worldwide – especially young people – to demand more decisive political actions to combat climate change. These movements highlight the growing intersection of science, policy, and societal

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58 *Ibid*., 12.
59 J.R. STEELMAN, *Science and Public Policy*, Washington DC, 1947. Reprinted 1980.
60 *Ibid.*, vol. I, 31.
61 See, in particular, Articles 2, paragraph 1, and 4, paragraph 3, of the Agreement.

engagement, underscoring the transformative power of scientific discovery when effectively communicated and integrated into collective action.

This brief overview highlights that the increasing prominence of climate research findings in public debate is closely tied to the growing scientific consensus on climate change.[62] While the reasons for this are numerous and evident, it is worth outlining them explicitly here.

Firstly, when there is broad agreement within the scientific community on a particular issue, policymakers are more likely to design and implement public policies grounded in solid scientific evidence. This credibility ensures that decisions are informed by reliable data and analyses, enhancing their effectiveness and public acceptance.

Secondly, a strong scientific consensus helps combat misinformation and reduce public skepticism. By presenting unified findings, the scientific community can effectively educate and raise awareness about the risks associated with climate change. This, in turn, fosters a more informed public and creates a supportive environment for international cooperation, which is essential for addressing a global challenge of this magnitude.

Finally, scientific consensus attracts increased funding and resources for climate research. This financial support drives innovation and enables the development of new technologies for mitigation and adaptation. Moreover, it advances our understanding of the climate system and improves the predictive capabilities of climate models, which are critical for crafting effective long-term strategies.[63]

The challenge, however, is that even when a strong scientific consensus on an issue – such as climate change – is reached, it may not be sufficient if the complexities of communicating scientific information to the public are not effectively addressed. Many scientific discoveries rely on highly technical and intricate concepts that are

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62 See S. LEWANDOWSKY, G.E. GIGNAC, S. VAUGHAN, *The pivotal role of perceived scientific consensus in acceptance of science*, in *Nature Climate Change*, 399(3), 2013, which conducted two studies revealing (*i*) that acceptance of various scientific assertions is influenced by a common factor related to perceived scientific consensus; (*ii*) that scientific consensus increases the acceptance of anthropogenic global warming.

63 See N. ORESKES, *The Scientific Consensus on Climate Change: How Do We Know We're Not Wrong?*, in E.A. LLOYD, E. WINSBERG (eds.), *Climate Modelling*, Chicago, 2018,which, by examining a series of criteria that philosophers have traditionally or recently identified as possible bases for confidence in scientific conclusions, demonstrates that climate science meets all these criteria.

difficult to grasp for those without specialized training. This inherent complexity can hinder effective communication if the information is not translated into accessible language while still maintaining its accuracy.

An additional obstacle is the general lack of interest or foundational knowledge among the public regarding scientific topics. Many individuals may not have a natural inclination toward science or the necessary background to easily comprehend new information. This gap can lead to widespread misinformation, misunderstanding, and even skepticism, ultimately undermining the broader societal acceptance of scientific findings and the urgency of collective action on climate issues.[64]

One potential solution to these obstacles is to foster active public engagement through public debates, interactive events, or citizen science projects. According to the *Oxford English Dictionary*, citizen science refers to "*the collection and analysis of data relating to the natural world by the public, typically as part of a collaborative project with professional scientists.*"[65] A notable example is the Earth Echo Water Challenge, which engages citizens worldwide in protecting the water sources upon which we all depend. The project provides volunteers with water quality testing kits, enabling them to collect and analyze samples from local water sources, with the results subsequently uploaded to an online platform.[66]

These projects serve multiple purposes: public participation in scientific research democratizes the process of science, bridging the gap between scientists and society. Additionally, such initiatives facilitate large-scale data collection, significantly increasing the quantity and quality of data on biodiversity, meteorological phenomena, and air and water quality. Just as importantly, they enhance public awareness and understanding of environmental issues, fostering a sense of responsibility and collective action in addressing global challenges.

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64 H.P. PETERS, *Handbook of Public Communication of Science and Technology*, London, 2008.

65 See also P. SCHRÖGEL, A. KOLLECK, *The Many Faces of Participation in Science. Literature Review and Proposal for a Three-Dimensional Framework*, in *Science & Technology Studies. Special Issue: Many Modes of Citizen Science*, 32(2), 2019 and C.B. COOPER, B.V. LEWENSTEIN, *Two Meanings of Citizen Science*, in D. CAVALIER (ed.), *From The Rightful Place of Science: Citizen Science*, Tempe, 2016.

66 Further information can be found on the website https://www.monitorwater.org/about.

Continuous climate education is essential, as it "*inspires people to rethink who they are, what they believe, how they behave, and to take action.*"[67] Only through sustained education can environmental literacy be achieved, leading to long-term changes in individual and societal behavior. The importance of climate education is underscored by the Paris Agreement, which, in Article 12, calls on member states to "*enhance climate change education, training, public awareness, public participation, and public access to information.*" Similarly, Sustainable Development Goal (SDG) 13.3 emphasizes the need to "*improve education, awareness-raising, and human and institutional capacity on climate change mitigation, adaptation, impact reduction, and early warning.*"

There are numerous successful examples of educational initiatives promoting climate literacy. One notable program is the *Global Learning and Observations to Benefit the Environment* (GLOBE), an international science and education initiative engaging students, teachers, and researchers of all ages. GLOBE participants study Earth system science through data collection and research in collaboration with scientists from various international agencies. The program's findings are shared on the GLOBE website, making them accessible to the global community.[68] Thousands of schools worldwide have participated in this program, fostering greater environmental awareness and contributing valuable data to climate research.

From the foregoing, it is evident that integrating science, public policy, and education is essential for effectively addressing global climate challenges. When these three elements are well-coordinated, they provide a strong and coherent response to the complex problems posed by climate change.

Science serves as the primary source of knowledge about climate phenomena. Through rigorous research and data collection, scientists provide empirical evidence describing global warming, climate variations, and their impacts on ecosystems and societies. This foundation is critical for understanding the scale of the climate crisis and for devising evidence-based solutions. Furthermore, predictive models developed

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[67] U.N. SYSTEM STAFF COLLEGE, *Climate Change Education: the key to advancing climate action*, July 28, 2022, https://www.unssc.org/news-and-insights/blog/climate-change-education-key-advancing-climate-action.

[68] https://www.globe.gov/.

by scientists allow for the anticipation of future climate conditions and the assessment of mitigation and adaptation strategies. These models enable policymakers to plan more effectively, preparing for potential climate impacts and crafting robust strategies to address them.

Evidence-based public policies are equally vital for mitigating the effects of climate change. Governments can introduce regulations to reduce greenhouse gas emissions, promote renewable energy adoption, and improve energy efficiency. These measures establish a regulatory framework that encourages sustainable behaviors while minimizing environmental impact. Policies can also focus on climate adaptation through resilient urban planning, the protection of water resources, and the promotion of sustainable agricultural practices. Such measures help communities become more resilient to climate impacts by reducing vulnerabilities and enhancing their capacity to recover from adverse events.

Finally, education plays a fundamental role in fostering public awareness of climate issues. Educational programs in schools and universities, public awareness campaigns, and citizen science initiatives are powerful tools for informing people about the risks of climate change and the actions they can take to mitigate its effects. Effective education creates an informed and engaged citizenry. When individuals understand the science of climate change and the rationale behind environmental policies, they are more likely to support mitigation and adaptation measures and adopt sustainable practices in their everyday lives.

The following section (Paragraph 3) will examine how these three factors – science, public policies, and the democratization of science – are reflected in the legal domain. It will analyze the legal frameworks and norms that allow science to be incorporated into the development of laws and policies. Additionally, it will explore the challenges that this integration poses within a democratic system, focusing on how scientific expertise can align with the principles of transparency, accountability, and public participation that are fundamental to democratic governance.

3. Climate Science and Legal Frameworks

3.1 *Science-Based Legislation: Navigating the Complexities of Climate Law*

In the previous paragraphs, the critical role of scientific research in the development and implementation of environmental policies was emphasized. Specific examples of legislation influenced by climate science demonstrated how scientific discoveries have shaped regulations designed to protect the environment and mitigate the effects of climate change.

It has now been established that scientific research provides a robust foundation of data and predictions essential for identifying pollution thresholds, determining safe emission levels, and setting sustainability goals. However, the integration of science into legislative and regulatory processes is not driven solely by logic or common sense; it is also, and perhaps more importantly, mandated by law.

For instance, Article 4(1) of the Paris Agreement provides that "[i]*n order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible,* […] *and to undertake rapid reductions thereafter in accordance with best available science* […]." Similarly, the Twenty-Sixth United Nations Climate Change Conference (COP26), held in November 2021, underscored the centrality of science in the Glasgow Climate Pact, recognizing "*the importance of the best available science for effective climate action and policymaking.*"[69]

At the European level, Article 191(3) TFEU states that "[i]*n preparing its policy on the environment, the Union shall take account of available scientific and technical data.*" Additionally, the European Court of Human Rights acknowledges that measures adopted by States must "*be monitored, taking into account particularly scientific and social developments.*"[70]

In Italy, the law establishing the SNPA, which oversees the network of environmental agencies (Arpa-Appa-Ispra), mandates that data and scientific

[69] COP26, *Glasgow Climate Pact*, November 13, 2021, https://www.storiairreer.it/sites/default/files/norme/2021%2011%2013%20glasgow%20%28italiano%29.pdf.

[70] It has done so particularly in Rees v. United Kingdom, app. no. 9532/81, § 47; Cossey v. United Kingdom, app. no. 10843/84, § 40; Fretté v. France, app. no. 36515/97, § 42; S.H. & Others v. Austria, app. no. 57813/00, §§ 97, 103, 117, 118; Dubská and Krejzová v. Czech Republic, app. nos. 28859/11 and 28473/12, § 100; Oluić v. Croatia, app. no. 22330/05, §§ 29- 31.

information provided by the System "*constitute official and binding reference for the activities within the competence of public administrations*" [translated]. Furthermore, the Constitutional Court has affirmed that scientific findings and institutions serve as limits to political discretion (judgments nos. 185/1998 and 282/2002) and private autonomy (judgment no. 116/2006), as well as to the free conviction of judges (judgment no. 121/1999).

This extensive jurisprudence of the Constitutional Court forms the basis of what is referred to as the "scientific reserve,"[71] a constitutional principle asserting that regulatory provisions grounded in science "*must be rationally justifiable based on data and arguments from qualified and institutionalized sources within the scientific community*" [translated].[72]

Among the referenced constitutional rulings, the principle of scientific reserve is particularly prominent in the Court's jurisprudence on medical-therapeutic matters. A notable example is judgment no. 282/2002, in which the Court invalidated a Marche Region law that temporarily banned electroconvulsive therapy without sufficient scientific assessment. The Court established that therapeutic decisions must rely on verified scientific knowledge, assessed by competent national or supranational institutions, rather than on purely discretionary political evaluations.

Specifically, the Court emphasized that "*an intervention on the merits of therapeutic choices in relation to their appropriateness could not arise from purely discretionary political evaluations of the legislator itself but should involve the formulation of guidelines based on the verification of the state of scientific knowledge and acquired experimental evidence, through institutions and bodies – usually national or supranational – designated for this purpose* […]*; or in any case should be the result of such verification*" [translated] (point 5).

What made this ruling particularly innovative was the Court's application of a reasonableness review similar to that typically employed by administrative courts when assessing measures affected by abuse of power. In this case, the Constitutional

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71 A. MANGIA, Si caelum digito tetigeris. *Osservazioni sulla legittimità costituzionale degli obblighi vaccinali*, in *Rivista AIC*, 3, 2021, 435.

72 D. SERVETTI, *Riserva di scienza e tutela della salute. L'incidenza delle valutazioni tecnico-scientifiche di ambito sanitario sulle attività legislativa e giurisdizionale*, Pisa, 2019, 2.

Court evaluated whether the Region had gathered and considered all relevant factual elements, effectively scrutinizing the legislative process itself.[73] This approach integrated a "scientific reasonableness" review into constitutional adjudication, adding a new dimension to the evaluation of legislative norms.[74]

The principle of scientific reserve was further reinforced in judgment no. 5/2018, which upheld the introduction of new vaccination requirements for minors. The Court validated these obligations based on adequate scientific assessments, including an opinion from the World Health Organization (WHO). In its reasoning, the Court reaffirmed that regulatory decisions must be justified by scientific evidence, underscoring how scientific progress serves as a continuous limit on legislative discretion. This ruling demonstrated the necessity of updating regulations to reflect advancements in scientific knowledge, thereby ensuring that laws remain both rational and evidence-based.[75]

In an article on the relationship between science and politics during the Covid-19 pandemic, Giada Ragone effectively summarizes key Constitutional Court rulings on the features of the scientific reserve in the medical-therapeutic field. These rulings emphasize three fundamental principles:[76]

(i) "*The legislative authority is required to base its regulatory choices on specific technical-scientific findings, verified by competent bodies*" [translated] (judgment no. 282/2002 and subsequent cases);

(ii) "*These bodies must have national or supranational relevance, as decisions cannot be based solely on opinions expressed by regional scientific communities*" [translated] (judgments nos. 338/2003 and 8/2011);

(iii) "*The involvement of experts should not be a one-time activation but must continue to ensure ongoing updates of issued regulations*" [translated] (judgment no. 96/2005).

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[73] G. RAGONE, *Imparare dalla pandemia: saperi scientifici e processi di decisione politica*, in *Quaderni costituzionali*, 1, 2022, 79.

[74] S. PENASA, *La «ragionevolezza scientifica» delle leggi nella giurisprudenza costituzionale*, in *Quaderni costituzionali*, 4, 2009, 835.

[75] A. MORRONE, Ubi scientia ibi iura*. A prima lettura sull'eterologa*, in *Forum di Quaderni costituzionali*, 2014, 6.

[76] G. RAGONE, 80.

What has been outlined thus far applies primarily to the medical-therapeutic field. However, the principle of scientific reserve has also found application in other areas. For instance, in matters concerning Genetically Modified Organisms (GMOs), the Constitutional Court has affirmed that "*the imposition of limits on the exercise of economic initiative freedom, based on the principles of prevention and precaution in the interest of the environment and human health, can be constitutionally justified only on the basis of 'guidelines based on the verification of the state of scientific knowledge and acquired experimental evidence, through institutions and bodies, usually national or supranational, designated for this purpose, given the essential role that technical-scientific bodies play for these purposes*'" [translated] (judgment no. 116/2006).

What stands out and is worth emphasizing is that across its entire body of jurisprudence, regardless of the area, the Court does not advocate for precautionary decisions to be exclusively delegated to technical experts. Instead, it insists on fostering a dialogue between political and scientific authorities to prevent unreasonable decision-making. In other words, the relationship between science and politics should not be entirely science-driven but rather science-based. This distinction underscores that while politics defines the objectives of a decision, "*technical-scientific evaluations are limited to suggesting the most appropriate tools to achieve them*" [translated]. In this way, science informs and supports political choices without overstepping into the domain of political decision-making.[77]

This difference is central to the legitimacy and functionality of legal and political systems when addressing complex challenges such as climate change. Science-based decision-making represents an approach in which scientific knowledge is used to support and inform the policymaker's understanding of problems, offering data, scenarios, and tools without overriding political discretion. The policymaker retains the responsibility of weighing diverse social, ethical, and economic factors, thus preserving democratic control over policy choices.[78]

Conversely, science-driven decision-making risks placing excessive power in the hands of scientific experts. In this model, decisions are shaped almost exclusively

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77 *Ibid.*, 77.

78 H. HILLIGARDT, *Partisan science and the democratic legitimacy ideal*, in *Synthese* 202, 2023, 135 https://doi.org/10.1007/s11229-023-04370-5.

by technical recommendations, with policymakers potentially abdicating their role to balance competing societal values.[79] While expertise is essential in assessing risks, consequences, and possible trade-offs, the elevation of science to a decision-making authority in its own right could erode democratic legitimacy. This issue is exacerbated when decisions are urgent and the stakes are high, such as during public health crises or climate emergencies. In such situations, the public may expect policymakers to "follow the science," creating pressure to defer to experts without adequately considering other perspectives.[80]

This dynamic was evident during the COVID-19 pandemic, where governments faced difficult choices on lockdowns, resource allocation, and vaccination campaigns. While expert recommendations were crucial in understanding the virus and mitigating its spread, many of these recommendations carried implicit value judgments. For example, prioritizing economic recovery over public health, or vice versa, is a political decision that cannot be fully determined by scientific evidence alone. Thus, science can provide critical insight into the potential outcomes of policy choices but cannot dictate which outcome is preferable in terms of societal values and priorities.[81]

To maintain a proper balance, procedural rules are necessary to guide the interaction between policymakers and scientific advisors.[82] These rules should ensure transparency, accountability, and a clear division of roles: science provides evidence and scenarios, while politics determines the goals and value-based compromises that shape decisions.[83] A structured and well-regulated dialogue between science and politics can reduce the risk of either scientific dominance (science-driven decisions) or disregard for evidence (political decisions disconnected from reality).[84]

Moreover, science-based decision-making aligns with the concept of "epistemic humility" in governance. Policymakers must recognize the limitations of

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79 G. RAGONE, 95.

80 A. ANTOCI, F. SABATINI, P.L. SACCO, M. SODINI, *Experts vs. policymakers in the COVID-19 policy response*, in *Journal of Economic Behavior & Organization*, 201, 2022, 22.

81 A. LAVAZZA, M. FARINA, *The Role of Experts in the Covid-19 Pandemic and the Limits of Their Epistemic Authority in Democracy*, in *Frontiers in Public Health*, 8, 2020.

82 G. RAGONE, 96.

83 *Ibid*.

84 G.A. WILLIAMS, J. FIGUERAS, S. LESSOF, S.M. ULLA DÌEZ, *Translating Evidence into Policy During the Covid-19 Pandemic: Bridging Science and Policy (and Politics)*, in *Eurohealth*, 26(2), 2020.

scientific certainty, particularly in rapidly evolving fields like climate science or epidemiology. Offering advice in probabilistic terms, as practiced by institutions such as the U.S. National Academy of Sciences, helps decision-makers understand the likelihood and risks associated with various options without coercively promoting any single path forward.[85]

In the context of climate litigation, these principles are equally relevant. Courts must navigate complex evidence while respecting the separation of powers. Judges are tasked with assessing the credibility of scientific claims but must avoid assuming the role of policymakers. The line between science-based and science-driven judgments is especially delicate in cases where causal links between climate harm and policy inaction are at stake, as in attribution science.

The next section will explore the ethical dimensions of this integration between science and law. This analysis will focus on the responsibilities and challenges arising from the reliance on scientific expertise, including questions of fairness, equity, and the representation of diverse perspectives in both legal and political decision-making. Ethical considerations are indispensable to ensuring that the interplay between science and law serves the public interest and upholds democratic values.

3.2 *Science, Ethics, and Politics in Developing Effective Climate Policies*

In paragraph 1, the how, when, and why of climate science's influence on public opinion and policies were explored. The discussion addressed the methods and strengths that make science reliable, despite facing challenges with replicability and precision compared to other hard sciences. However, it was also demonstrated that science alone cannot guarantee effective climate regulation.

The complexity of environmental issues demands political intervention capable of balancing diverse interests and perspectives. Translating scientific discoveries into practical policies involves decisions that extend beyond pure scientific logic, requiring

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[85] S. JUKOLA, S. CANALI, *On evidence fiascos and judgments in COVID-19 policy*, in *History and Philosophy of the Life Sciences*, 43, 2021, 61.

consideration of economic, social, and political factors. Politicians are often tasked with making difficult choices, weighing the need for economic development against environmental protection and social well-being.[86] These decisions must be made responsibly, taking into account the necessary trade-offs to achieve a sustainable balance between progress and conservation.

Politics, therefore, plays a crucial role in the decision-making process. Informed and responsible leadership is essential – leadership that can effectively integrate scientific evidence with society's practical and regulatory needs. This is particularly important because science, while valuable, has limitations when it comes to guaranteeing objectivity and efficiency in political choices.

In her works, Professor Mariachiara Tallacchini has emphasized that "*the assumptions and criteria underpinning the development of science are currently undergoing profound crises and revisions*" [translated].[87] Citing various scholars from the late 20th century, she highlights how the integration of science into politics often creates more problems than it solves, due to several factors:

(i) Unreliable data – many studies published in prestigious journals have been retracted in recent years due to errors or unconfirmed findings;[88]

(ii) Non-reproducibility of experimental outcomes – it is estimated that up to 80% of articles in scientific journals face reproducibility issues. As discussed in paragraph 1, this challenge is especially relevant in fields like climatology;

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[86] The case of Ilva in Taranto, Italy, exemplifies the complex tension between conflicting interests. On one side are the fundamental rights of Taranto's inhabitants, who have endured decades of severe pollution caused by the steel plant. On the other side is the economic reality that closing the plant would lead to the loss of thousands of jobs. In its ruling on the matter, the Italian Constitutional Court emphasized the need to balance these competing rights, stating: "*All the fundamental rights protected by the Constitution are in a relationship of mutual integration, and it is therefore not possible to identify one of them as having absolute precedence over the others. Protection must always be 'systemic and not fragmented into a series of uncoordinated norms that are potentially in conflict with each other' (judgment no. 264 of 2012). Without such coordination, one right could expand indefinitely, becoming a 'tyrant' over other constitutionally recognized and protected legal situations, which collectively express human dignity*" (Italian Constitutional Court, judgment no. 85/2013).

[87] M. TALLACCHINI, *Il Governo della scienza. Dall'autoreferenzialità alle interazioni sistemiche tra scienza, policy e democrazia*, in *Rivista di Filosofia Neo-Scolastica*, 4, 2018, 732, but see also M. TALLACCHINI, *Scienza e potere*, in *Enciclopedia del Diritto*, volume *Potere e costituzione*, 2023, 1059-1095.

[88] Editorial – *Scientists Who cheat*, New York Times, June 1, 2015, https://www.nytimes.com/2015/06/01/opinion/scientists-who-cheat.html?_r=0.

(iii) Fraud, conflicts of interest, and failures of the peer-review system – which further undermine the credibility of scientific advice.

Tallacchini argues that these problems stem largely from science's self-referentiality. In the so-called "*scientific advice systems*" – defined as "*the set of subjects, structures, and mechanisms aimed at producing the science that informs and legitimizes norms and, more broadly, public decisions from an epistemic point of view*" [translated] – the integrity and validity of scientific knowledge are ensured internally, through the ethics and self-governance of scientists. This approach, however, isolates science from the politically and legally organized 'lay' society.[89]

To address these issues, Tallacchini advocates for the democratization of science, which would break its self-referentiality by involving citizens in policy-making processes.[90] This concept ties into the idea of citizen science, mentioned at the end of paragraph 1, as a practical tool to achieve this goal. Citizen science not only makes scientific knowledge accessible and understandable to the public but also enhances the accountability of science in public policy by allowing greater public scrutiny and participation.

It has been noted that involving citizens in scientific processes enhances transparency, helping to reduce suspicions of conflicts of interest and fraud while increasing trust in science and science-based policies. Citizen participation can also enrich scientific work by encouraging professionals to consider new ideas, questions, and approaches. This diversity of perspectives can lead to more robust results that are applicable across various contexts. Additionally, citizen involvement can aid in monitoring and evaluating the social and environmental impacts of research, ensuring that policy decisions better reflect societal needs and values, thereby promoting greater social responsibility.[91]

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89 *Ibid.*, 1077.

90 M. TALLACCHINI, 2018, 733-734. See also M. CAROLAN, *Science, Expertise, and the Democratization of the Decision-Making Process*, in *Society & Natural Resources*, 19, 2006, 661-668, K. BÄCKSTRAND, *Civic Science for Sustainability: Reframing the Role of Experts, Policy-Makers and Citizens in Environmental Governance*, in *Global Environmental Politics*, 3(4), 2003, 24-41, P. WEINGART, *Trust and Distrust of Scientific Experts*, in G. EYAL, T. MEDVETZ, *The Oxford Handbook of Expertise and Democratic Politics*, Oxford, 2023.

91 *Ibid*.

However, opening the scientific process to public participation also presents several challenges. One major concern is that excessive public influence could slow down scientific decision-making, reducing efficiency. The need to mediate between diverse interests and opinions may complicate and delay the implementation of science-based policies. Furthermore, citizens may bring personal biases or agendas that risk introducing distorting political or social pressures into the research process. Another challenge is the resource burden: public involvement requires significant investments in education and outreach, which could divert resources from research conducted by highly qualified professionals, potentially hindering scientific progress.[92]

The case of GMOs illustrates the challenges posed by public skepticism towards science. In an article published in *Les ateliers de l'éthique*, the authors examine how science – particularly GMO research – has generated significant concerns among citizens. Many are wary of the safety, naturalness, and socio-economic consequences of GMOs. In response to these concerns, the idea of public participation in scientific policymaking has gained traction, leading to the concept known as the Public Participation Paradigm (PPP).

The PPP argues that to effectively address scientific controversies, public involvement in decision-making processes is essential. Proponents of this approach believe that open dialogue between skeptical citizens and the scientific community can foster more balanced and democratic decisions. However, the authors critically assess this premise, questioning whether it holds up under current theories of democratic legitimacy.

Specifically, the article highlights that many influential theories of democratic legitimacy do not necessarily endorse extensive public participation in cases of scientific controversy. For instance, John Rawls' theories on political legitimacy emphasize that policies should be justified by public reasons – reasons that all reasonable citizens can accept.[93] From this perspective, objections based on personal

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92 See J.L. DICKINSON, B. ZUCKERBERG, D.N. BONTER, *Citizen Science as an Ecological Research Tool: Challenges and Benefits*, in *Annual Review of Ecology, Evolution, and Systematics*, 41, 2010, 149-172.

93 J. RAWLS, *Political Liberalism*, New York, 1993.

or religious beliefs, such as claims that GMOs are “unnatural,” do not provide a valid foundation for public policy.

The authors note that the PPP emerged as a response to the shortcomings of the deficit model, which assumed that public skepticism stemmed solely from a lack of knowledge. However, efforts to simply disseminate information have not succeeded in eliminating distrust of GMOs. As a result, the authors argue that public participation can sometimes hinder scientific progress, slowing decision-making and diverting resources from professional research. The lengthy debate on GMOs in Europe, for example, has led to moratoriums and strict regulations that have delayed the adoption of potentially beneficial technologies.

An alternative to the democratization of science to address its self-referentiality could be the creation of independent scientific oversight bodies. These bodies would include experts from various scientific disciplines, representatives of governmental institutions, and members of civil society. Their primary task would be to evaluate the quality, integrity, and impartiality of the scientific research that informs political decisions, while also providing advice to policymakers.

These committees would implement a range of measures to ensure transparency and accountability. First, they would carry out extensive and transparent reviews of the scientific studies underlying policy decisions, verifying that the research is based on reliable data and rigorous methodologies. Second, they would periodically monitor and audit publicly funded research projects to ensure adherence to the highest ethical and methodological standards.

Third, the committees would promote multidisciplinary collaboration, encouraging interaction among scientists from different fields to provide a broader, more integrated perspective. This approach would help reduce the risk of self-referentiality by incorporating diverse expertise. In addition, external and international experts could be consulted to offer independent opinions and critical evaluations of national scientific policies and research programs.

To safeguard the integrity of decision-making, the establishment of strict conflict-of-interest policies would be crucial. These policies would require full disclosure and management of any potential conflicts, ensuring that scientific and political decisions remain free from undue influence. Furthermore, continuous

education and training for scientists—covering topics such as ethics, science communication, and public engagement—would enhance their ability to operate responsibly and transparently.

By implementing these measures, it would be possible to reduce the self-referentiality of science and strengthen public trust in both scientific processes and policy decisions based on scientific evidence. This approach offers a viable alternative to direct democratization while maintaining scientific rigor and accountability.

In her monograph *The Fifth Branch: Science Advisers as Policymakers*, Sheila Jasanoff explores the role of scientific advisers in political decision-making and emphasizes the importance of oversight institutions to safeguard scientific integrity and accountability. Though published some time ago, her insights remain highly relevant, sparking continued debate on how science and politics intersect.

Jasanoff, a pioneer in the study of the relationship between science, technology, and society, laid the groundwork for contemporary discussions on the influence of science on public policy – and vice versa. Her concept of the "fifth branch of government" underscores the significant role that scientists play in shaping political decisions, a role that has become increasingly critical in today's global policy landscape.

Jasanoff identifies two dominant paradigms for regulating how science is used by governmental agencies:

(i) The technocratic approach, which asserts that scientific legitimacy is achieved by increasing the influence of expert communities in decision-making processes;

(ii) The democratic approach, which emphasizes accountability through mechanisms such as open procedures, advanced publication of guidelines, and judicial review.[94]

However, Jasanoff critiques both models for failing to adequately account for the complexities of science and politics. The technocratic approach overlooks the fact that science can be influenced by commercial and industrial interests seeking to

[94] S. JASANOFF, *The Fifth Branch: Science Advisers as Policymakers*, Cambridge (MA), 1990, 15-16.

promote their own agendas. Conversely, the democratic approach underestimates the challenge of legitimizing decisions without the endorsement of the scientific community.[95]

To address these limitations, Jasanoff proposes a third alternative that blends negotiation and boundary work. The negotiation model promotes adjustments between differing scientific perspectives, ensuring more balanced policy decisions.[96] Meanwhile, boundary work involves delineating clear distinctions between science and policy, with scientists setting boundaries to protect scientific claims from unwarranted reinterpretation or challenge by non-experts. Despite seeming contradictory, these approaches can work in tandem: "*The most politically successful examples of boundary work,*" Jasanoff argues, "*are those that allow agencies and their advisers to negotiate the location and meaning of the boundaries.*"[97]

The model of independent scientific oversight bodies aligns with Jasanoff's third approach by institutionalizing both negotiation and boundary-setting mechanisms. Examples of such institutions already exist. In the United States, the National Academies of Sciences, Engineering, and Medicine (NASEM) operates as a congressionally chartered organization providing independent oversight of scientific research and policy advice through transparent, evidence-based reviews. In Europe, the European Research Council (ERC) funds and monitors scientific research, ensuring that supported projects adhere to high standards of excellence and integrity.

3.3 *Future Directions in Climate Science and Legal Frameworks: A New Right to Climate?*

In recent decades, climate change has become one of the most pressing and multifaceted challenges facing humanity. The growing awareness of its risks has driven both scientists and policymakers to develop innovative and sustainable solutions aimed at mitigating its effects and adapting to evolving environmental

95 *Ibid.*, 17.
96 *Ibid.*, 234.
97 *Ibid.*, 236.

realities. Within this context, an important debate is emerging around the recognition of a new fundamental right: the right to climate. This subparagraph examines future directions in climate law and science, exploring whether this right has been established and what implications it may hold for environmental governance.

The right to climate represents a potential paradigm shift, both in environmental protection and human rights. Recognizing this right entails a collective duty to safeguard a healthy and safe environment for current and future generations. This concept transcends traditional approaches to climate mitigation and adaptation, establishing a foundation for climate justice that highlights the deep interconnection between planetary health and human well-being.

However, acknowledging this right is inextricably linked to climate science, which provides essential evidence to support policies and regulations. Climate science not only tracks changes and forecasts their impacts but also proposes technological innovations and mitigation strategies. This interplay between science and climate law is crucial to ensure that policy decisions are grounded in reliable data and can be effectively implemented.

This subparagraph will present an overview of future perspectives in climate law and science, outlining possible pathways and recommendations for promoting and safeguarding the right to climate. Achieving this goal will require a strong synergy between science, technology, and politics to build a sustainable and resilient future capable of addressing climate challenges with both responsibility and effectiveness. To begin, we must ask: when did the law first begin to address anthropogenic climate change?

The origins of legal responses to anthropogenic climate change can be traced back to the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, known as the Earth Summit. At this landmark event, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted – an international treaty aimed at stabilizing atmospheric concentrations of greenhouse gases to prevent dangerous anthropogenic interference with the climate system.

The recognition of a formal right to climate, however, came later. It was first acknowledged in a 2009 report by the United Nations High Commissioner for Human Rights, which examined the relationship between climate change and human rights. In

Chapter III, the report highlighted the obligations of States to protect individuals from foreseeable threats to human rights caused by climate change, establishing a crucial link between environmental stability and human rights protection.

This evolving concept of climate rights gained further momentum through strategic climate litigation. In 2007, the U.S. Supreme Court decision in *Massachusetts v. EPA* marked a pivotal moment by affirming the Environmental Protection Agency's authority to regulate greenhouse gases. Similarly, the Dutch *Urgenda* case set a precedent by compelling the government to take stronger climate action, with both cases relying on scientific and legal arguments to advocate for the recognition and enforcement of a right to climate.

Thus, the right to climate was born. We have seen who, when, and where. Perhaps it is now necessary to also ask how and why. To do so, we cannot overlook defining what a right is. Attilio Pisanò, who has long studied the processes of recognizing new rights – and the right to climate in particular – uses Elena Pariotti's definition, according to which rights are "*claims justified by particularly strong reasons from a moral standpoint and supported, within a legal system, by sources of a particular hierarchical level: the Constitution or the law, in its function of implementing constitutional norms, concerning fundamental rights, and international law concerning human rights*" [translated].[98] Thus, not all claims become rights; only those with strong moral reasons do.[99]

In essence, the genesis of a new right follows a gradual process of "*positivization of claims.*" Rights often originate from bottom-up social movements, beginning as moral claims fueled by an innate human sense of justice. Over time, these claims gain legal recognition and become enshrined as rights.[100]

The claim underpinning the right to climate arises from the need to confront the climate emergency and prevent dangerous disruptions to the Earth's natural climate systems. This right seeks to ensure that human activities do not destabilize the climate,

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98 E. PARIOTTI, *I diritti umani: concetto, teoria, evoluzione*, Milano, 2013, 2.

99 A. PISANÒ, *La genesi di un nuovo diritto. Argomenti e ragioni a sostegno del diritto al clima*, in *Ars interpretandi*, 22(2), 2022, 29-31.

100 *Ibid.*, 32-33.

a prerequisite for the survival of ecosystems and the well-being of present and future generations.

What, then, is *not* the right to a stable climate?

It is not a right to abstain from any interference with the climate – an impossible standard. Rather, it is a right to be free from harmful interferences.

It is not a right of possession; the climate is not something humanity can claim ownership of or control entirely.

Nor is it a right to *have* a stable climate, since, as discussed earlier, the climate is naturally dynamic and variable by its very nature.[101]

The States that have ratified the UNFCCC, the Kyoto Protocol, and the Paris Agreement are already bound by specific legal commitments to reduce greenhouse gas emissions. These international treaties impose clear obligations aimed at limiting harmful anthropogenic interference with the climate system. The objectives of these commitments extend beyond mitigating climate change to preserving a livable environment for future generations. Recognizing the right to climate reinforces these responsibilities by emphasizing the urgency of adopting effective and sustainable policies to address the climate crisis.

In climate litigation, those who advocate for the recognition of a right to climate argue that States are violating their international treaty obligations. They contend that this failure results in reckless policies that either directly harm the environment or fail to prevent harmful human activities. As highlighted earlier, those engaged in strategic climate litigation rely on both legal and scientific arguments to support their claims.

This dual approach is crucial because, as Attilio Pisanò reminds us, "*the climate-determining capacity of humans* […] *is a disvalue recognized by law but is also a scientific fact, discussed (and verified* […]*) within climatology*" [translated].[102] This underscores a key point: the legal approach to climate issues must be grounded in scientific evidence. It also explains the pivotal role played by the IPCC, whose reports provide the scientific foundation for assessing State responsibilities and formulating climate policies.

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101 *Ibid*.

102 *Ibid.*, 36.

As mentioned in previous paragraphs, the IPCC is recognized as the most authoritative scientific source for the technical-scientific assessments required by legislators, administrators, and judges in managing climate change. Its reports:

(i) Confirm the anthropogenic nature of climate change and propose solutions, such as reducing greenhouse gas emissions, to limit human influence on the climate system;

(ii) Establish mitigation targets to stabilize global temperatures, serving as both a critical tool for climate activists and a benchmark for assessing the adequacy of State policies against the goals of the Paris Agreement;

(iii) Emphasize the significance of time in addressing climate change, providing activists with compelling arguments for immediate action to prevent irreversible damage.

The disparity between the risk of harm and the occurrence of actual harm necessitates proactive mitigation policies to avoid surpassing "tipping points" or "points of no return." Failure to act now could lead to irreversible damage to ecosystems and human life, escalating the climate crisis into a planetary emergency and further shrinking the "safe operating space for humanity."[103]

Despite this urgency, the right to climate has not yet been universally recognized as an independent legal right. However, a significant milestone was reached when the ECtHR recently acknowledged its existence. This recognition came in a case brought by *Senior Women for Climate Protection Switzerland* – an association of over 2,000 women over the age of 65 – supported by Greenpeace Switzerland. The case set an important precedent for climate justice, marking the first instance in which an international court declared that a State has a legal obligation to meet climate targets established by international treaties.

However, the journey toward full recognition of a right to climate remains long. In Italy, around the same period, the Rome Tribunal used procedural tactics to avoid addressing the merits of a case related to climate rights. The plaintiffs had sought to hold the State liable under Articles 2043 and, alternatively, 2051 of the Civil Code,

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[103] *Ibid.*, 37-38. See also M. MONTEDURO, *Le decisioni amministrative nell'era della recessione ecologica*, in *AIC. Rivista dell'Associazione Italiana dei Costituzionalisti*, 2, 2018 1-74.

citing insufficient reductions in emissions in violation of European and international law. They also invoked the right to climate and related fundamental rights protected by national law and the European Convention on Human Rights (ECHR), such as the right to life (Article 2), the right to private and family life (Article 8), and the prohibition of discrimination (Article 14). While the court hinted that a right to climate does not yet exist, it left room for future interpretative developments within the legal system.

In Italy, Constitutional Law no. 1/2022 introduced amendments to Articles 9 and 41 of the Constitution, reinforcing environmental protection as a constitutional priority. Article 9 tasks the Republic with safeguarding "*the environment, biodiversity, and ecosystems, also in the interest of future generations,*" while Article 41 prohibits private economic initiatives that harm health or the environment, granting lawmakers the authority to direct and coordinate economic activities toward not only social but also environmental objectives.[104]

At the European level, the Parliament's resolution on the Green Deal, adopted on January 15, 2020, emphasized the need to recognize a right to climate. The resolution underscored that "*all people living in Europe should be granted the fundamental right to a safe, clean, healthy, and sustainable environment and to a stable climate, without discrimination,*" and called for this right to be enforceable through national and EU judicial systems via ambitious policies.[105]

The Council of Europe also addressed the right to climate at a historic summit in Reykjavik in 2023.[106] In May 2024, a declaration was ratified, noting "*the increased recognition of the right to a clean, healthy, and sustainable environment*" in various

[104] A. BORDNER, J. BARNETT, E. WATERS, *The human right to climate adaptation*, in *Nature – npj Climate Action*, 43(2), 2023, demonstrate that there is a right to climate adaptation within an existing set of human rights norms.

[105] Available online at https://www.europarl.europa.eu/doceo/document/TA-9-2020-0005_IT.html.

[106] I. KAMINSKI, *Pressure builds on Council of Europe to put right to healthy environment in law, in Climate Home News*, May 3, 2023, https://www.climatechangenews.com/2023/05/03/pressure-builds-on-council-of-europe-to-put-right-to-healthy-environment-in-law/?ref=the-wave.net.

legal frameworks and committing to intensify efforts toward the political recognition of this right, including further reflection on its content and implications.[107]

Internationally, both the Human Rights Council – with Resolution 48/13 on October 8, 2021 – and the United Nations General Assembly – with Resolution 76/300 on July 28, 2022 – have recognized the human right to a clean, healthy, and sustainable environment. David R. Boyd, former UN Special Rapporteur on Human Rights and the Environment, echoed this momentum in the newsletter *The Wave*. Boyd expressed optimism about incorporating the right to climate into the Universal Declaration of Human Rights: "*I think that'd be a really cool and symbolic next step. The Universal Declaration hasn't been amended ever, since* [it was agreed in] *1948, so that suggests that it's challenging. But I think if there's any human right that urgently needs to be added to it, it would be this one in the face of a global climate and environmental emergency.*"[108]

Despite these developments, in the Italian case, the judge found the first objection raised by the defendant decisive: the claim of absolute lack of jurisdiction. The court held that the judiciary cannot interfere with strictly political activities, including decisions on the selection and implementation of measures to address complex phenomena like the ongoing climate crisis.

The Ordinary Tribunal further emphasized that "*the interest for which compensation is sought under Articles 2043 and 2051 of the Civil Code does not fall within the category of legally protected subjective interests.*" It reasoned that "*decisions regarding the methods and timing of addressing anthropogenic climate change involve discretionary socio-economic evaluations and cost-benefit analyses across various sectors of society. As such, these matters fall under the purview of political bodies and are not subject to judicial oversight in the present case*" [translated].[109] By this ruling, the Tribunal effectively denied the existence of a right to climate, diverging from the evolving jurisprudence of the ECtHR.

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107 COUNCIL OF EUROPE, *Reykjavík Declaration, United around our values*, 4th Summit of Heads of State and Government of the Council of Europe, May 16-17, 2024, https://rm.coe.int/4th-summit-of-heads-of-state-and-government-of-the-council-of-europe/1680ab40c1?ref=the-wave.net, 20-21.

108 The interview is available on the website https://www.the-wave.net/?ref=the-wave-newsletter.

109 Tribunal of Rome, II Section, case no. 39415/2021, judgment dated February 26, 2024, 12.

This restrictive approach was, however, partially reversed by the Supreme Court's Sezioni Unite in *Greenpeace and ReCommon v. ENI* (Cass., Sez. Un., 21 July 2025, no. 20381). In this landmark decision, the Court clarified that while actions aimed at compelling the State or Parliament to adopt general climate policies remain outside judicial review, tort claims against corporations for climate-related damages are justiciable before ordinary courts. The Court emphasized that such claims may be grounded in international and constitutional obligations, interpreted in light of climate science, and enforced through Articles 2043, 2050, 2051, and 2058 of the Civil Code. Although it stopped short of declaring a freestanding "right to climate," the ruling shifted the debate from jurisdictional exclusion to substantive assessment on the merits, thereby opening the way for civil liability based on climate harms.

For better or worse, this case highlights the crucial role courts can play in ensuring that States fulfill their climate obligations. When faced with legislative inertia, citizens vulnerable to the effects of climate change often have no choice but to turn to the judiciary to seek recognition and redress for violations committed by governments and corporations. These claims frequently rely on data and evidence gathered by scientists.

However, this expanded judicial role has ignited a debate. Supporters view the courts as essential actors in holding governments accountable for climate commitments, especially when political institutions fail to act. Critics, on the other hand, argue that courts, empowered by scientific evidence, are overstepping their bounds by making decisions that traditionally belong to political authorities. This tension underscores the complex interplay between law, science, and governance in the context of climate justice.

4. Conclusions

This chapter was designed to provide a conceptual and methodological basis for analyzing the role of science in strategic climate litigation. The overarching goal was to clarify the dual significance of scientific evidence: first, as a tool for proving the existence and impacts of anthropogenic climate change, and second, as a key

element that informs legal strategies aimed at promoting broader regulatory and policy shifts. By achieving this, the chapter sought to position readers to better understand the complex interplay between climate science and law in a legal context where climate obligations are increasingly scrutinized.

A critical objective was to familiarize readers with the science at the core of these legal cases – climatology. It was crucial to highlight how this discipline differs from other sciences and why its models, methods, and long-term projections have sometimes been perceived as controversial or less reliable. This is particularly important given that courts and policymakers often face pressure to make decisions based on scientific evidence that may appear uncertain or probabilistic. However, it was equally important to underscore that, despite its perceived limitations, climate science offers an essential, credible foundation for addressing climate change, both legally and politically.

Another key aim was to examine the normative frameworks that enable the integration of scientific knowledge into legal systems. The chapter sought to illustrate how international, European, and domestic legal orders recognize the role of science in shaping environmental and human rights law. This recognition, however, raises fundamental questions about the democratic legitimacy of science-driven legal decisions. A core objective was to demonstrate that concerns about technocratic overreach can be mitigated through mechanisms that balance expert authority with democratic values such as transparency, accountability, and participation. This balance ensures that science informs rather than dictates legal and policy choices, thereby preserving judicial independence and democratic oversight.

In the next section, the analysis will focus on how courts handle scientific data in climate-related litigation, particularly in strategic cases, to identify the challenges that arise in integrating science into legal proceedings. These challenges, which involve both procedural and substantive aspects, will then be explored in detail in the third chapter to offer insights into how legal systems can better accommodate scientific expertise in the pursuit of climate justice.

SECOND CHAPTER

ADJUDICATING CLIMATE SCIENCE: A COMPARATIVE ANALYSIS OF COURTS (ICJ, ECTHR, ITALY)

Case Studies in Judicial Approaches

In the preceding chapter, this study explored the multifaceted relationship between climate science and the legal system, with a particular focus on how climatology, characterized by its interdisciplinary nature, has become a cornerstone of climate litigation. Drawing upon fields such as meteorology, physics, oceanography, and social sciences, climatology offers a comprehensive framework for understanding the complex dynamics of the Earth's climate system. However, its reliance on probabilistic data and models, along with the integration of diverse methodologies, has sometimes fueled skepticism, both within the scientific community and among the general public. This skepticism often stems from the perceived complexity of climatology, its probabilistic conclusions, and the political implications of its findings, which contrast with the deterministic approaches of traditional hard sciences.

The chapter also explored the legal frameworks that facilitate the integration of scientific evidence into judicial proceedings, focusing on the principle of "scientific reserve" as developed in the Italian legal context. This principle ensures that legal decisions are grounded in scientifically sound evidence while maintaining a balance between judicial independence and the epistemic authority of scientific expertise. By examining the interplay between law and science, the chapter demonstrated how courts can navigate the challenges of integrating scientific uncertainty and interdisciplinary insights into legal reasoning. At the same time, it underscored the broader ethical and

procedural challenges, such as ensuring the reliability of scientific evidence and addressing the self-referential nature of science, which sometimes complicates its role in informing public policies and legal doctrines.

Building on this foundation, this chapter investigates what scientific evidence is introduced in climate litigation, through which evidentiary instruments it enters judicial proceedings, and what role it plays in legal reasoning. Rather than focusing on the substantive legal arguments advanced in climate cases, the chapter examines the operationalization of scientific knowledge in legal settings, highlighting the procedural mechanisms through which courts evaluate and incorporate climate science.

A key aspect of this analysis is understanding how different courts define and assess the admissibility, reliability, and probative value of scientific evidence. Scientific knowledge in climate litigation often takes the form of expert testimony, reports from intergovernmental bodies such as the IPCC, and specialized studies on causation and attribution science. The extent to which courts accept, scrutinize, or challenge these sources depends on their evidentiary frameworks, the role of judicial discretion, and the procedural tools available for evaluating expert input. Some courts, for example, rely heavily on party-appointed experts, leading to potential adversarial biases, while others appoint independent court experts to ensure greater neutrality in scientific assessments. The weight assigned to such evidence can significantly impact legal outcomes, particularly in cases where liability or state obligations hinge on the demonstration of causal links between emissions and climate harm.

To this end, the analysis focuses on three judicial contexts: the ICJ, the ECtHR, and Italian national courts. These courts have been selected for their distinct yet complementary roles in shaping climate accountability. The ICJ is of particular interest given the recent advisory opinion of 23 July 2025 on states' climate obligations, which affirmed that States must act with due diligence, under a stringent standard proportionate to the seriousness of climate risks, in preparing and implementing their climate commitments. The ECtHR stands out as one of the most innovative courts in climate litigation, having developed a rights-based approach that expands the possibilities for holding states accountable for their climate policies. Finally, Italian courts provide an important national perspective on climate litigation, reflecting

broader global trends while offering insights into a jurisdiction that is particularly relevant to my legal background.

The selection of these courts is also guided by their differing institutional mandates, procedural frameworks, and capacity to influence climate governance at various levels. The ICJ, as the principal judicial organ of the United Nations, plays a unique role in interpreting international law and setting normative benchmarks that can shape future state practice, even in the absence of binding enforcement mechanisms. Its recent advisory opinion of 23 July 2025 clarified that states' climate obligations must be carried out in accordance with a rigorous standard of due diligence, thereby providing authoritative guidance not only for states but also for other judicial bodies and international institutions. The ECtHR, by contrast, operates within a regional human rights framework that allows individuals and civil society actors to bring claims against states, making it a key forum for strategic litigation aimed at compelling government action. Its approach to climate litigation, rooted in fundamental rights such as the right to life and the right to private and family life, demonstrates how climate science can be integrated into judicial reasoning to establish state responsibility for environmental harm. Italian courts, while operating within a national legal system, serve as a case study for how domestic jurisdictions engage with scientific evidence in climate-related disputes.

Their jurisprudence reflects the challenges and opportunities of implementing international climate commitments at the national level, highlighting procedural issues such as the role of court-appointed technical experts and the standards for assessing climate-related harm. Taken together, these three judicial contexts provide a comprehensive perspective on the ways in which courts at different levels engage with scientific evidence and contribute to the evolving landscape of climate litigation.

By adopting a comparative approach, this chapter aims to illustrate how different courts integrate scientific evidence into their legal reasoning, the evidentiary standards they apply, and the broader implications of these practices for the development of climate litigation and climate governance. Understanding these dynamics is crucial not only for assessing the role of courts in climate accountability but also for evaluating how legal systems can adapt to the complexities of scientific knowledge in addressing the global climate crisis.

1. International Court of Justice

1.2 The Role of the International Court of Justice in Climate Litigation

The ICJ, as the primary judicial organ of the United Nations, has now assumed a pivotal role in the evolving field of climate litigation. As the climate crisis deepens, resulting in increased impacts on ecosystems, human rights, and economic stability worldwide, the ICJ has emerged as a critical forum to articulate the obligations of states under international law. Traditionally focused on resolving disputes between states, the ICJ's role has expanded to encompass issues of global public interest, such as environmental protection and human rights, recognizing the need for legal frameworks that respond to the transnational and intergenerational dimensions of climate change.[110]

In this context, the ICJ's advisory jurisdiction, which allows it to provide legal interpretations at the request of UN bodies, is particularly significant. The advisory opinion on climate obligations requested by the United Nations General Assembly in March 2023 and delivered on 23 July 2025 exemplifies the Court's potential influence in climate governance. In this opinion, the Court clarified that states are under binding international obligations to prevent significant harm to the climate system, to cooperate in good faith, and to respect and ensure human rights threatened by climate impacts.[111] It identified as relevant sources not only the UN Charter, the UNFCCC, the Kyoto Protocol, and the Paris Agreement, but also UNCLOS, other environmental treaties, customary international law (notably the no-harm and cooperation duties), and core human rights instruments.[112] In doing so, it explicitly rejected the idea that climate

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110 M. WEWERINKE-SINGH, *ICJ Advisory Opinion and the Future of Climate Responsibility*, SDG Knowledge Hub, September 11, 2024, https://sdg.iisd.org/commentary/guest-articles/icj-advisory-opinion-and-the-future-of-climate-responsibility/; E. KOSOLAPOVA, *ICJ to Rule on States' Climate-related Obligations: How Did We Get Here?*, SDG Knowledge Hub, March 20, 2024, https://sdg.iisd.org/commentary/policy-briefs/icj-to-rule-on-states-climate-related-obligations-how-did-we-get-here/.

111 *Obligations of States in respect of Climate Change*, [112-404].

112 *Ibid*., [174-270].

treaties operate as *lex specialis* excluding the general law of State responsibility, which the Court reaffirmed is "in many respects" reflected in the ILC Articles.[113]

Building upon existing treaty law and customary principles, the Court affirmed that these obligations are *erga omnes* – and, in the treaty context, *erga omnes partes* – owed to the international community as a whole. They must therefore be implemented with a rigorous standard of due diligence consistent with the principle of common but differentiated responsibilities and respective capabilitie, and proportionate to the severity and irreversibility of climate risks.[114] Among other things, the Court underscored obligations under the Paris Agreement to act diligently, to prepare, communicate, and maintain successive and progressive nationally determined contributions (NDCs) that, taken together, are capable of meeting the temperature goal, and to pursue concrete measures to realize those NDCs, alongside adaptation and cooperation duties performed in good faith.[115]

The ICJ's advisory opinion did not arise in a vacuum. It followed the advisory opinion delivered by the International Tribunal for the Law of the Sea (ITLOS) on 21 May 2024, which had already recognized anthropogenic greenhouse gas emissions as a form of marine pollution under UNCLOS and articulated concrete obligations to mitigate their impacts.[116] The ICJ engaged with this reasoning, reinforcing and expanding it within the broader fabric of international law.[117] The interplay between the two opinions illustrates how different international judicial bodies, each within its own mandate, contribute to the progressive development of climate law and to the creation of a multi-layered legal order that strengthens accountability.

The ICJ's advisory opinion addressed two core questions. First, what are the obligations of states under international law to ensure the protection of the climate system for present and future generations? Second, what are the legal consequences

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113 *Ibid*., [162-171].

114 *Ibid*., [439-443]; M. WEWERINKE-SINGH, 2024; M.A. TIGRE, J. A. CARRILLO BAÑUELOS, *The ICJ's Advisory Opinion on Climate Change: What Happens Now?*, Climate Law – A Sabin Center blog, March 29, 2023, https://blogs.law.columbia.edu/climatechange/2023/03/29/the-icjs-advisory-opinion-on-climate-change-what-happens-now/.

115 *Obligations of States in respect of Climate Change*, [444-455].

116 *Request for an Advisory Opinion submitted by the Commission of Small Island States on Climate Change and International Law*, Advisory Opinion, ITLOS, May 21, 2024, [384-440].

117 The ICJ refers extensively to the ITLOS Advisory Opinion throughout its reasoning (see, e.g., [252, 291, 294, 302]).

for states whose actions or inactions cause significant harm to the environment, particularly concerning vulnerable states and populations? On the first, the Court articulated a comprehensive catalogue of obligations drawn from treaties, custom, and human rights law.[118] On the second, it confirmed that breaches constitute internationally wrongful acts, giving rise to duties of cessation, guarantees of non-repetition, and full reparation – including restitution, compensation, and satisfaction – provided a "sufficiently direct and certain causal nexus" is established.[119]

The Court clarified that the wrongful act lies not in emissions as such, but in the breach of the identified obligations.[120] It distinguished scientific "attribution" from legal attribution, reaffirming orthodox rules: the conduct of state organs is attributable to the state; with respect to private actors, responsibility may arise where states fail to exercise regulatory due diligence to limit emissions.[121] Acknowledging the collective and cumulative nature of greenhouse gas emissions, the Court further stressed that each injured state may invoke responsibility against any wrongdoing state, with questions of apportionment and scientific determination left to case-by-case assessment.[122]

Having clarified attribution, the Court then turned to the distinct but related issue of causation. It reiterated that causation of damage is not generally required to establish responsibility – this depends on the content of the primary obligation – but is central to reparation.[123] It confirmed a flexible standard of "sufficiently direct and certain causal nexus," and set out a two-step inquiry: first, whether a climatic event or trend can be attributed to anthropogenic climate change (a scientific matter), and second, to what extent damage can be legally linked to a particular state or group of states (a legal matter, to be decided *in concreto*).[124]

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118 *Obligations of States in respect of Climate Change*, [112-404].
119 *Ibid*., [444-455].
120 *Ibid*., [427].
121 *Ibid*., [427-428]; E. KOSOLAPOVA, 2024; GREENPEACE INTERNATIONAL, *Major milestone reached in historic climate judgement as States submit arguments to world's highest court*, March 22, 2024, https://www.greenpeace.org/international/press-release/65921/major-milestone-reached-in-historic-climate-judgement-as-states-submit-arguments-to-worlds-highest-court/.
122 *Ibid*., [431-432].
123 *Ibid*., [433].
124 *Ibid*., [436-438].

The opinion also reinforced the integration of human rights into climate law. It recognized the rights to life, health, an adequate standard of living, and a clean, healthy, and sustainable environment, as well as the principle of intergenerational equity.[125] By characterizing climate obligations as *erga omnes* (and *erga omnes partes* in the treaty context) the Court confirmed the *jus standi* of all states to invoke responsibility under Article 48 of the ILC Articles, while carefully limiting its findings to general legal consequences rather than identifying the responsibility of particular states.[126] Among the remedies, it also highlighted the importance of assurances and guarantees of non-repetition, thus aligning climate obligations with well-established doctrines of State responsibility.[127]

The broader significance of this advisory opinion is clear. While not binding, it provides an authoritative interpretation of international obligations, setting a benchmark likely to influence both international and domestic courts. Its precedent-setting potential lies in its capacity to strengthen existing climate lawsuits, inspire new ones, and give greater normative force to obligations under the Paris Agreement, which otherwise lack strict enforcement mechanisms.[128] By grounding states' commitments in a due-diligence framework and linking them to *erga omnes* obligations, the Court has reinforced the enforceability and coherence of international climate law.[129]

The interaction between the ICJ and ITLOS advisory opinions could also play a crucial role in the development of international legal standards on climate-related harm. ITLOS' findings on the obligations of states to mitigate marine pollution through climate action inform the ICJ's broader assessment of state responsibility for environmental harm under general international law. For instance, the ITLOS opinion supports the ICJ in endorsing principles such as the "polluter pays" principle, which

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125 *Ibid*., [143-154, 369-404].
126 *Ibid*., [439-443].
127 *Ibid*., [447-448].
128 R. HARVEY, I. MUHAMAD, *International Court of Justice climate ruling should include legal duty to protect climate-stabilizing biodiversity*, WWF, July 15, 2024, https://wwf.panda.org/wwf_news/?11676441/WWF-ICJ-submission-climate-change-biodiversity; GREENPEACE INTERNATIONAL, 2024.
129 J. MCGOWAN, *International Court Releases Detailed Hearing Schedule For Climate Change Opinion*, Forbes, November 12, 2024, https://www.forbes.com/sites/jonmcgowan/2024/11/12/international-court-releases-detailed-hearing-schedule-for-climate-change-opinion/; NATURE, *Who is legally responsible for climate harms? The world's top court will now decide*, in *Nature*, 632(475), 2024.

holds that those responsible for pollution should bear the costs of mitigating its effects. Such guidance shapes not only judicial decisions but also influences legislative and regulatory frameworks aimed at strengthening climate accountability.[130]

The ICJ's advisory opinion represents a major step in the integration of human rights and environmental law within the context of climate change. Vanuatu's leadership in bringing this initiative to the ICJ was motivated by the profound impacts of climate change on small island developing states, where rising sea levels, extreme weather events, and biodiversity loss pose existential threats. For these nations, climate change is not only an environmental issue but a human rights crisis affecting the right to life, health, and an adequate standard of living.[131] The ICJ's opinion thus explicitly engages with the concept of intergenerational equity, recognizing states' responsibilities toward future generations – a notion that has gained traction in international human rights discourse.[132]

The ICJ's consideration of human rights implications is reinforced by recent resolutions and declarations from the United Nations and other international bodies. The UN Human Rights Council, for instance, has repeatedly affirmed that a stable climate is essential for the protection of human rights.[133] The ICJ's advisory opinion, by addressing both present and future harms caused by climate change, has the potential to solidify the right to a healthy environment as a cornerstone of international law, bolstering the legal basis for climate justice claims.[134]

However, the ICJ's engagement in climate issues is not without controversy. Critics argue that climate change, as a highly political and complex issue, should be addressed primarily by states through legislative and diplomatic channels, rather than by courts. They contend that judicial bodies may lack the capacity to address the

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130 NATURE, 2024.

131 M.A. TIGRE, J. A. CARRILLO BAÑUELOS, 2023; R. HARVEY, I. MUHAMAD, 2024.

132 *Obligations of States in respect of Climate Change*, [155-157].

133 See, for example, U.N. HUMAN RIGHTS COUNCIL, Resolutions Nos. 48/13 dated October 8, 2021 – recognizing for the first time that having a clean, healthy, and sustainable environment is a human right and calling on States to collaborate for its implementation –, and 18/22 dated September 30, 2011 – emphasizing that human rights obligations and principles can strengthen international and national climate policies, promoting legitimacy and sustainable outcomes –, and the Statement by the UN High Commissioner for Human Rights dated June 5, 2023 – highlighting the critical link between climate protection and human rights, and the disproportionate impact of climate change and environmental degradation on vulnerable populations.

134 M. WEWERINKE-SINGH, 2024; NATURE, 2024.

economic and social implications of climate policies.[135] Proponents of the advisory opinion, however, argue that the legal system has a crucial role in upholding international commitments, particularly when political action falls short. The ICJ's intervention is thus viewed as a necessary step to uphold accountability in the global climate regime, ensuring that states are held to their obligations even in the absence of direct enforcement mechanisms.[136]

Furthermore, the ICJ's involvement in climate litigation can be seen as a response to the growing demand for climate justice from civil society and vulnerable communities worldwide. The advisory opinion process provided an unprecedented platform for small island states, youth groups, and non-governmental organizations to voice their experiences and expectations. This participatory dimension reflects the evolving nature of international law, where courts are increasingly seen as venues for addressing urgent global issues beyond traditional state-centered disputes.[137]

In short, the ICJ's advisory opinion builds upon the findings of ITLOS, creating a complementary legal framework that strengthens the legal obligations of states in addressing climate change. By clarifying standards, embedding due diligence, and addressing both present and future impacts, the ICJ contributes to a more accountable climate governance framework. This opinion is likely to influence national courts, inspire further climate litigation, and serve as a reference point for future climate-related legal standards.

Thus, as the climate crisis intensifies, the ICJ's role in climate litigation exemplifies the power of international law to drive accountability and justice in global environmental governance. This role is further enriched by the integration of scientific understanding, which the advisory opinion incorporates not as a mere backdrop but as a decisive element in shaping legal obligations. By treating scientific knowledge as an

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135 C.E. BLATTNER, *Separation of Powers and KlimaSeniorinnen*, in *Climate Law: A Sabin Center Blog*, April 30, 2024, https://blogs.law.columbia.edu/climatechange/2024/04/30/separation-of-powers-and-klimaseniorinnen/; J. SPRENGER, *The separation of powers doctrine: a barrier to climate litigation?*, in *Canada Climate Law Initiative*, November 22, 2023, https://ccli.ubc.ca/the-separation-of-powers-doctrine-a-barrier-to-climate-litigation/; J. NEDEVSKA, *An Attack on the Separation of Powers? Strategic Climate Litigation in the Eyes of U.S. Judges*, in *Sustainability* 13(15), 2021, 8335.

136 M.A. TIGRE, J. A. CARRILLO BAÑUELOS, 2023; R. HARVEY, I. MUHAMAD, 2024.

137 J. MCGOWAN, 2024; GREENPEACE INTERNATIONAL, 2024.

evolving benchmark for due diligence, the Court bridges the gap between science and judicial reasoning in an unprecedented way.

In its reasoning, the Court drew extensively on the reports of the IPCC, describing them as the authoritative synthesis of the best available science.[138] These reports were not simply cited for context; they informed the content of states' obligations by calibrating the level of diligence required. The Court emphasized that as scientific knowledge advances, the due diligence standard becomes progressively more demanding.[139] In this way, international law is made dynamic, evolving in parallel with the scientific understanding of climate risks.[140]

Equally significant, the Court integrated the precautionary approach into the framework of state responsibility. It underlined that scientific uncertainty cannot be invoked as a justification for inaction: where the potential for serious or irreversible harm exists, states must act proactively to prevent damage.[141] In doing so, the Court linked scientific assessments directly to the principle of common but differentiated responsibilities and respective capabilities, stressing that while capacities may differ, the obligation to respond in light of available knowledge is universal.[142]

This science-informed approach also sets a precedent for other courts worldwide. Domestic courts in Europe, such as in *Urgenda* and *Neubauer*, had already relied heavily on climate science, but the ICJ's reasoning confirms that such reliance is not only legitimate but necessary under international law. By grounding its interpretation in the IPCC findings and related sources, the Court reinforced the legitimacy of the scientific consensus and rejected claims of uncertainty often raised to delay action. The result is a new benchmark in climate jurisprudence, one that enhances the credibility of judicial decisions, shapes expectations for the use of scientific evidence in future cases, and fosters a more robust dialogue between law and science.[143]

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138 *Obligations of States in respect of Climate Change*, [74].
139 *Ibid*., [283-286].
140 GREENPEACE INTERNATIONAL, 2024; E. KOSOLAPOVA, 2024.
141 *Obligations of States in respect of Climate Change*, [293-294].
142 *Ibid*., [148-151].
143 R. HARVEY, I. MUHAMAD, 2024.

1.2 Scientific evidence in ICJ proceedings regarding climate

The role of scientific evidence in the proceedings of the ICJ reflects a dynamic interaction between the legal and scientific domains. While traditionally grounded in legal doctrines, the ICJ increasingly faces disputes where scientific expertise is pivotal, especially in cases involving environmental and technical issues. The court's approach to integrating scientific evidence has evolved significantly over time, shaped by case law and critiques from scholars and practitioners.

The ICJ's engagement with scientific evidence can be traced back to cases like *Gabcikovo-Nagymaros* (Hungary/Slovakia, 1997), where the Court faced criticism for its limited engagement with complex scientific arguments. In this case, involving the construction and operation of a system of locks on the Danube River, the ICJ's approach to scientific evidence was viewed as insufficiently robust, undermining its credibility in addressing environmental disputes. The case exemplified the challenges of reconciling the legal demand for finality with the inherent uncertainties of scientific inquiry. [144]

The landmark case of *Pulp Mills on the River Uruguay* (2010) underscored the complexities of managing scientific evidence, too.[145] The case involved Argentina's claims that Uruguay had violated the 1975 Statute of the River Uruguay by authorizing the construction and operation of two pulp mills without proper notification, causing alleged environmental harm.

A central procedural issue was the ICJ's reliance on evidence presented by the parties, rather than exercising its powers under Article 50 of the ICJ Statute to appoint independent experts. The ICJ emphasized its role as the arbiter of evidence, stating: "[D]*espite the volume and complexity of the factual information submitted to it, it is the responsibility of the Court, after having given careful consideration to all the evidence placed before it by the Parties, to determine which facts must be considered*

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144 L.C. LIMA, *The Debate on the Use of Experts by the International Court of Justice: an Inquiry through Sociological Lenses*, in *Temple International and Comparative Law Journal*, 34(5), 2020, 253.

145 J. ELLWOOD, *When Scientific Expert Evidence in the International Court of Justice Proves Pivotal: A Case Study on the Silala*, in *New Zealand Journal of Environmental Law*, 27, 2023, 229.

relevant, to assess their probative value, and to draw conclusions from them as appropriate".[146]

The ICJ faced criticism for not appointing court-appointed experts to independently evaluate the conflicting scientific claims, relying instead on party-appointed experts. The Court itself noted deficiencies in the way experts were introduced, particularly when they were included as members of legal teams, shielding them from cross-examination. It observed: "[T]*hose persons who provide evidence before the Court based on their scientific or technical knowledge and on their personal experience should testify before the Court as experts, witnesses or in some cases in both capacities, rather than counsel, so that they may be submitted to questioning by the other party as well as by the Court*".[147]

Moreover, the use of so-called "phantom experts," unofficial consultants providing advice during deliberations, raised concerns about transparency and procedural fairness. Judges Al-Khasawneh and Simma criticized this practice, arguing it deprived parties of their right to address all evidence influencing the Court's decision-making.[148] This lack of transparency reflects broader tensions in reconciling the procedural safeguards of law with the complexities of scientific inquiry.

This decision demonstrates the Court's cautious engagement with scientific uncertainty and its preference for robust, empirical support before attributing causation. The case also highlights the ICJ's struggle to balance competing interests – ensuring procedural fairness, maintaining judicial independence, and effectively addressing technical complexities.

Despite the procedural innovations seen in later cases, such as the expert "hot-tubbing" in *Silala* (2022), which will be soon illustrated, the *Pulp Mills* case illustrates the enduring challenges of integrating scientific evidence into legal frameworks. It underscores the need for more transparent methodologies and greater use of court-appointed experts to enhance the credibility of decisions involving scientific disputes.

Another challenge lies in the selection and role of experts. The ICJ's reliance on party-appointed experts often results in conflicting testimonies, which can

146 *Pulp Mills*, [168].
147 *Ibid.*, [167].
148 *Ibid.*, Joint Dissenting Opinion of Judges Al-Khasawneh and Simma, [14-15].

complicate fact-finding. While court-appointed experts offer neutrality, their use has been limited, partly due to concerns about costs and perceptions of bias. The debate over the use of "phantom experts" further illustrates this dilemma. Critics argue that such practices erode trust and transparency, while proponents contend that they provide essential technical support to judges.[149]

The *Silala* case exemplifies procedural innovations in handling scientific evidence, indeed. In this dispute over transboundary watercourses, the ICJ requested written summaries from party-appointed experts, focusing on contentious issues and areas of agreement. This "hot-tubbing" of experts, where opposing parties engage in collaborative analysis, marked a significant procedural advancement. It facilitated consensus on several points, effectively narrowing the scope of judicial deliberation. This method reflects the court's effort to balance adversarial and inquisitorial models, drawing from both civil and common law traditions.[150]

Another seminal example of how the ICJ addresses complex disputes involving scientific evidence is *Whaling in the Antarctic* case (*Australia v. Japan: New Zealand intervening*, 2014).[151] Central to this case was the question of whether Japan's "JARPA II" program, which involved the killing of whales under special permits, qualified as "scientific research" under Article VIII, paragraph 1, of the International Convention for the Regulation of Whaling (ICRW). The ICJ's approach to scrutinizing scientific evidence in this dispute demonstrates an evolving willingness to engage deeply with the methodologies and assumptions underlying expert testimony and research programs.

In its analysis, the Court emphasized the need for objective standards to evaluate whether JARPA II was genuinely for "scientific research." It concluded: "*The Court notes that, in order to ascertain whether the use of lethal methods is for purposes of scientific research, it is necessary to evaluate whether, in the use of such methods,*

149 *Ibid.*; M.A. SOLHCHI, F. BAGHBANNO, *Evaluating the Credibility of Witness and Expert Reports in ICJ Proceedings*, in *International Journal of Law*, 1, 2023, 47.
150 J. ELLWOOD, 2023.
151 L.C. LIMA, 2020.

the design and implementation of the program are reasonable in relation to achieving its stated objectives."[152]

This statement reflects the Court's commitment to scrutinizing the underlying scientific rationale for using lethal methods, particularly whether non-lethal alternatives were feasible. The judgment noted Japan's failure to provide sufficient justification for the program's design: "*The Research Plan provides no explanation of the basis for determining the overall sample size for fin and humpback whales.*"[153]

The Court further assessed the scientific output of JARPA II and the extent of collaboration with other research institutions. It observed that the program's scientific contributions were minimal and inadequately documented, stating: "*The scientific output to date is limited, and Japan has not demonstrated that JARPA II activities are reasonable in relation to achieving its stated objectives.*"[154]

Moreover, Japan's lack of meaningful cooperation with the International Whaling Commission (IWC) Scientific Committee was highlighted as a procedural deficiency: "*The Court considers that Japan failed to act in conformity with its obligation to give due regard to the recommendations of the IWC Scientific Committee.*"[155]

The ICJ demonstrated an adaptive approach by engaging directly with experts during oral hearings. Both parties called scientific witnesses who were cross-examined, a practice that enriched the fact-finding process. For example, Australia's expert, Professor Marc Mangel, provided critical testimony on the program's deficiencies, which was subject to extensive cross-examination by Japan's counsel.[156]

This case underscored the importance of transparency and rigorous evaluation of scientific methodologies in legal proceedings. By insisting on robust evidence and clear reasoning, the ICJ sought to reconcile the divergent epistemic frameworks of law and science.

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152 *Whaling in the Antarctic* (Australia v. Japan: New Zealand intervening), Judgment, ICJ Reports 2014, 226, [127].
153 *Ibid.*, [211].
154 *Ibid.*, [219].
155 *Ibid.*, [224].
156 *Ibid.*

In conclusion, the ICJ's handling of scientific evidence reveals an ongoing effort to reconcile the demands of legal procedure with the realities of scientific inquiry. While significant strides have been made, particularly in procedural innovations like expert hot-tubbing and collaborative summaries, the court must continue refining its approach to enhance transparency, fairness, and the effective resolution of science-intensive disputes.

1.3 Reflecting on the ICJ's Approach to Scientific Evidence in Climate Litigation

The integration of scientific evidence into the proceedings of the ICJ represents a crucial evolution in its jurisprudence, particularly as environmental and climate-related disputes become increasingly prevalent. The ICJ's historical reluctance to engage deeply with scientific complexities, as seen in cases like *Pulp Mills* or *Gabcikovo-Nagymaros*, has given way to a more proactive approach in recent judgments, such as *Whaling in the Antarctic* and procedural innovations in the *Silala* case. However, the adjudication of climate disputes, with their unique blend of scientific uncertainty and legal complexity, will demand a more consistent and robust engagement with scientific methodologies.

Attribution science, a field that examines the causal links between specific anthropogenic emissions and their environmental impacts, is likely to play a pivotal role in future climate litigation. This field relies heavily on probabilistic models to determine the extent to which human activities contribute to phenomena such as extreme weather events or rising sea levels. For instance, recent advancements have enabled scientists to attribute a percentage of a flood's intensity or a heatwave's duration to greenhouse gas emissions.[157]

However, the probabilistic nature of attribution science may pose significant challenges for the ICJ, which traditionally relies on deterministic evidence. In legal

[157] R. CHO, *Attribution Science: Linking Climate Change to Extreme Weather*, State of the Planet: News from the Columbia Climate School, October 4, 2021, https://news.climate.columbia.edu/2021/10/04/attribution-science-linking-climate-change-to-extreme-weather/.

proceedings, establishing causation often requires a direct and conclusive link, which contrasts with the inherently probabilistic conclusions of climate science. This epistemic divergence raises critical questions about the standards of evidence the Court might adopt in climate-related cases. Would the ICJ accept probabilistic causation as sufficient for liability, or would it adhere to stricter standards that risk excluding cutting-edge scientific findings? Precedents such as *Whaling in the Antarctic* suggest that the ICJ may be willing to engage with innovative methodologies, but a clear framework for assessing the probative value of probabilistic evidence remains to be developed.

Also, the ICJ's reliance on party-appointed experts has been a double-edged sword in science-intensive cases. While such experts provide valuable technical insights, their adversarial nature often leads to conflicting testimonies that complicate the Court's fact-finding process. This issue was evident in *Pulp Mills*, where party-appointed experts presented divergent views on the environmental impact of the disputed pulp mills, leaving the Court to navigate a morass of contradictory evidence .[158] As seen in the paragraph above, the ICJ's reluctance to exercise its powers under Article 50 of its Statute to appoint neutral, court-selected experts has drawn criticism from scholars and practitioners alike. While the use of court-appointed experts could enhance neutrality and objectivity, concerns about cost, potential bias, and procedural delays have limited their adoption.[159]

An alternative approach, as seen in the *Silala* case, involves procedural innovations like expert "hot-tubbing." By encouraging party-appointed experts to engage in collaborative discussions and identify areas of consensus, the Court can streamline its deliberations and focus on resolving the most contentious issues. This method, inspired by common law traditions, offers a promising avenue for balancing adversarial and inquisitorial elements in ICJ proceedings.[160] However, the success of

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158 A. BOYLE, *Pulp Mills Case: A Commentary*, British Institute of International and Comparative Law, 2010, https://www.biicl.org/files/5167_pulp_mills_case.pdf; D. K ANTON, *Case Notes: Case Concerning Pulp Mills on the River Uruguay (Argentina v Uruguay) (Judgment) [2010] ICJ Rep (20 April 2010)*, in *Australian International Law Journal*, 2011, 213.

159 M. BENNOUNA, *Experts before the International Court of Justice: What for?*, in *Journal of International Dispute Settlement*, 9(3), 2018, 345; D. PEAT, *The Use of Court-Appointed Experts by the International Court of Justice*, in *British Yearbook of International Law*, 84, 2013, 271.

160 ASHURST AUSTRALIA, *Hot Tubbing in International Arbitration: Finding a path through the maze of expert evidence*, Australia Disputes Center, March 1, 2016, https://disputescentre.com.au/wp-

this approach in climate cases will depend on the willingness of parties to participate in good faith and the Court's ability to manage the process effectively.

One of the ICJ's most significant challenges in climate-related disputes lies in developing procedural frameworks that can accommodate the complexities of scientific evidence. Environmental impact assessments (EIAs) provide a case in point. In *Pulp Mills*, the Court emphasized the importance of EIAs as procedural safeguards but refrained from defining objective scientific standards for evaluating their adequacy. Instead, it allowed states considerable discretion in determining the content and methodology of EIAs, which some critics argue undermines their effectiveness.[161] In climate litigation, where the stakes are higher and the scientific issues more complex, such deference to state discretion could prove problematic.

The ICJ could benefit from aligning its approach with international best practices, such as the guidelines outlined in the Espoo Convention and the UNEP Principles on Environmental Impact Assessment. These frameworks provide detailed criteria for assessing the adequacy of EIAs, including thresholds for risk and methodologies for evaluating transboundary impacts. By adopting similar standards, the ICJ could enhance the credibility and consistency of its rulings, particularly in cases involving the global commons.[162]

Another fundamental tension in the ICJ's handling of scientific evidence is the divergence between legal and scientific epistemologies. Legal proceedings prioritize finality, clarity, and the resolution of disputes, whereas scientific inquiry embraces uncertainty, iterative processes, and the continuous evolution of knowledge.[163] This epistemic mismatch has significant implications for climate-related cases, where scientific uncertainty is often an inherent feature of the evidence presented.

In *Whaling in the Antarctic*, the ICJ demonstrated an adaptive approach by engaging directly with expert testimony and scrutinizing the methodologies underlying

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content/uploads/2016/03/653646152_2_Hot-tubbing-in-international-arbitration-FINAL.pdf; N. GERTNER, J. SANDERS, *Alternatives to Traditional Adversary Methods of Presenting Scientific Expertise in the Legal System*, in *Daedalus*, 147(4), 2018, 135; P. CAILLARD, *Hot-tubbing – The Expert's Friend?*, HKA, February 14, 2023, https://www.hka.com/hot-tubbing-the-experts-friend/.

[161] K. SULYOK, *Science and Judicial Reasoning. The Legitimacy of International Environmental Adjudication*, Cambridge, 2020, 78.

[162] *Ibid.*, 80-81.

[163] *Ibid.,* 83; J. D'ASPREMONT, M.M. MBENGUE, *Strategies of Engagement with Scientific Fact-finding in International Adjudication*, in *Journal of International Dispute Settlement*, 5(2), 2014, 240.

scientific claims. The Court's decision to assess the reasonableness of Japan's JARPA II program in light of its stated objectives and scientific output reflects a nuanced understanding of the interplay between law and science.[164] However, such adaptive practices must be institutionalized to ensure consistency across cases. One potential solution is the establishment of specialized scientific panels within the ICJ to advise judges on technical issues, similar to the practices of other international bodies like the WTO.[165]

As climate litigation becomes more prominent, the ICJ's ability to navigate the complexities of scientific evidence will have far-reaching implications for global environmental governance. The Court's rulings could set important precedents for the allocation of responsibility for climate harms, the interpretation of international environmental treaties, and the integration of scientific evidence into legal decision-making. For example, disputes arising under the Paris Agreement or other climate frameworks are likely to hinge on scientific assessments of emission reductions, adaptation measures, and the attribution of transboundary harms.

Moreover, the ICJ's engagement with scientific evidence in climate cases could influence broader debates about the role of international law in addressing global challenges. By demonstrating a capacity to integrate scientific expertise effectively, the Court can enhance its legitimacy and relevance in an era where science and technology play an increasingly central role in shaping legal norms and policies.

2. European Court of Human Rights

2.1 The Role of the European Court of Human Rights in Climate Litigation

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164 M. YOUNG, *Whaling in the Antarctic (Australia v Japan: New Zealand intervening)*, in *The Comparative and International Law Journal of Southern Africa*, 48(1), 2015, 59; M.M. MBENGUE, *Scientific Fact-finding at the International Court of Justice: An Appraisal in the Aftermath of the Whaling Case*, in *Leiden Journal of International Law*, 29(2), 2016, 529; S.E. ROLLAND, *Whaling in the Antarctic (Australia v. Japan: New Zealand Intervening)*, in *American Journal of International Law*, 108(3), 2014, 496.

165 K. SULYOK, 179; C.E. FOSTER, *Consulting the science in World Trade Organization dispute settlement: Structured for trust*, in *Questions of International Law*, 98, 2023, 21.

The ECtHR has emerged as a pivotal forum in strategic climate litigation, offering a unique avenue for addressing state inaction on climate change through the lens of human rights.[166] By interpreting the ECHR, the Court allows individuals and groups to challenge failures in climate policies that lead to significant violations of fundamental rights. Strategic climate litigation has found fertile ground in the ECtHR, where rights guaranteed under the ECHR – such as the right to life (Article 2), the right to private and family life (Article 8), and the prohibition of inhuman or degrading treatment (Article 3) – provide a legal basis to argue that inadequate state action on climate change constitutes a breach of positive obligations. These obligations compel states not only to refrain from directly infringing on protected rights but also to take proactive measures to prevent foreseeable harm from environmental and climate risks.[167]

A critical example of this approach is the case of *Verein KlimaSeniorinnen Schweiz and Others v. Switzerland*, which represented a significant victory for climate justice. The case was brought by a group of elderly Swiss women, arguing that the Swiss government's inadequate climate policies violated their rights under Articles 2 and 8 of the ECHR by exposing them to severe health risks from increasingly frequent and intense heatwaves. The ECtHR ruled in favor of the applicants, recognizing that insufficient state action to combat climate change amounted to a violation of their human rights.[168] This ruling marked a historic moment by affirming the link between climate change and human rights and setting a precedent for the recognition of positive state obligations to mitigate climate risks.

The *KlimaSeniorinnen* case, along with other emerging climate cases before the ECtHR, underline the Court's capacity to influence state behavior by linking

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166 COUNCIL OF EUROPE, *Tre sentenze della Corte europea dei diritti dell'uomo sul cambiamento climatico*, April 9, 2024, https://www.coe.int/it/web/portal/-/three-climate-change-rulings-from-the-european-court-of-human-rights?.

167 COUNCIL OF EUROPE, *New factsheet on the execution of ECHR judgments concerning environment*, October 20, 2020, https://www.coe.int/en/web/portal/-/new-factsheet-on-the-execution-of-echr-judgments-concerning-environment?; EUROPEAN COURT OF HUMAN RIGHTS, *Factsheet – Climate change*, April 2024, https://www.echr.coe.int/documents/d/echr/fs_climate_change_eng?.

168 *Case of Verein Klimaseniorinnen Schweiz and Others v. Switzerland*, Judgment, ECtHR, Application no. 53600/20, April 9, 2024.

climate inaction to human rights violations.[169] Unlike national courts, which are bound by domestic laws and political constraints, the ECtHR operates as a supranational body with the authority to issue judgments binding on 46 member states of the Council of Europe. This makes it uniquely positioned to address cross-border issues and create harmonized standards for human rights-based obligations concerning climate change. Framing climate change as a human rights issue elevates its importance in both the legal and political spheres, emphasizing that insufficient climate action is not merely a policy failure but a breach of fundamental rights requiring judicial intervention.[170] This approach has been strategically employed by applicants and NGOs to compel states to meet their climate commitments and address systemic inequities caused by the climate crisis.

By holding states accountable for the cumulative impact of their emissions and policies, the ECtHR has the potential to bridge significant gaps in international climate governance, where enforcement mechanisms under agreements like the Paris Agreement remain weak or absent. However, the Court's engagement with climate cases is not without challenges. As seen also for the ICJ, one of the primary obstacles is the difficulty of demonstrating causation – linking specific climate harms to state inaction or insufficient policies. Scientific advances in climate attribution have made it possible to establish connections between anthropogenic greenhouse gas emissions and extreme weather events, yet translating this evidence into legally actionable claims remains a complex endeavor. In cases like *KlimaSeniorinnen*, applicants must not only prove that state inaction contributed to global climate change but also show that this inaction directly infringed on their specific rights under the ECHR.

This dual burden of proof is particularly challenging in cases involving multiple states, where the cumulative emissions of many jurisdictions must be linked to the harm suffered by the applicants. Additionally, the ECtHR's procedural requirements, such as the exhaustion of domestic remedies, can pose significant

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[169] AMNESTY INTERNATIONAL, *Europe: European Court of Human Rights sets vital precedent with ruling in landmark climate case*, April 9, 2024, https://www.amnesty.org/en/latest/news/2024/04/europe-european-court-of-human-rights-sets-vital-precedent-with-ruling-in-landmark-climate-case/?.

[170] E. MORANDUZZO, *COP28: perché non c'è giustizia climatica senza diritti umani, National Geographic Italia*, December 5, 2023, https://www.nationalgeographic.it/cop28-perche-non-ce-giustizia-climatica-senza-diritti-umani?.

barriers to applicants seeking redress, as demonstrated in the dismissal of the *Duarte Agostinho* case. These procedural hurdles, while ensuring that the Court functions as a last-resort mechanism, may limit its accessibility for climate cases that inherently involve global or multilateral issues.

Another significant limitation arises from the Court's reliance on the "margin of appreciation" doctrine, which grants states a degree of discretion in how they fulfill their obligations under the ECHR.[171] While this doctrine is intended to respect the diverse political, economic, and social contexts of member states, it can also constrain the ECtHR's ability to impose specific obligations on states in the realm of climate policy. The Court may be reluctant to dictate the exact measures states must take to mitigate or adapt to climate change, deferring instead to national governments' judgments. While this approach avoids overstepping into the domain of political decision-making, it risks undermining the transformative potential of ECtHR judgments in addressing climate inaction. States may interpret the Court's rulings as broad guidelines rather than binding mandates, reducing their practical impact on climate governance.

Despite these challenges, the ECtHR's involvement in climate litigation represents a critical opportunity to advance climate justice and establish new legal standards for state responsibilities in combating climate change. By interpreting the ECHR in a way that incorporates scientific evidence and acknowledges the interconnectedness of human rights and environmental protection, the Court can reinforce the principle that climate change poses an existential threat to rights protected under the Convention. A forward-looking approach by the ECtHR could emphasize states' obligations to protect not only current but also future generations from the foreseeable impacts of climate change, aligning its jurisprudence with principles of intergenerational equity.

Furthermore, by engaging directly with expert testimony and scientific findings, the Court can strengthen the evidentiary basis of its decisions, ensuring that

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171 M. R. HUTCHINSON, *The Margin of Appreciation Doctrine in the European Court of Human Rights*, in *International & Comparative Law Quarterly*, 48(3), 1999, 638; A. GIANNINI, *La Corte EDU e il margine di apprezzamento applicato ai simboli religiosi: due pesi per una stessa misura*, FiloDiritto, May 12, 2016, https://www.filodiritto.com/la-corte-edu-e-il-margine-di-apprezzamento-applicato-ai-simboli-religiosi-due-pesi-una-stessa-misura?.

its rulings are not only legally robust but also grounded in scientific consensus. This integration of science and human rights is particularly crucial in climate cases, where the consequences of inaction are profound and far-reaching. The ECtHR's influence extends beyond its immediate judgments, shaping broader legal and policy frameworks across Europe and beyond. A landmark ruling on a climate case, even if procedurally limited, could provide significant legal clarity on the intersection of human rights and climate change, setting a precedent for other courts and tribunals to follow.

Moreover, the visibility of ECtHR proceedings amplifies public awareness of the human rights dimensions of climate change, galvanizing social movements and advocacy efforts. By framing climate inaction as a violation of human rights, the ECtHR can help shift the narrative around climate change, emphasizing its urgency and the moral imperative for action. This dynamic not only strengthens the legitimacy of human rights-based climate litigation but also fosters greater accountability among states, encouraging them to adopt more ambitious climate policies in compliance with their obligations under the ECHR.

To maximize its effectiveness in addressing climate-related cases, the ECtHR could explore procedural adaptations to better accommodate the complexities of climate litigation. For example, increased reliance on interdisciplinary collaboration between legal scholars, human rights experts, and climate scientists could enhance the Court's capacity to evaluate technical evidence and navigate the uncertainties inherent in climate science. Additionally, the ECtHR could refine its approach to balancing state discretion under the margin of appreciation doctrine with the need for consistent and enforceable climate obligations. By providing more detailed guidance on the minimum standards states must meet to comply with their positive obligations under the ECHR, the Court could strengthen the enforceability of its judgments and promote greater uniformity in climate governance across its member states.

The ECtHR occupies a critical role in the landscape of strategic climate litigation, offering a powerful mechanism to hold states accountable for their climate obligations through the framework of human rights. While cases like *Duarte Agostinho* and *KlimaSeniorinnen* reveal both the potential and the challenges of climate litigation before the ECtHR, they highlight the transformative role the Court can play in

advancing justice, equity, and accountability in the global effort to combat climate change.

2.2 Scientific evidence in ECtHR proceedings regarding climate

The ECtHR has progressively engaged with scientific evidence, particularly in cases involving environmental degradation, toxic exposure, and public health. Although the ECHR does not explicitly refer to environmental rights or scientific standards, the Court has nonetheless utilized scientific findings to interpret rights under Articles 2, 8, and other provisions. This dynamic has established the ECtHR as a significant forum where science informs human rights adjudication. Despite its achievements, however, the Court's approach reveals a number of conceptual, procedural, and practical challenges.

One of the most notable aspects of the ECtHR's practice is its broad admissibility of evidence. The Court typically does not impose rigid requirements on the form, origin, or type of evidence submitted, embracing flexibility in its evidentiary rules.[172] This openness allows parties to introduce diverse types of scientific data, ranging from epidemiological studies and toxicological analyses to expert testimonies. For instance, in cases such as *Tătar v. Romania*, applicants relied heavily on scientific reports to demonstrate the adverse health impacts of environmental pollution. However, while this flexibility is advantageous in accommodating the complexities of scientific evidence, it also raises concerns about the consistency and rigor with which such evidence is evaluated.[173]

Unlike national courts, the ECtHR lacks detailed procedural rules for admitting and scrutinizing scientific evidence, which can result in inconsistencies in its evaluation. In some cases, the Court adopts a precautionary approach, giving significant weight to expert testimony to justify preventive measures even in the face

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[172] EUROPEAN COURT OF HUMAN RIGHTS, *Practical Guide on Admissibility Criteria*, August 31, 2023 https://www.echr.coe.int/documents/d/echr/admissibility_guide_eng?; M.B. DEMBOUR, *The Evidentiary System of the European Court of Human Rights in Critical Perspective*, in *European Convention on Human Rights Law Review*, 4, 2023, 365.

[173] *Ibid*.

of scientific uncertainty. In others, however, it dismisses similar evidence due to uncertainties or challenges in proving causation.[174] This inconsistency is further compounded by judges' limited technical expertise, which may lead to either over-reliance on or excessive skepticism toward scientific findings.[175] Additionally, applicants, particularly individuals or small groups, often face resource disparities, lacking access to high-quality expert witnesses or comprehensive studies compared to state authorities or corporations.[176]

A central challenge for the Court is handling causation, a recurring issue in cases involving toxic exposure or environmental harm. Establishing a causal link between a state's actions or omissions and the alleged harm is often fraught with scientific uncertainty. For example, in cases like *Fadeyeva v. Russia*, the applicants sought to prove that industrial pollution directly affected their health and well-being.[177] While the Court acknowledged the severity of the pollution, it required a high standard of evidence to establish causation, often described as "*beyond reasonable doubt.*"[178] This standard, rooted in criminal law traditions, poses significant barriers for applicants in environmental and public health cases, where scientific uncertainty is inherent. Scientific studies in such cases often rely on probabilistic data or inferential reasoning, which may fall short of the Court's evidentiary threshold.

The ECtHR applies the beyond reasonable doubt (BRD) standard to establish state responsibility for human rights violations, primarily to ensure the legitimacy and credibility of its rulings. While BRD is traditionally a criminal law standard in common law systems, the Court has adapted it to fit the human rights context, where direct evidence is often scarce due to state obstruction or lack of cooperation. Unlike in criminal trials, the ECtHR allows for circumstantial evidence, logical inferences, and, in some cases, a reversal of the burden of proof, requiring states to disprove allegations. This approach balances the need for a high evidentiary threshold –

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174 A. ALEMANNO, *The Shaping of the Precautionary Principle by European Courts: From Scientific Uncertainty to Legal Certainty*, in L. CUOCOLO, L. LUPARIA (eds.), *Cahiers Europèens*, Halley, 2007, 8-12, 16-18, 22-25.

175 *Ibid*., 14-16, 19, 23.

176 *Ibid*., 17-19, 22, 24.

177 K. SULYOK, 152.

178 *Nadezhda Mikhaylovna Fadeyeva against Russia*, Judgment, ECtHR, Application no. 55723/00, June 9, 2005, [79].

protecting states from unfounded accusations – with the reality that proving human rights violations often requires a more flexible evidentiary framework. The use of BRD also aligns the ECtHR with international legal standards and reinforces the reliability of its decisions in addressing state accountability.[179]

Despite these challenges, the ECtHR has made important contributions to integrating science into human rights adjudication. Its jurisprudence has gradually evolved to recognize the interplay between environmental protection and human rights, even in the absence of explicit environmental provisions in the ECHR. Cases like *López Ostra v. Spain* and *Tătar v. Romania* have set important precedents, demonstrating that states have both negative and positive obligations to prevent environmental harm that interferes with the enjoyment of fundamental rights. These decisions underscore the Court's potential to bridge the gap between scientific knowledge and legal standards, fostering a more holistic understanding of human rights in the context of environmental and public health challenges.

In *López Ostra v. Spain*, the ECtHR effectively utilized scientific evidence to interpret Article 8 of the ECHR, acknowledging the impact of environmental pollution on the applicant's private and family life. The Court emphasized that "*severe environmental pollution may affect individuals' well-being and prevent them from enjoying their homes in such a way as to affect their private and family life adversely, without, however, seriously endangering their health*".[180] By integrating findings from expert reports – such as those documenting hydrogen sulfide emissions exceeding permissible levels and linking these emissions to health risks – the Court established a direct connection between the scientific assessment of pollution and the legal standard of a state's positive obligations under Article 8.

The Court concluded that the state failed to strike a "*fair balance between the interest of the town's economic well-being* [...] *and the applicant's effective enjoyment of her right to respect for her home and her private and family life*".[181] This reasoning

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[179] C. BICKNELL, *Uncertain Certainty?: Making Sense of the European Court of Human Rights' Standard of Proof*, in *International Human Rights Law Review*, 8(2), 2019, 155; T.J. GUNN, *Limitations Clauses, Evidence, and the Burden of Proof in the European Court of Human Rights*, in *Religion & Human Rights*, 15(1-2), 2020, 192.

[180] *Case of López Ostra v. Spain*, Judgment, ECtHR, Application no. 16798/90, December 9, 1994, [51].

[181] *Ibid.*, [58].

highlights how the ECtHR used scientific insights to substantiate its legal determinations, demonstrating a nuanced approach that connects empirical evidence with the broader framework of human rights protection.

In *Tătar v. Romania*, the ECtHR engaged extensively with scientific evidence to assess the state's compliance with its obligations under Article 8 of the ECHR. The case stemmed from the environmental and health consequences of cyanide pollution caused by a gold mining operation near the applicants' home. The Court recognized the applicants' contention that "*l'existence d'un risque sérieux et substantiel pour la santé et pour le bien-être des requérants faisait peser sur l'État l'obligation positive d'adopter des mesures raisonnables et adéquates capables à protéger les droits des intéressés au respect de leur vie privée et leur domicile et, plus généralement, à la jouissance d'un environnement sain et protégé*"[182] and criticized the state for failing to adequately monitor and mitigate these risks.

It highlighted shortcomings in environmental impact assessments and insufficient precautionary measures, noting that "*les conditions d'exploitation fixées par les autorités roumaines en l'espèce se sont révélées insuffisantes pour prévenir une situation lourde de conséquences pour l'environnement et le bien-être de la population*".[183] By grounding its reasoning in scientific reports detailing the toxicological and ecological risks of sodium cyanide, the Court reinforced its interpretation of states' positive obligations to prevent environmental harm infringing on fundamental rights. This case illustrates the ECtHR's ability to address scientific uncertainty while emphasizing the critical role of precautionary measures in safeguarding human rights.

Nevertheless, the ECtHR's engagement with scientific evidence remains a work in progress. Its reliance on traditional legal frameworks, such as the burden of proof and the standard of review, often struggles to accommodate the complexities of modern scientific inquiry.[184] The absence of a standardized approach to evaluating

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182 *Affaire Tătar c. Roumanie*, Judgment, ECtHR, Application no. 67021/01, January 27, 2009, [107].

183 *Ibid*, [112].

184 M.B. DEMBOUR, 364-366; M. AMBRUS, *The European Court of Human Rights and Standards of Proof: An Evidentiary Approach towards the Margin of Appreciation*, in L. GRUSZCZYNSKI, W. WERNER (eds), *Deference in International Courts and Tribunals: Standard of Review and Margin of Appreciation*, Oxford, 2014.

expert evidence and addressing scientific uncertainty further exacerbates these difficulties. For instance, while the Court has invoked the precautionary principle in environmental cases such as *Tătar v. Romania*, its application remains limited. In *Tătar*, the Court acknowledged the precautionary principle when addressing the insufficient environmental impact assessments conducted by the state, noting that such measures failed to satisfactorily assess potential risks associated with the cyanide spill at a gold mine.[185] However, this reasoning was confined to regulatory failures and did not extend to resolving scientific uncertainty regarding the health impacts on the applicants. The Court dismissed probabilistic medical evidence suggesting a causal link between the spill and respiratory conditions, highlighting its hesitancy to base legal conclusions on uncertain science.[186]

Moreover, the ECtHR often defers to state authorities, reflecting the inherent tension between judicial oversight and respect for state sovereignty.[187] This deference is evident in the Court's broad recognition of the margin of appreciation granted to states in balancing individual rights and collective interests. For instance, in cases involving environmental nuisances, such as *Fadeyeva v. Russia*, the Court emphasized the need for states to strike a "fair balance" between economic development and the protection of private life, thereby granting substantial leeway to national authorities in determining acceptable levels of environmental harm. Such an approach underscores the Court's reluctance to intrude on domestic policy decisions, even when scientific evidence suggests significant risks to human rights. This cautious stance, while respecting state sovereignty, risks undermining the Court's capacity to provide robust protection against environmental harms exacerbated by scientific uncertainties.

To address these issues, the ECtHR could consider a more systematic use of precautionary reasoning to mitigate the challenges posed by scientific uncertainty. For example, adopting a flexible burden-shifting mechanism in cases involving probabilistic evidence or explicitly recognizing a lower standard of proof in such contexts could enhance the Court's ability to adjudicate complex environmental

185 *Affaire Tătar c. Roumanie*, [120].
186 *Ibid*., [108].
187 K. SULYOK, 145; M.B. DEMBOUR, 365-368.

disputes while maintaining procedural fairness.[188] By doing so, the Court could better navigate the interplay between science and human rights law, ensuring that applicants are not disadvantaged by the inherent ambiguities of scientific evidence.

The *Klimaseniorinnen* judgment illustrates how the ECtHR is already refining its approach by embedding scientific evidence into its assessment of state discretion. While the Court maintained a broad margin of appreciation regarding policy choices,[189] it significantly narrowed this discretion when it came to setting climate targets, requiring states to establish carbon budgets and update them in accordance with the latest scientific findings.[190] By insisting that states justify their commitments using objective, science-based benchmarks, the Court reinforced the role of scientific expertise in shaping legal obligations. This approach not only aligns with the need for stronger precautionary reasoning but also ensures that climate obligations are not merely political commitments but enforceable duties, responsive to both human rights imperatives and the realities of climate science.

2.3 Reflecting on the ECtHR's Approach to Scientific Evidence in Climate Litigation

Building on the challenges identified, the ECtHR could benefit significantly from adopting a more structured and adaptive approach to integrating scientific evidence into its adjudication processes. The Court's current engagement with scientific data, while commendable in its inclusivity, often falls short in ensuring consistency, fairness, and a robust framework for evaluating complex information. To address these shortcomings, a range of procedural, methodological, and substantive reforms should be considered, ensuring the Court's jurisprudence remains responsive to the intricate demands of cases involving environmental degradation, toxic exposure, and public health risks.

188 K. SULYOK, 145-146; M.B. DEMBOUR, 365-367.
189 *Case of Verein Klimaseniorinnen Schweiz and Others v. Switzerland*, [449, 457].
190 *Ibid*., [543, 548-550].

One of the most immediate steps the ECtHR could take is to formalize its approach to admitting and evaluating scientific evidence.[191] While the Court does not engage in fact-finding, the absence of clear procedural guidelines results in significant variability in how scientific evidence is weighed, leading to inconsistencies that undermine legal certainty. To address this, the Court could develop standardized principles for evaluating expert reports, technical studies, and probabilistic data, ensuring that the scientific information relied upon meets a baseline level of reliability and relevance.

Rather than prescribing rigid admissibility rules, such guidelines could provide a structured framework for assessing the credibility of competing scientific claims, particularly in cases involving complex environmental and climate-related disputes. Standardization would enhance consistency across cases, offering clearer expectations for applicants and states regarding the evidentiary weight accorded to scientific findings. Additionally, the Court could consider mechanisms such as independent expert consultations or reference to established scientific consensus to navigate conflicting claims, reinforcing the objectivity and legitimacy of its decisions without departing from its role as a legal adjudicator rather than a fact-finding body.[192]

To address the Court's limited technical expertise, the establishment of an independent scientific advisory body should be considered. Such a body could consist of leading experts across disciplines relevant to the Court's docket, including environmental science, epidemiology, toxicology, and public health. These experts would serve as a resource for judges, offering impartial assessments of the scientific evidence presented and contextualizing complex findings within the legal issues at stake.

This approach would have several benefits. First, it would reduce the risk of judicial over-reliance on, or undue skepticism toward, expert testimony provided by the parties, ensuring a balanced and informed evaluation. Second, it would help mitigate disparities between resource-rich states or corporations and less-resourced

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[191] The project "*Evidence in the European Court of Human Rights*" by Ghent University examines how the formal and informal rules governing the handling of evidence by the Court impact fairness between the parties, https://hrc.ugent.be/research/evidence-in-the-ecthr/?.

[192] J. VUILLE, L. LUPÀRIA, F. TARONI, *Scientific evidence and the right to a fair trial under Article 6 ECHR*, in *Law, Probability and Risk*, 16(1), 2017, 55.

applicants, who often struggle to match the level of expertise mobilized by their opponents. Third, it would improve the quality and depth of judicial reasoning in cases involving technical evidence, reinforcing the Court's legitimacy in addressing scientifically complex disputes.[193]

The ECtHR should also consider reforming its evidentiary standards to better accommodate the probabilistic and inferential nature of much scientific evidence.[194] In cases involving environmental or health-related harms, absolute certainty is often unattainable due to the inherent limitations of scientific methodologies. The Court could move away from rigid standards such as "beyond reasonable doubt" and instead adopt a contextual standard that takes into account the nature of the evidence and the broader implications of the case. For instance, a "balance of probabilities" standard, commonly used in civil law, could be applied to cases where harm is likely but not definitively proven. Alternatively, the Court could adopt a sliding scale of proof, requiring less stringent evidence when the potential harm is severe or irreversible. This approach would align the Court's reasoning with the realities of scientific uncertainty, allowing for more equitable outcomes in cases where traditional evidentiary requirements would disadvantage applicants.

Considering that demonstrating harm is often essential to establishing victim status under the ECHR, the ECtHR should explore burden-shifting mechanisms that apply once applicants have met an initial evidentiary threshold.[195] For example, in cases where individuals or small groups provide credible indications of harm and a plausible link to state actions or omissions, the burden could shift to the state to demonstrate that it has acted in compliance with its obligations. This approach would acknowledge the procedural challenges faced by applicants while preserving the requirement that they substantiate their victim status. Moreover, it would help level the playing field by placing responsibility on states, which are often in a better position to access and produce relevant data, to justify their policies and actions. Burden-shifting mechanisms could be particularly effective in cases involving environmental degradation or industrial pollution, where the imbalance in access to scientific

193 K. SULYOK, 139-143.
194 M. AMBRUS, 107; T.J. GUNN, 192.
195 M.B. DEMBOUR, 364-365, 367.

evidence is most pronounced. By requiring states to justify their actions in light of the precautionary principle, the Court would reinforce the importance of preventive governance and encourage adherence to international environmental standards.

The precautionary principle, though recognized in ECtHR jurisprudence, remains underutilized as a judicial tool. The Court could expand its application by explicitly framing it as an extension of states' positive obligations under Articles 2 and 8 of the ECHR.[196] This would involve interpreting the principle not merely as a regulatory guideline but as a fundamental safeguard for protecting human rights in the face of scientific uncertainty. In practice, this could mean requiring states to demonstrate that they have taken reasonable and adequate measures to address potential risks, even when those risks are not fully understood. For example, in cases like *Tătar v. Romania*, the Court could have gone further by holding the state accountable for failing to act on early warnings about the cyanide spill's potential impacts. By embedding the precautionary principle more deeply into its reasoning, the ECtHR would signal a commitment to prioritizing the prevention of harm over the resolution of disputes after harm has occurred.

Beyond adjudication, the ECtHR could play a role in promoting proactive state compliance with scientific and environmental standards.[197] Through its judgments, the Court could establish benchmarks for state behavior, providing guidance on best practices for integrating scientific knowledge into policymaking. These benchmarks could cover areas such as environmental impact assessments, public health monitoring, and risk communication, offering states a roadmap for fulfilling their obligations under the ECHR. Additionally, the Court could use its powers to issue advisory opinions on emerging scientific and environmental issues.[198] By clarifying the expectations for state action in advance, the Court would help prevent disputes and reinforce its role as a leader in the intersection of human rights and science.

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196 K. SULYOK, 145-146; A.U. MELCON, *Positive Obligations and Climate Change Under the European Convention on Human Rights*, in The American University International Law Review, September 6, 2023, https://auilr.org/2023/09/06/positive-obligations-and-climate-change-under-the-european-convention-on-human-rights/?.

197 M.B. DEMBOUR, 368-370.

198 K. SULYOK, 143-145.

To ensure fairness in proceedings, the ECtHR should explore mechanisms to address resource disparities between parties. For example, the Court could establish a fund to support applicants in accessing expert witnesses or conducting necessary studies. Alternatively, it could partner with non-governmental organizations, academic institutions, or international bodies to provide technical assistance to under-resourced parties.[199] Such initiatives would enhance access to justice for marginalized groups, ensuring that the quality of evidence presented is not determined by financial resources. They would also reinforce the Court's commitment to equality and fairness in the adjudication process.

The ECtHR could deepen its engagement with the scientific community by fostering partnerships with academic and research institutions.[200] These collaborations could take the form of regular workshops, expert consultations, or the establishment of a scientific advisory council. By staying abreast of developments in environmental and health sciences, the Court would be better equipped to interpret and apply scientific evidence in its decisions. Additionally, such collaborations could help bridge the gap between scientific knowledge and legal standards, ensuring that the Court's reasoning reflects the latest advancements in relevant fields. This would enhance the credibility and effectiveness of the ECtHR's jurisprudence in addressing complex scientific issues.

Finally, the ECtHR should strive to balance procedural fairness with substantive justice in its handling of scientific evidence.[201] While maintaining rigorous standards for evidence evaluation is essential, the Court must also consider the broader implications of its decisions for human rights and environmental protection. By adopting a holistic approach that integrates legal, scientific, and ethical considerations, the Court can ensure that its judgments serve both justice and sustainability.

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199 J. VUILLE, L. LUPÀRIA, F. TARONI, 57-59; A. KÜÇÜKSU, *Enforcing Rights Beyond Litigation: Mapping NGO Strategies in Monitoring ECtHR Judgement Implementation*, in *Human Rights Law Review*, 22(2), 2022, 1.

200 K. SULYOK, 145-147; J. VUILLE, L. LUPÀRIA, F. TARONI, 57-59; L.R. HELFER, *Redesigning the European Court of Human Rights: Embeddedness as a Deep Structural Principle of the European Human Rights Regime*, in *European Journal of International Law*, 19(1), 2008, 125.

201 J. VUILLE, L. LUPÀRIA, F. TARONI, 57-59; M.B. DEMBOUR, 364-369; T. KLEINLEIN, *The Procedural Approach of the European Court of Human Rights: Between Subsidiarity and Dynamic Evolution*, in *International and Comparative Law Quarterly*, 68(1), 2019, 91.

By implementing these reforms, the ECtHR could strengthen its capacity to adjudicate cases involving scientific evidence while addressing the conceptual, procedural, and practical challenges highlighted in its current approach. These changes would not only enhance the consistency and rigor of the Court's reasoning but also reinforce its role as a guardian of human rights in an era of increasing scientific and environmental complexity.

3. Italian Courts

3.1 Climate Litigation in Italy

Italy has recently entered the landscape of climate litigation with two landmark cases that have marked a turning point in the country's legal response to the climate crisis. The first, the *Giudizio Universale* lawsuit, filed by NGOs and private citizens in 2021, sought to hold the Italian government accountable for its insufficient climate action.[202] The second, the *Greenpeace and ReCommon v. ENI* case, culminated in the 2025 decision of the Supreme Court's Sezioni Unite, which for the first time recognised the jurisdiction of ordinary courts over climate disputes framed as tort actions. Together, these proceedings have exposed both the limitations of Italy's legal framework and the potential of civil courts to play a more active role in climate governance.

The Italian constitutional framework provides a unique context for these developments. The 2022 amendments to Articles 9 and 41 of the Constitution explicitly integrated environmental protection, biodiversity, ecosystems, and intergenerational equity into the broader framework of fundamental rights and economic freedoms. These provisions, coupled with general tort law under Articles 2043 and 2050 of the Civil Code, provide a normative basis for climate litigation. Yet Italy still lacks a comprehensive climate law comparable to those in Germany or the Netherlands. Climate regulation remains fragmented, anchored in sectoral measures

202 https://giudiziouniversale.eu.

and policy documents such as the National Integrated Energy and Climate Plan. This structural gap constrains judicial engagement with systemic mitigation obligations and explains the difficulties encountered in the *Giudizio Universale* case.

That case was groundbreaking in its ambition. The plaintiffs sought to compel the government to achieve a 92% reduction in greenhouse gas emissions by 2030 compared to 1990 levels, far beyond Italy's existing pledge of a 36% reduction. Grounding their claims in constitutional rights (Articles 2 and 32), the ECHR (Articles 2 and 8), and tort law (Articles 2043 and 2058 Civil Code), they argued that insufficient mitigation policies violated fundamental rights and demanded judicially imposed emissions targets.[203] However, the Tribunal of Rome dismissed the case in February 2024, citing an absolute lack of jurisdiction. It held that ordering the government to adopt specific climate measures would breach the separation of powers, as such prerogatives belong to the legislature and executive,[204] and further declined its own jurisdiction in favor of the administrative courts, suggesting that the plaintiffs' concerns should be pursued in that forum.[205] The judgment, criticised for its brevity and lack of substantive reasoning, aligned Italy with jurisdictions reluctant to allow courts to scrutinize climate policy choices.[206]

The landscape changed dramatically in July 2025, when the Sezioni Unite delivered their ruling in *Greenpeace and ReCommon v. ENI*.[207] Unlike *Giudizio*

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[203] U. LATTANZI, *Climate Litigation Reaches Italian Courts: Giudiuzio Universale*, in VerfBlog, April 21, 2024, https://verfassungsblog.de/climate-litigation-reaches-italian-courts/; M. VINKEN, P. MAZZOTTI, *The First Italian Climate Judgement and the Separation of Powers: A Critical Assessment in Light of the ECtHR's Climate Jurisprudence*, in VerfBlog, April 22, 2024, https://verfassungsblog.de/the-first-italian-climate-judgement-and-the-separation-of-powers/.

[204] The Tribunal stated that "[c]*on l'azione civile proposta gli attori chiedono nella sostanza al Tribunale di annullare i provvedimenti anche normativi di carattere primario e secondario* […]*, che costituiscono attuazione delle scelte politiche del legislatore e del governo per il raggiungimento degli obiettivi assunti a livello internazionale ed europeo (nel breve e lungo periodo) in violazione di un principio cardine dell'ordinamento rappresentato dal principio di separazione dei poteri*", 12.

[205] "*Le asserite carenze del piano sotto il profilo della adeguatezza, coerenza e ragionevolezza rispetto a tali obiettivi nel nostro ordinamento sono censurabili dinanzi al Giudice amministrativo. La questione attiene alla legittimità dell'atto amministrativo e, comunque, a comportamenti e omissioni riconducibili all'esercizio di poteri pubblici in materia di contrasto al cambiamento climatico antropogenico e quindi è afferente alla giurisdizione amministrativa generale di legittimità*", 14.

[206] U. LATTANZI, 2-3; M. VINKEN, P. MAZZOTTI, 8-9; A. VILLANI, E. ANDRICH, B. PORCELLATO, *Italy: The "Last Judgement" - a halt for climate litigation?*, in Linjlaters, March 26, 2024, https://sustainablefutures.linklaters.com/post/102j3ur/italy-the-last-judgement-a-halt-for-climate-litigation.

[207] Italian Supreme Court, Sezioni Unite, ordinance no. 20381, July 21, 2025.

Universale, this case targeted a private corporation and its public shareholders, alleging that ENI's decarbonisation strategy was inconsistent with scientific scenarios and international obligations, and that its continued reliance on fossil fuels violated fundamental rights. The plaintiffs sought both damages and injunctions to reduce emissions, grounding their claims in Articles 2043, 2050, 2051, and 2058 Civil Code. The Supreme Court, resolving a preliminary jurisdictional dispute, held that ordinary courts do have jurisdiction when climate actions are framed as tort claims against private actors. It drew a crucial distinction: actions seeking to compel the State or Parliament to adopt general climate policies remain outside judicial review, but tort actions against corporations for climate-related damages are justiciable before civil courts.[208]

This reasoning has profound implications. By affirming jurisdiction, the Court opened the door for civil liability claims against companies whose activities contribute to climate change. Importantly, it recognised that remedies could include not only monetary damages but also specific performance under Article 2058 Civil Code, potentially obliging corporations to align their business practices with climate science.[209] At the same time, the Court emphasised that the merits of such claims, particularly the demonstration of causation and the binding effect of international and constitutional norms on private actors, remain for the trial court to assess.[210] This balance preserves the separation of powers while acknowledging the judiciary's role in protecting rights against corporate misconduct.

The contrast between *Giudizio Universale* and *ENI* illustrates the evolving boundaries of judicial intervention in climate governance. Whereas the former reflected judicial restraint, the latter signals a more assertive role for civil courts,

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208 The Sezioni Unite stated that "[a] *differenza delle predette ipotesi, la fattispecie in esame si configura come una comune azione risarcitoria, fondata sull'allegazione di un danno* […] *con la condanna degli stessi ad adottare le misure idonee a ridurre le emissioni entro i limiti previsti dalle fonti internazionali indicate.* […] *Nel caso di specie, gli attori non fanno valere una responsabilità dello Stato legislatore* […]*, ma una responsabilità dei convenuti, quali soggetti operanti direttamente o indirettamente nel settore della produzione e distribuzione dei combustibili fossili* […]*: il compito affidato al Giudice consiste pertanto soltanto nel verificare se le fonti internazionali e costituzionali invocate* […] *risultino idonee ad imporre un dovere d'intervento direttamente a carico dei convenuti, tale da fondare una responsabilità extracontrattuale degli stessi* […]" [7.1].

209 *Ibid.*, [7] and [7.1].

210 *Ibid.*, [7.2].

especially where claims are grounded in tort law rather than demands for legislative reform. This evolution mirrors international trends: at one end, cases like *Urgenda* show courts willing to impose state obligations; at the other, Italy's Sezioni Unite have delineated a path focused on private liability, consistent with the constitutional framework after 2022.

Science remains central in this process. In both cases, plaintiffs relied heavily on IPCC reports, international agreements, and attribution studies to substantiate claims.[211] The Sezioni Unite explicitly recognised that judges must verify whether international and constitutional sources, interpreted in light of climate science, impose obligations directly binding on private defendants.[212] This acknowledgement underscores the judiciary's increasing reliance on scientific expertise to evaluate corporate conduct and measure compliance with climate goals. Yet it also highlights challenges, particularly regarding the judiciary's capacity to interpret complex scientific data and the risk of judicial overreach into policy domains.[213]

The separation of powers thus continues to frame the Italian debate, but in a more nuanced way. The Tribunal of Rome dismissed the *Giudizio Universale* case by invoking the limits of judicial authority, whereas the Sezioni Unite distinguished between political discretion and tortious liability, affirming that courts may act without encroaching upon the legislative sphere. This approach aligns Italian jurisprudence more closely with recent European developments, such as the ECtHR's *KlimaSeniorinnen* ruling, which also balanced respect for state discretion with the protection of fundamental rights.

Finally, the *ENI* case raises important questions about remedies and corporate accountability. By recognising the possibility of specific performance remedies, the Supreme Court has opened the way for orders requiring companies to modify their business models in line with climate science. This innovation could make Italian courts a significant forum for climate accountability, even in the absence of a framework climate law. It also demonstrates the potential of civil litigation to complement, rather

211 *Ibid.*, [1].
212 *Ibid.*, [7.1].
213 M. VINKEN, P. MAZZOTTI, 8-9.

than replace, political and legislative action, fostering a multi-layered approach to climate governance.

In sum, Italian climate litigation has moved from an initial phase of judicial restraint to a new stage where courts are prepared to hear claims against private actors and potentially impose science-based remedies. The combined lessons of *Giudizio Universale* and *ENI* illustrate the dynamic interplay of law, science, and politics in shaping Italy's response to the climate crisis. They highlight both the structural limitations of the Italian legal framework and the transformative potential of litigation as a catalyst for climate justice.

3.2. Italian Courts and scientific evidence

3.2.1. Civil courts

The integration of scientific evidence in Italian civil proceedings represents a pivotal aspect of modern legal practice, offering both opportunities and challenges in the pursuit of fair and accurate judicial outcomes. In contrast to the general role of science across legal systems, the Italian context demonstrates distinctive features shaped by its procedural traditions and evolving jurisprudential framework. The incorporation of scientific knowledge is not merely an auxiliary function but a critical component of judicial reasoning, especially in complex cases where technical expertise can illuminate factual determinations.

In civil proceedings, scientific evidence serves as an essential tool for bridging the gap between the specialized nature of factual disputes and the legal principles that govern their resolution. Italian courts rely heavily on technical consultants (*consulenti tecnici d'ufficio*, or CTUs) to provide expertise in areas beyond the judge's or lawyers' training. This procedural mechanism aims to ensure that decisions are grounded in reliable data and rational evaluation. However, the selection and use of these experts

introduce challenges, including the potential for bias, variations in expertise, and the risk of over-reliance on their opinions at the expense of judicial discretion.[214]

Italian procedural law adheres to the principle of "free evaluation of evidence," which grants judges significant autonomy in weighing proofs presented during litigation. While this principle underscores judicial independence, it also exposes the process to inconsistencies in handling scientific evidence.[215] For instance, judges may rely on their interpretation of scientific data or dismiss expert testimony deemed less convincing. This discretionary power necessitates careful balancing to prevent judicial overreach while maintaining a fair and transparent evaluation of facts. As Taruffo notes, the effectiveness of scientific evidence lies not in its symbolic authority but in its ability to support rational, empirically grounded decision-making.[216]

The standards of proof in Italian civil law further shape the role of scientific evidence. Unlike criminal proceedings, which require proof "beyond a reasonable doubt," civil cases operate under the "balance of probabilities" standard. This lower threshold accommodates the inherent uncertainties in many forms of scientific analysis but also raises questions about the adequacy of probabilistic reasoning in determining facts. For example, cases involving epidemiological data or statistical models often present challenges in aligning probabilistic evidence with the legal requirement to establish causation.[217]

A salient issue in this context is the differentiation between "hard" sciences, such as genetics or engineering, and social sciences, like psychology or sociology.[218] The former are generally perceived as more objective and verifiable, making their findings easier to integrate into judicial reasoning. By contrast, the interpretative and context-dependent nature of social sciences can lead to disputes over their admissibility and probative value. In some instances, judges may opt to rely on common sense or personal understanding rather than seeking specialized input, potentially undermining the reliability of outcomes.

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214 M. TARUFFO, *La Prova Scientifica nel Processo Civile*, in *Rivista trimestrale di diritto processuale civile*, 4, 2005, 1081-1083, 1085-1087; A. CARRATTA, *La Scienza del Processo Civile in Italia all'Inizio del XXI Secolo*, in *Diritto & Questioni Pubbliche*, 19, 2019, 14-16.

215 M. TARUFFO, 1080-1082, 1084-1087; A. CARRATTA, 12-14.

216 M. TARUFFO, 1080-1083.

217 *Ibid.*, 1090-1093.

218 *Ibid.*, 1084-1087.

The procedural emphasis on legal certainty and the right to effective remedies adds another layer of complexity.[219] While scientific evidence can enhance the accuracy of judicial determinations, its misuse or misinterpretation may erode the very principles it seeks to uphold. The risk of "junk science" infiltrating courtrooms underscores the importance of robust standards for the admissibility and evaluation of expert testimony. Lessons from international jurisprudence, such as the U.S. Supreme Court's Daubert standard, offer valuable insights into mitigating these risks by requiring scientific evidence to meet criteria of reliability, relevance, and methodological rigor.

The Italian experience also highlights broader themes of interdisciplinarity and the evolving role of the judiciary in mediating between specialized knowledge and societal needs. The increasing prevalence of complex litigation – such as environmental disputes or mass tort cases – has amplified the demand for a more nuanced integration of scientific expertise within procedural frameworks. This dynamic underscores the necessity of ongoing reforms to ensure that scientific evidence not only supports judicial efficiency but also aligns with the ethical and legal imperatives of justice.

Ultimately, the role of science in Italian civil proceedings is a testament to the evolving relationship between law and knowledge. While significant progress has been made in incorporating technical expertise into legal processes, challenges remain in standardizing practices and safeguarding against potential abuses. A balanced approach that respects judicial autonomy while leveraging the strengths of scientific methodologies is essential for ensuring that justice is both effective and equitable.

3.2.2. Criminal courts

While the criminal justice system may appear less central to climate litigation, analyzing the role of scientific evidence in criminal trials offers crucial insights. In Italy, where guilt must be established "beyond a reasonable doubt," this arena has

[219] A. CARRATTA, 12-14; M. TARUFFO, 1089-1090.

sparked intense debate about the intersection of law and empirical science. Understanding how scientific data is integrated into the judicial process sheds light on broader implications for legal certainty and the pursuit of justice.

Scientific evidence in criminal trials typically refers to the application of scientific principles, such as DNA analysis, forensic toxicology, or digital evidence, to reconstruct facts of a case. As noted by Stefano Di Pinto, this involves translating empirical findings into legally admissible evidence to establish causation, intent, or culpability.[220] Unlike the reproducible context of scientific experiments, judicial proceedings often deal with unique, non-replicable past events. This distinction underscores the challenges in aligning scientific methodologies with legal reasoning, which relies heavily on normative judgments and contextual interpretation.[221]

One key difficulty lies in the different standards of proof. Criminal law requires certainty "beyond a reasonable doubt," yet scientific conclusions are often probabilistic and contingent on available data. For example, DNA analysis may identify a suspect with near-certainty, but it cannot always account for external variables, such as contamination or procedural errors. Similarly, statistical evidence, though persuasive, requires robust contextual corroboration to be meaningful in court .[222] The judiciary must therefore exercise caution in weighing scientific inputs, distinguishing between reliable methodologies and those lacking sufficient validation.

A key framework for evaluating the admissibility of scientific evidence comes from the Daubert standard, established by the United States Supreme Court. Under this approach, judges act as gatekeepers, determining whether evidence is both relevant and reliable. The Daubert principles outline criteria such as whether the method is testable, whether it has undergone peer review, the known error rate, and the existence of standards controlling its application. Additionally, judges consider whether the scientific community generally accepts the methodology.

While not universally applied outside the U.S., these principles provide a valuable benchmark for ensuring that courts do not admit pseudo-scientific or

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220 S. DI PINTO, *La Prova Scientifica nel Processo Penale*, in *Rivista di Polizia*, 9-10, 2018, 909-910.

221 *Ibid*., 910-911.

222 *Ibid*., 911-912.

unverified methods.[223] In Italy, similar concerns have arisen, though the focus has been more on balancing innovation with traditional procedural safeguards. Methods like bloodstain pattern analysis (BPA) or voice recognition exemplify the need for such evaluations, as their utility depends on rigorous validation against these criteria.[224]

The adversarial nature of criminal trials adds another layer of complexity. While the prosecution might employ forensic experts to substantiate claims, the defense is equally entitled to contest findings through counter-experts. This dynamic often transforms scientific evidence into a battleground of conflicting interpretations. Concerns have been raised about equitable access to expert resources, as wealthier parties may have greater means to present their case effectively, potentially skewing outcomes.[225]

Judges, as gatekeepers of admissibility, play a pivotal role in determining the validity of scientific evidence. The Daubert standard offers a structured approach to this challenge, promoting uniformity in judicial reasoning when handling complex scientific inputs. However, as Luca Santa Maria observes, many judges lack adequate training in scientific methods, which can lead to inconsistent or flawed assessments.[226] For instance, methods like BPA or voice recognition, while useful, require rigorous scrutiny to ensure they meet the standards of reliability and relevance. Without proper expertise, judges may either over-rely on the perceived infallibility of science or dismiss critical evidence prematurely.

Italy has introduced procedural safeguards, such as the "incidente probatorio," which allows for the early acquisition of evidence under adversarial conditions to prevent its deterioration. While this mechanism has improved transparency and fairness, challenges persist in standardizing its application. [227] The use of frameworks

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223 A. CAPPELLINO, *The Daubert Standard, in Expert Institute*, May 9, 2024, https://www.expertinstitute.com/resources/insights/the-daubert-standard-a-guide-to-motions-hearings-and-rulings/; *Daubert sets standard for court's scientific method (Daubert v. Merrell Dow Pharmaceuticals, Inc.*, in American Bar Association, March 2, 2017, https://www.americanbar.org/groups/law_students/resources/on-demand/quimbee-daubert-v-merrell-dow-pharmaceuticals-inc/.

224 S. DI PINTO, 915-916.

225 *Ibid*., 913.

226 L. SANTA MARIA, *La Mia Idea di una Scienza del Diritto Penale*, in Diritto Penale Contemporaneo, March 26, 2018, https://archiviodpc.dirittopenaleuomo.org/d/5934-la-mia-idea-di-una-scienza-del-diritto-penale, 1-4.

227 S. DI PINTO, 914-915.

like Daubert could potentially enhance this system, offering more consistent criteria for evaluating innovative or untested scientific techniques.

The implications of these challenges extend beyond criminal law. The criminal justice system's handling of scientific evidence provides a valuable framework for other areas of litigation, including environmental and climate disputes. Both fields require courts to reconcile empirical data with normative legal principles, ensuring that scientific contributions enhance rather than undermine procedural fairness and substantive justice. In this regard, the Daubert principles could inspire similar standards in climate litigation, where courts often deal with complex attribution science. By adopting clear benchmarks for admissibility, courts could better balance scientific rigor with the demands of legal proof.

Fostering interdisciplinary dialogue between legal and scientific communities is essential to addressing these challenges. Adopting principles like Daubert across jurisdictions, while tailoring them to local legal contexts, could strengthen the integration of science into the judiciary. This would not only enhance procedural fairness but also ensure that courts are equipped to handle the complexities of modern disputes, from criminal cases to climate litigation. By promoting better understanding and cooperation, the legal system can improve its integration of scientific evidence, ensuring that it serves justice effectively in all its complexities.

3.2.3. Administrative courts

Science plays a crucial role in administrative proceedings, where technical and specialized knowledge often intersects with legal decision-making. The increasing complexity of contemporary administrative disputes necessitates integrating scientific data to address issues ranging from environmental regulations to public health policies. Administrative law frequently deals with decisions requiring scientific expertise, such as environmental impact assessments or public health regulations. Courts and administrative bodies must rely on scientific evidence to assess compliance with legal standards. This reliance underscores the importance of ensuring that the scientific

evidence presented is both reliable and relevant. In these contexts, the law acts as a framework for managing uncertainties and disputes related to scientific findings.

One of the most significant challenges in incorporating science into administrative proceedings is dealing with scientific uncertainty. As observed, science often produces probabilistic results rather than absolute truths, making it difficult to apply binary legal standards.[228] For example, debates over climate change policies often hinge on scientific models that predict future impacts with varying degrees of certainty. Another challenge is the selection and role of expert witnesses or technical consultants. Experts play a pivotal role in bridging the gap between scientific data and legal decision-making. However, issues such as potential bias, conflicts of interest, and varying interpretations of scientific data can undermine the credibility of expert testimony. Also administrative courts must navigate these complexities to ensure fair and informed decisions.

In cases involving significant scientific uncertainty, the precautionary principle often guides administrative decisions. This principle, widely applied in environmental law, allows for preventive action in the face of uncertain risks to public health or the environment. It shifts the burden of proof onto those proposing potentially harmful activities, emphasizing the importance of erring on the side of caution. While this approach aims to protect public interests, it can lead to disputes over the interpretation of scientific evidence and the proportionality of regulatory measures.[229]

Even in administrative proceedings judges face the challenge of evaluating complex scientific evidence without possessing specialized expertise. This necessitates a careful balance between deference to expert opinions and independent judicial scrutiny. The principle of "judicial deference" often applies, whereby courts give weight to the expertise of administrative agencies or appointed experts. However, this deference is not absolute, as courts retain the authority to assess whether scientific evidence has been applied appropriately and within legal boundaries.[230]

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228 A. BARONE, *La Scienza "incerta" Davanti al Giudice Amministrativo*, in *Diritto e Processo Amministrativo*, 2-3, 2015, 8-10.

229 *Ibid*., 10-12.

230 *Ibid*., 13-15.

Several notable cases illustrate the interaction between science and administrative law. For instance, disputes over industrial pollution or the licensing of genetically modified organisms often require courts to evaluate extensive scientific data.[231] These cases highlight the importance of transparent and rigorous methodologies in presenting scientific evidence. Additionally, they underscore the need for courts to remain vigilant against the misuse of scientific data to justify arbitrary or discriminatory decisions.

However, integrating science into administrative law raises important ethical questions. The reliance on scientific evidence must align with principles of fairness, transparency, and accountability.[232] Ensuring that all parties have access to relevant scientific data and the opportunity to challenge its validity is crucial for maintaining public trust in administrative processes. Moreover, ethical considerations extend to the selection and conduct of expert witnesses, who must adhere to standards of impartiality and objectivity.

The interplay between science and administrative proceedings is both complex and essential. As administrative bodies increasingly confront issues requiring scientific expertise, they must navigate challenges of uncertainty, ethical considerations, and the potential for conflicting interpretations of data. By fostering a robust framework for the integration of science, administrative law can enhance its capacity to address the multifaceted issues of modern governance. Ultimately, the effective use of science in administrative proceedings can contribute to more informed and equitable decision-making processes.

3.3. *How Italian Courts' Approach to Scientific Evidence Shapes Tomorrow's Legal Battles in Climate Litigation*

The way Italian courts handle scientific evidence holds profound implications for the future of climate litigation in the country. As climate-related disputes continue

231 *Ibid*., 14-16.
232 *Ibid*., 17-18.

to grow in volume and complexity, the judiciary's capacity to engage effectively with scientific data will determine not only the outcomes of individual cases but also the broader trajectory of Italy's climate governance. Italian courts, by their very nature, act as the arbiters of disputes within a framework defined by legal principles. However, climate litigation often demands a multidisciplinary approach, intertwining legal reasoning with the nuanced realities of climate science. The judiciary's ability to bridge these domains will be critical in fostering an environment where science can complement legal norms without overshadowing them.

In particular, the unique challenges posed by climate science – from its reliance on probabilistic models to its inherent uncertainties – require a judiciary equipped to discern robust evidence from speculative claims. This necessitates enhanced judicial education on climate-related issues and the development of specialized expertise within the legal profession. Courts must evolve into forums capable of integrating complex scientific narratives into their reasoning processes, ensuring that legal determinations align with the best available knowledge while adhering to principles of fairness and justice. The reliance on technical expertise –especially through CTUs – will likely play a pivotal role in climate litigation. However, as highlighted in prior sections, the selection, scope, and evaluation of expert testimony remain contentious issues. In the context of climate disputes, these challenges are magnified by the interdisciplinary nature of the science involved and the potential for bias in expert selection.

To address these concerns, Italian courts must establish rigorous standards for the appointment and evaluation of CTUs in climate cases. This includes ensuring transparency in the selection process, promoting diversity of expertise, and instituting mechanisms for peer review of expert submissions. By doing so, courts can enhance the credibility of scientific testimony and mitigate the risk of undue influence by vested interests.

One of the most promising outcomes of integrating climate science into legal processes is its potential to catalyze the evolution of jurisprudence. Climate litigation inherently challenges traditional legal doctrines, particularly those concerning causation, liability, and remedies. For instance, the science of attribution – which links specific events or harms to anthropogenic climate change – has already begun to

reshape the contours of causation in tort law. Similarly, emerging legal principles such as the "precautionary principle" and the "principle of intergenerational equity" may gain renewed significance as courts grapple with the long-term implications of climate harm.

Italian courts, by engaging proactively with these developments, can position themselves at the forefront of global efforts to adapt legal frameworks to the realities of climate change. This requires a willingness to experiment with novel legal doctrines, embrace comparative jurisprudence, and participate in international dialogues on climate governance. The integration of science into climate litigation also raises fundamental questions about the judiciary's role in a democratic society. Critics often argue that courts, by adjudicating climate disputes, risk encroaching on the domains of the executive and legislative branches. This tension underscores the need for judicial restraint and a clear articulation of the judiciary's mandate in addressing climate-related issues.

At the same time, courts have a unique opportunity to act as catalysts for governmental accountability and as safeguards against policy inaction. By grounding their decisions in sound scientific evidence, Italian courts can reinforce the legitimacy of their rulings while promoting more informed and effective climate policies. This balance between judicial activism and deference will be crucial in shaping the future of climate governance in Italy. The manner in which Italian courts engage with climate science will also have broader implications for international climate litigation. As a country deeply affected by climate impacts yet committed to ambitious mitigation and adaptation goals, Italy occupies a strategic position in global climate governance. Italian jurisprudence has the potential to influence the development of legal norms beyond its borders, particularly within the European Union and other jurisdictions that share similar legal traditions.

By establishing a robust framework for the integration of science into climate litigation, Italian courts can contribute to the harmonization of legal standards on a global scale. This includes fostering greater consistency in the evaluation of scientific evidence, promoting the recognition of climate-related rights, and advancing the development of transnational legal principles. To realize these opportunities, several practical steps can be taken: developing specialized training programs for judges and

legal practitioners on climate science and its implications for legal reasoning, establishing dedicated climate divisions within courts or creating specialized tribunals to handle complex climate disputes, strengthening partnerships between the judiciary and scientific organizations to enhance access to reliable and impartial expertise, promoting greater transparency and public participation in climate litigation processes to build trust and legitimacy, and engaging in cross-border exchanges of best practices and collaborating on the development of international legal standards for climate governance.

The intersection of law and science in Italian courts represents a critical frontier in the fight against climate change. By embracing this challenge, the judiciary has the potential to not only resolve individual disputes but also shape the broader legal and policy landscape in ways that advance climate justice. As climate litigation continues to evolve, the Italian judiciary's approach to scientific evidence will serve as both a test case and a beacon for other jurisdictions navigating similar challenges. Ultimately, the integration of science into legal processes is not merely a technical exercise but a profound ethical commitment to safeguarding the rights and interests of present and future generations. By rising to this challenge, Italian courts can affirm their role as pivotal actors in the global quest for a more sustainable and equitable future.

4. Conclusions

Across the ICJ, the ECtHR, and Italian courts, the role of scientific experts emerge as a crucial – yet deeply ambivalent – feature of climate litigation. On the one hand, the highly technical nature of climate science renders expert input indispensable: judges must rely on climatologists, hydrologists, and other specialists to interpret data, model projections, and substantiate claims about risk and harm. On the other hand, this reliance generates a structural tension between epistemic authority and judicial independence. The ICJ's jurisprudence illustrates this ambivalence with particular clarity. In cases such as *Pulp Mills*, the Court's dependence on party-appointed experts produced adversarial fragmentation, leaving judges to arbitrate between incompatible claims without recourse to a neutral evidentiary baseline. The Court's refusal to invoke

Article 50 of its Statute to appoint independent experts – paired with the opaque practice of relying on so-called "phantom experts" during deliberations – undermined procedural transparency and exposed a broader unease: if scientific knowledge becomes decisive but unchallengeable, the judicial process risks losing both legitimacy and coherence.

This predicament is not unique to the ICJ. Italian civil courts also heavily rely on CTUs, whose selection, scope of inquiry, and evaluative methods are only loosely standardized. While these experts can serve as valuable mediators between science and law, their authority is often determinative, raising concerns about the effective delegation of adjudicative functions. The principle of "scientific reserve" in Italian law aims to preserve judicial discretion while ensuring that legal decisions rest on solid scientific foundations. Yet, this balance remains delicate. If judges rely uncritically on technical expertise, they risk becoming passive arbiters of information they cannot meaningfully interrogate. If, conversely, they dismiss expert evidence out of caution or unfamiliarity, they may fail to account for the very knowledge that renders climate disputes legally cognizable in the first place.

The ECtHR presents a different configuration. Lacking live testimony and operating primarily through written submissions, the Court is shielded from direct contestation of expert claims but exposed to the epistemic opacity of relying on documents whose assumptions and methodologies often remain implicit. The Court's reliance on IPCC reports and similar sources gives it access to authoritative science, but the absence of procedural mechanisms to clarify or contextualize those findings can lead to uneven or overly cautious judicial engagement.

The question of causation compounds these difficulties. Climate change challenges the foundational legal assumption that responsibility arises from identifiable, linear chains of cause and effect. Instead, causation in climate cases is probabilistic, collective, and temporally dispersed. Attribution science – capable of estimating the increased probability or severity of specific weather events due to anthropogenic emissions – can now provide quantifiable insights into the contribution of human activity to climate-related harm. However, this knowledge resists integration into traditional legal frameworks, which often require conclusive demonstration of a direct causal link between conduct and injury. The ICJ, despite its recent procedural

innovations, has not yet resolved whether probabilistic causation suffices to establish international responsibility. In its past practice, the Court has tended to emphasize empirical certainty, reinforcing the impression that cutting-edge scientific insights may still fall short of the evidentiary threshold for legal liability.

The ECtHR faces an even more acute tension. In climate litigation before the Court, applicants bear a dual burden: they must demonstrate that state inaction or insufficient policy contributed to the global climate crisis, and that this contribution materially infringed upon their specific Convention rights. This cumulative burden is particularly onerous when the harm stems from multiple jurisdictions, diffuse emissions, and indirect policy choices. While the Court has occasionally relaxed its evidentiary requirements through inferential reasoning or burden-shifting, the standard of proof remains nominally tied to the "beyond reasonable doubt" formula – an evidentiary legacy arguably ill-suited to the nature of climate science.

Italian courts, too, have struggled with this challenge. In *Giudizio Universale*, the Tribunal of Rome avoided the substantive question of causal attribution by invoking jurisdictional constraints. Yet the 2025 Sezioni Unite ruling has shifted the terms of the debate: questions of causation are no longer excluded from judicial scrutiny on jurisdictional grounds, but explicitly left to the merits stage, where they must be addressed through the evaluation of scientific evidence.

The interaction between expert evidence and causation is far from incidental. Procedurally, the difficulty of establishing causal chains in climate cases increases the importance of how scientific expertise is introduced, examined, and weighed. Substantively, the uncertainties of climate science press against the rigidity of legal norms concerning liability and proof. These two axes of tension –epistemic and normative – are mutually reinforcing: unclear causation heightens dependence on experts, and heavy reliance on expert opinion raises concerns about the fairness and intelligibility of judicial decisions. The ICJ's experiment with "hot-tubbing" in the *Silala* case, which encouraged dialogue and convergence among party-appointed experts, signals one possible path forward. By clarifying areas of agreement and identifying genuine points of contention, such procedures can enhance the Court's ability to navigate complex technical debates without relinquishing control over fact-finding. The ECtHR, lacking similar procedural tools, has tended to rely on

documentary evidence and institutional reports, which can obscure rather than illuminate causal analysis. Italian civil courts, equipped with the CTU model, have a more flexible mechanism at their disposal, but without clearer standards for the selection, independence, and oversight of experts, this advantage remains underutilized.

Critically, the substantive legal standards governing causation remain largely unadjusted to the demands of climate litigation. Courts across jurisdictions have been hesitant to reframe causality in terms of risk contribution, material increase in harm, or collective responsibility. The reluctance is understandable: modifying core doctrines could open the door to legal uncertainty or perceived judicial activism. Yet a rigid adherence to binary, deterministic notions of causation risks rendering courts irrelevant in the face of scientifically demonstrable, yet legally intangible, harm. Some precedents – such as the Dutch *Urgenda* ruling –have shown greater doctrinal creativity, grounding state obligations in the precautionary principle and drawing directly on scientific consensus regarding thresholds of dangerous interference. These examples suggest that causation in climate law need not hinge solely on the backward-looking identification of discrete injury, but can be grounded in forward-looking duties of care, based on foreseeable risk and normative responsibility.

The implications of these developments extend beyond procedural design or doctrinal refinement. At stake is the status of scientific knowledge in legal reasoning and the evolving role of courts in confronting systemic, globalized harm. If legal institutions treat scientific uncertainty as a disqualifying condition for adjudication, they risk abdicating their function as guarantors of rights and obligations in an age where many harms are inherently uncertain yet deeply foreseeable. Conversely, if courts delegate too much authority to scientific expertise – treating it as dispositive rather than informative – they risk eroding their own normative legitimacy and unsettling the balance between technocracy and democratic accountability. The challenge, then, is to structure legal processes and doctrines in ways that respect both the limits of judicial expertise and the epistemic strengths of science.

This balance requires reform on multiple fronts. Procedurally, courts should institutionalize mechanisms that foster transparency, critical engagement, and epistemic pluralism. These might include court-appointed interdisciplinary panels,

standardized criteria for expert admissibility, and burden-shifting devices that reflect the asymmetric access to scientific resources between plaintiffs and states. Substantively, the integration of principles such as proportional causation, intergenerational equity, and the precautionary principle can help adapt legal reasoning to the realities of collective and long-term climate harm. Italian law's evolving notion of "scientific reserve," reinforced by the Sezioni Unite in 2025, the ECtHR's recent emphasis on carbon budgeting and science-based benchmarks in *KlimaSeniorinnen*, and the ICJ's 2025 advisory opinion clarifying states' binding obligations to act on the basis of the best available science all reflect embryonic but meaningful shifts in this direction.

Ultimately, the integration of scientific expertise and probabilistic causation into climate litigation is not a technical problem but a constitutional one. It goes to the heart of how courts understand their mandate in a context where rights, risks, and responsibilities are distributed across generations, borders, and disciplines. The ICJ, the ECtHR, and Italian courts each offer a partial but instructive response to this challenge. With the 2025 ENI ruling, Italian jurisprudence has now joined the international trend, affirming that climate harms can be litigated as civil wrongs and that scientific knowledge provides not only evidentiary support but also normative standards for liability. If these tensions are confronted rather than avoided – through innovation, reflexivity, and principled engagement – the law may yet prove capable of adjudicating the complex, uncertain, and urgent claims of the climate crisis. If not, it may find itself increasingly sidelined in the very struggles where its authority is most needed.

THIRD CHAPTER

NAVIGATING EPISTEMOLOGICAL TENSIONS: EXPERTS, CAUSATION, AND THE WAY FORWARD

Towards Reconciliation of Scientific and Legal Reasoning

In the previous chapters, this dissertation has explored the interaction between science and law in the context of strategic climate litigation, addressing both its legal foundation and its practical implications. Chapter 1 examined the legal basis that allows scientific knowledge – particularly climate science – to be integrated into the formulation of laws and policies. This analysis highlighted that while such integration is essential to ensuring that legislative and regulatory frameworks reflect the best available scientific knowledge, it also raises concerns regarding democratic legitimacy. The reliance on expert knowledge in decision-making processes may, in some cases, limit public participation and shift authority away from democratically elected institutions toward technical experts. This tension underscores the need to carefully balance scientific input with democratic principles to maintain both effective governance and legitimacy.

Chapter 2 moved from a theoretical perspective to a comparative analysis of case law on strategic climate litigation. This investigation examined how courts at different levels – international, European, and national – engage with scientific evidence in climate disputes. The analysis revealed varying judicial approaches to handling scientific data and illuminated the challenges judges face in doing so. While courts increasingly recognize the relevance of climate science in adjudicating environmental and human rights claims, they often struggle with issues related to the interpretation, evaluation, and application of complex scientific findings within legal

reasoning. These difficulties arise from the intrinsic differences between legal and scientific methodologies: whereas law seeks definitive conclusions and clear lines of accountability, science operates within a paradigm of probabilistic reasoning and continuous refinement of knowledge.

From this analysis, two overarching issues appear particularly significant in the context of strategic climate litigation. The first concerns the role of experts in judicial proceedings. Courts often rely on expert testimony to interpret climate data and establish key facts in litigation. However, the selection, credibility, and influence of these experts raise questions about impartiality, epistemic authority, and procedural fairness. In some cases, conflicting expert opinions complicate judicial decision-making, leading to concerns about the objectivity of adjudication and the risk of 'dueling experts.' Furthermore, procedural approaches to expert testimony vary across jurisdictions, affecting how courts weigh and manage scientific input. A critical aspect of this issue is the extent to which judges are equipped with the necessary scientific literacy to evaluate expert opinions effectively, which may necessitate specialized training or advisory mechanisms within judicial structures.

The second critical issue relates to the establishment of causation. Climate litigation frequently hinges on proving a causal link between specific greenhouse gas emissions and particular climate-related harms. However, establishing such a connection poses significant legal and evidentiary challenges. Climate attribution science, which seeks to quantify the contribution of human activities to specific climatic events, has advanced considerably in recent years. Nonetheless, its probabilistic nature does not always align with the strict standards of proof required in legal proceedings. Courts must grapple with how to translate complex scientific models into legally actionable claims, particularly in cases where multiple actors contribute to climate change in a diffuse and cumulative manner. Judicial strategies for addressing causal uncertainty include adapting evidentiary standards, recognizing systemic causation, and applying principles like the precautionary approach. These approaches reflect an evolving understanding of the relationship between science and legal liability, demonstrating a shift towards more flexible frameworks that acknowledge the intricacies of climate attribution.

This chapter will focus on these two major issues – expert involvement and causal reasoning – and explore their interconnected nature. The first section will examine the role of experts in climate litigation, assessing the necessity of expert testimony, the challenges associated with its use, and judicial approaches to managing expert evidence. The second section will address the difficulties of establishing causation, analyzing the legal and scientific obstacles and considering how courts have sought to mitigate evidentiary challenges. The final section will explore the interplay between expert testimony and causation, offering recommendations for enhancing fairness and effectiveness in climate litigation. Among the solutions considered will be institutional reforms, such as the establishment of scientific advisory bodies for courts, and procedural innovations aimed at improving expert selection and testimony, including pre-trial expert conferencing and mechanisms to ensure greater transparency in expert contributions. Furthermore, this chapter will discuss the potential benefits of interdisciplinary collaboration between legal and scientific communities to bridge knowledge gaps and foster a more coherent approach to integrating scientific evidence into legal proceedings.

By tackling these questions, this chapter aims to contribute to the broader discussion on how courts can navigate the intersection of science and law in a way that is both legally sound and scientifically informed. Through a critical examination of expert testimony and causal reasoning, this analysis will offer insights into how climate litigation can evolve to better incorporate scientific advancements while maintaining legal certainty and procedural fairness. Ultimately, the goal is to outline pathways that enable courts to more effectively address the complexities of climate science within legal frameworks, ensuring that litigation serves as a meaningful tool for climate accountability and justice.

1. The Role of Experts in Climate Litigation

1.1 The Need for Expert Testimony in Climate Cases

As discussed in the previous chapters, integrating scientific evidence into legal arguments is a fundamental aspect of climate litigation, influencing how courts assess liability, causation, and state obligations. Yet, courts often struggle with the complexities of climate science, particularly when dealing with issues of attribution, environmental impact assessment, and policy effectiveness. This challenge highlights the crucial role of expert testimony, which serves as a bridge between the scientific and legal domains, providing courts with the necessary tools to interpret and apply climate science in judicial decision-making.[233]

Unlike general scientific reports such as those published by the IPCC, expert testimony is tailored to the specific context of each case, offering targeted analyses and interpretations that can shape the outcome of litigation. The growing reliance on expert witnesses in climate cases raises important questions: why do courts increasingly depend on expert testimony? How does it complement broader scientific assessments like IPCC reports? What impact does expert testimony have on strategic climate litigation? This paragraph explores these issues, illustrating the significance of experts through case law and analyzing how their role was particularly evident in the 2024 judgment of the European Court of Human Rights *Verein KlimaSeniorinnen Schweiz v. Switzerland*.[234]

Courts rely on expert testimony in climate litigation for multiple reasons. First and foremost, climate science is inherently complex, involving a multitude of factors that contribute to environmental changes over long periods.[235] Judges, who often lack technical expertise in climate modeling, atmospheric physics, or carbon budget

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[233] E.A. SCULLEN, *A Guide to Expert Testimony for Climate Scientists*, in *Mitchell Hamline School of Law*, July 2013, https://mitchellhamline.edu/wp-content/uploads/sites/44/2013/07/A-Guide-to-Expert-Testimony-for-Scientists-DRAFT.pdf, 26-27, 29-32; L. CLARK, *Climate Litigation Boosted by IPCC Report*, in *Scientific American*, April 12, 2022, https://www.scientificamerican.com/article/climate-litigation-boosted-by-ipcc-report/#:~:text=The%20report%20says%20that%20since,and%20ambitiousness%20of%20climate%20governance."; L.D. MERNER, *How the Latest IPCC Reports Can Strengthen Climate Litigation Efforts*, in The Equation: Union of Concern Scientists, April 18, 2022, https://blog.ucsusa.org/delta-merner/how-the-latest-ipcc-reports-can-strengthen-climate-litigation-efforts/, 4-5.

[234] E. HANIS, *The Art of Persuasive Expert Testimony in Environmental Law*, April 9, 2024, https://hanisconsulting.com/expert-witness-testimony-environmental-litigation-strategies/, 4-6; A.H. JAMALI, *The Value of IPCC Reports in Shaping Climate Change Jurisprudence*, in *Climate and Human Rights Litigation Database*, June 11, 2024, https://climaterightsdatabase.com/2024/06/11/the-value-of-ipcc-reports-in-shaping-climate-change-jurisprudence/, 2-3, 5.

[235] See *above*, Chapter I, [2].

calculations, depend on experts to clarify how human activities – such as fossil fuel emissions – translate into tangible environmental harm.[236] Expert testimony helps courts navigate these complexities by breaking down scientific data into accessible, legally relevant arguments. More importantly, experts play a central role in establishing causal links, a key challenge in climate litigation. Unlike conventional environmental damage cases, where direct causation is easier to prove, climate litigation often relies on probabilistic science, particularly in cases involving extreme weather events. Attribution studies, for instance, assess the likelihood that a given event – such as a devastating flood or prolonged heatwave – was made more severe by anthropogenic emissions. Courts are gradually recognizing the validity of these scientific methods, but without expert witnesses, translating these findings into legally convincing arguments would be significantly harder.

Another critical function of expert testimony is to provide courts with a case-specific application of general scientific principles. This is where the relationship between expert witnesses and IPCC reports becomes particularly relevant. While IPCC reports are widely regarded as the gold standard for climate science, they are not designed to address the evidentiary needs of litigation. The IPCC synthesizes global climate data, assessing long-term trends, potential risks, and mitigation strategies. These reports provide essential scientific consensus but lack the specificity required in court cases. Expert witnesses bridge this gap by interpreting IPCC findings in the context of individual claims, applying global climate models to local circumstances and helping courts assess the proportional responsibility of defendants.[237] This interplay between expert testimony and IPCC reports strengthens the evidentiary foundation of climate litigation, reinforcing claims while maintaining scientific rigor.

One of the most significant examples of the increasing reliance on expert testimony in climate law is the *Verein KlimaSeniorinnen Schweiz* case before the European Court of Human Rights. The case marked a milestone in climate litigation, as the Court concluded that Switzerland had failed to fulfill its positive obligations

236 E.A. SCULLEN, 27-28; E. HANIS, 3-4, 6; L.D. MERNER, 7-8; L. CLARK.
237 A.H. JAMALI, 2-3, 5; L. CLARK; L.D. MERNER, 6-7.

under Article 8 of the European Convention on Human Rights, which encompasses a right to effective protection against the serious adverse effects of climate change.[238]

A crucial aspect of the ruling was the Court's reliance on scientific evidence to assess the adequacy of Swiss climate policies. As noted in Chapter 2, the ECtHR does not operate under a rigid evidentiary regime comparable to national courts but adopts a flexible approach that often privileges reports from authoritative international bodies, particularly the IPCC, complemented by submissions from the parties and experts included within state delegations. In *KlimaSeniorinnen*, the Court primarily drew upon the IPCC's assessments to establish the scientific consensus on climate change and the insufficiency of Switzerland's mitigation measures.[239] At the same time, it also engaged with case-specific expert evidence introduced by the applicants and the State, which provided further insight into how climate change disproportionately affects older populations and reinforced the claim that inadequate mitigation efforts infringe upon human rights.[240]

The decision illustrates how the ECtHR is adapting its evidentiary standards to the scientific complexity of climate cases. By integrating authoritative scientific reports with targeted expert input, the Court moved beyond traditional doctrines of causation and embraced probabilistic approaches grounded in climate science. This method allowed it to conclude that Switzerland's climate policies were insufficient to meet international temperature targets and posed a foreseeable risk to human health, particularly for vulnerable groups such as elderly women.[241]

While expert testimony has become an essential tool in climate litigation, its use is not without challenges. Courts must carefully assess the credibility and impartiality of experts, particularly when parties present conflicting testimonies. The adversarial nature of litigation can sometimes lead to "scientific shopping," where litigants select experts who align with their legal strategy rather than those who provide the most accurate scientific assessment. Additionally, the probabilistic nature of climate science does not always align with the legal system's preference for

238 *Case of Verein Klimaseniorinnen Schweiz and Others v. Switzerland*, [202-211].
239 *Ibid*., [107-120].
240 *Ibid*., [377, 378, 382-383, 386, 394, 402].
241 *Ibid*., [392-393, 397, 399, 404-406].

deterministic causation, creating a gap between scientific findings and judicial expectations. Nonetheless, as seen in recent cases, courts are gradually adapting their evidentiary standards to accommodate scientific complexities, recognizing that uncertainty does not equate to unreliability.[242]

The *KlimaSeniorinnen* case exemplifies this trend: expert testimony was instrumental in shaping the Court's reasoning, not only in assessing Switzerland's obligations but also in clarifying the broader implications of climate inaction on human rights. The ruling underscores the evolving role of climate science in judicial reasoning, demonstrating that courts increasingly view scientific expertise as a fundamental component of legal argumentation rather than merely an evidentiary tool. As climate-related litigation continues to expand, expert testimony will remain central to shaping judicial approaches to environmental accountability. However, this growing reliance on experts also raises important questions about how courts should evaluate scientific evidence, ensuring that testimony is not only admissible but also effectively utilized in shaping legal outcomes.

1.2 *Challenges Associated with Expert Testimony*

Climate litigation increasingly relies on expert testimony to resolve complex scientific disputes. However, the appointment of experts – whether by the parties or the courts – presents significant challenges that affect the fairness and reliability of judicial decisions.

1.2.1 *Party-appointed experts*

Party-appointed experts, while essential in providing technical insights, are often selected strategically to align with the interests of the litigating party, raising concerns about bias. Experts chosen by parties may present findings that support their

[242] E. HANIS, 4-6; E.A. SCULLEN, 26, 31-32; L. CLARK.

client's position rather than an objective interpretation of the scientific data. This selection process can lead to confirmation bias, where experts selectively emphasize aspects of the evidence that bolster their client's legal arguments, undermining the objectivity of the litigation process.[243]

Another issue relates to the admissibility and reliability of expert testimony. While some jurisdictions apply rigorous standards, such as the Daubert test in the United States, which requires expert testimony to be based on peer-reviewed research with a known error rate, international courts such as the ICJ and ECHR do not follow comparable strict evidentiary standards.[244] This lack of uniformity makes it easier for litigants to introduce expert opinions that may not meet the highest scientific rigor. The reliability of climate models, for instance, has been a recurring point of contention in climate litigation. As seen in the first chapter, these models, though widely accepted in scientific circles, contain elements of uncertainty that can be exploited by opposing parties to challenge their admissibility, particularly in courts unfamiliar with their methodological limitations.[245]

The presentation of contradictory expert testimonies further complicates climate litigation. When both parties submit expert reports that offer conflicting conclusions, judges – who often lack the technical expertise to evaluate the scientific basis of each claim – may struggle to determine which evidence is more credible. This can lead to judicial hesitation, where courts avoid making definitive rulings on scientific issues due to the uncertainty created by opposing expert opinions.[246] In international litigation, where courts rely heavily on party-appointed experts, this issue is even more pronounced, as judges are left to navigate competing claims without established procedures for reconciling scientific disagreements.

An additional challenge is the disparity in resources available to the litigating parties. Wealthier parties, such as states or multinational corporations, can afford to

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243 M.M. MBENGUE, R. DAS, *Experts*, in *Max Planck Encyclopedias of International Law*, April 2022, 8-12.

244 S. CHEN, *Re-assessing the evidentiary regime of the International Court of Re-assessing the evidentiary regime of the International Court of Justice: A case for codifying its discretion to exclude evidence*, in *International Commentary on Evidence*, 13(1), 2015, 1-40; M.B. DEMBOUR, 363-374.

245 A. HASANI, *Forecasting the End of Climate Change Litigation: Why Expert Testimony Based on Climate Models Should Not Be Admissible*, in *Law School Student Scholarship*, 108, 2012, 18-19, 24-25, 26, 31-32.

246 M.M. MBENGUE, R. DAS, 12-13, 30-32.

hire multiple well-credentialed experts, while less financially equipped plaintiffs – such as NGOs or individuals – may struggle to secure comparable expertise. This imbalance can result in an uneven playing field, where the party with greater financial resources has an inherent advantage in shaping the scientific narrative of the case.[247] Strategic litigation tactics, such as introducing expert testimony primarily to delay proceedings or create uncertainty, further exacerbate this disparity and can obstruct the efficient resolution of climate disputes.[248]

1.2.2 *Court-appointed experts*

Court-appointed experts, intended to provide neutral scientific guidance, face their own set of challenges. The selection process for such experts varies widely across different legal systems, leading to inconsistencies in qualifications and expertise. In many jurisdictions, there are no standardized criteria for selecting experts in climate litigation, which means that courts may appoint professionals without sufficient experience in climate science. In Italy, for example, while courts maintain official lists of accredited experts, these lists may not always include specialists in climate science, leading to concerns about whether the appointed experts are truly qualified to assess complex environmental claims. At the ICJ, where the Court has full discretion in selecting experts, the absence of a permanent roster of accredited specialists has historically resulted in inconsistency in the integration of scientific expertise into judicial decision-making.[249]

Even when court-appointed experts are selected, their independence is not always guaranteed. Experts may have prior affiliations with governments, industries, or advocacy groups, raising concerns about their neutrality in high-stakes litigation. In cases before the ECHR, for instance, expert reports have sometimes closely aligned

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247 A. HASANI, 30-31; R. HACKNEY, *Flipping Daubert: Putting Climate Change Defendants in The Hot Seat*, in *Environmental Law*, 40, 2010, 293.

248 *Ibid*.

249 M.M. MBENGUE, R. DAS, 13-15; EUROPEAN COMMISSION FOR THE EFFICIENCY OF JUSTICE, *Guidelines on the role of court-appointed experts in judicial proceedings of Council of Europe's Member States*, 2014, [3.2, 3.2.1, 3.2.2]; J. DEVANEY, *Reappraising the Role of Experts in Recent Cases Before the International Court of Justice*, in *German Yearbook of International Law*, 62, 2019.

with government positions, leading to questions about whether their findings genuinely reflect independent scientific assessments.[250] Given the political and economic implications of climate litigation, ensuring that court-appointed experts remain free from external influence is essential for maintaining judicial credibility.

The effectiveness of court-appointed experts depends largely on how their findings are interpreted by judges. While some courts require judges to justify any decision that contradicts an expert report, others allow judicial discretion in disregarding expert conclusions without detailed reasoning. This raises concerns, particularly in climate litigation, where judges may lack the technical background to fully understand the implications of scientific findings.[251] In some cases, courts have resorted to informal consultations with experts outside the official judicial process, a practice known as the "phantom expert" phenomenon, previously discussed in relation to the ICJ. While this may help judges clarify complex issues, it raises transparency and due process concerns, as parties are often unaware of these consultations and cannot challenge the resulting opinions.[252]

Climate models, frequently used as evidence in climate litigation, pose additional challenges in expert testimony. As discussed in the first chapter, these models, despite their scientific legitimacy, involve probabilistic forecasts that opponents may argue lack the certainty required for legal adjudication. Courts that are unfamiliar with the methodologies behind climate modeling may either overestimate their predictive power or dismiss them outright as unreliable.[253] This issue underscores

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250 EUROPEAN COMMISSION FOR THE EFFICIENCY OF JUSTICE, [5.1.2]; M.M. MBENGUE, R. DAS, 18.

251 M.M. MBENGUE, R. DAS, 22-23, 29-30; A. HASANI, 30-31.

252 As discussed in Chapter 2, the ICJ has long been reluctant to appoint its own experts, relying instead on party-appointed ones or even resorting to "phantom experts," a practice criticized for its lack of transparency. Recent developments, however, such as the use of joint expert reports and hot-tubbing procedures in the *Silala* case, signal a growing awareness within the Court of the need to manage scientific complexity more systematically. Scholarly debate reflects this evolution: while Mbengue (M.M. MBENGUE, R. DAS, 13-15; EUROPEAN COMMISSION FOR THE EFFICIENCY OF JUSTICE, [3.2, 3.2.1, 3.2.2]) has emphasized the structural weaknesses of the Court's approach, Devaney has extensively analyzed the ICJ's fact-finding practices, highlighting both the potential and the persistent shortcomings of its engagement with experts, such as the lack of conceptual clarity over their role, the opaque reliance on experts *fantômes*, and the difficulties surrounding cross-examination. In response, he has advanced proposals for reform in the form of two Practice Directions intended to clarify the modalities of expert evidence and to reconcile the competing principles of party autonomy and the proper administration of justice (J. DEVANEY, 2019).

253 A. HASANI, 29-32.

the need for greater judicial education on scientific methodologies to ensure that courts can properly evaluate expert testimony in climate-related disputes.

Building on the analysis conducted in the previous chapter regarding how the ICJ, the ECHR, and Italian courts manage scientific evidence and the role of experts, the challenges surrounding expert involvement in climate litigation become even more evident. These challenges are particularly pronounced in the context of strategic climate litigation, where scientific complexity intersects with legal uncertainty, making expert testimony not just an accessory but often a decisive element in determining outcomes.

The differences in how international and national courts approach expert evidence highlight the fragmented and inconsistent framework governing the use of scientific expertise in litigation. At the ICJ, the court's reluctance to appoint its own experts and its reliance on party-appointed testimonies often result in conflicting scientific narratives, leaving judges to navigate competing claims without sufficient technical guidance. Similarly, the ECHR tends to rely heavily on state-provided scientific data, raising concerns about the impartiality of such evidence, especially in cases where government policies are under scrutiny. In the Italian context, while CTUs play a significant role, their opinions remain advisory and can be disregarded by judges without detailed justification, further complicating the effective integration of scientific findings into judicial reasoning.[254]

These systemic weaknesses are particularly problematic in climate litigation, where the attribution of specific environmental harms to human activities relies heavily on advanced climate modeling and probabilistic assessments. Without clear standards for expert selection, evaluation, and cross-examination, courts risk either overvaluing or underestimating expert contributions, undermining the integrity of the judicial process. Moreover, as discussed in the previous chapter, the use of informal consultations, such as the "phantom expert" phenomenon observed in ICJ proceedings, raises serious concerns about transparency and due process.

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[254] M.M. MBENGUE, R. DAS, 13-14, 18; EUROPEAN COMMISSION FOR THE EFFICIENCY OF JUSTICE, [8.1, 8.2].

Ultimately, the challenges faced by both party-appointed and court-appointed experts underscore the urgent need for procedural reforms. Standardized selection criteria, enhanced transparency in expert consultations, and judicial training in evaluating scientific methodologies are essential to ensure that expert testimony remains credible, impartial, and effectively utilized. Given the increasing reliance on scientific evidence in strategic climate litigation, addressing these issues is critical to maintaining the legitimacy and efficacy of judicial outcomes in this complex and evolving field. These possible solutions, aimed at enhancing the credibility and efficiency of expert involvement, will be examined in detail in the following section.

1.3 *Enhancing the Role of Experts in Climate Litigation by Promoting Impartiality, Transparency, and Reform Proposals*

One potential avenue to address the challenges associated with the appointment of experts in strategic climate litigation might involve the adoption of mechanisms aimed at ensuring greater transparency and accountability. The creation of public registers of qualified experts, as suggested by the CEPEJ guidelines and already implemented in some European jurisdictions, could represent a first step towards ensuring an impartial selection process.[255] By establishing clear criteria for inclusion in these registers, such as professional qualifications, peer recognition, and adherence to established scientific standards, courts could rely on a pre-vetted pool of experts, reducing concerns over partisan influence. Regular evaluations and updates to these registers could further strengthen their credibility and ensure that only experts with relevant expertise and demonstrated impartiality are included.[256]

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[255] EUROPEAN COMMISSION FOR THE EFFICIENCY OF JUSTICE, [3]; EUROPEAN PARLIAMENT DIRECTORATE-GENERAL FOR INTERNAL POLICIES, *Civil-Law Expert Reports in the EU: national rules and practices*, 2015, https://www.europarl.europa.eu/RegData/etudes/IDAN/2015/519211/IPOL_IDA(2015)519211_EN.pdf; see also the European e-Justice Portal – Find an Expert, which provides information on national registers of experts in various European countries, https://e-justice.europa.eu/37146/EN/find_an_expert.

[256] *Ibid*.

Such registers could serve as a tool for courts to select experts in a more structured and transparent manner. Instead of relying solely on party-appointed experts, which may lead to conflicting assessments driven by litigation strategies, courts could draw from publicly available lists of accredited professionals. This approach has been adopted in several European jurisdictions, where judicial authorities maintain official lists of court-approved experts.[257] These registers help to standardize the selection process and provide judges with a reliable mechanism for identifying individuals with the necessary technical expertise while maintaining procedural fairness. Moreover, requiring experts to disclose any potential conflicts of interest before being appointed could further enhance trust in their neutrality.

To further enhance adversarial fairness, some jurisdictions have experimented with procedures such as "hot-tubbing," where experts for both parties testify together, discussing their findings in real-time under judicial supervision.[258] This approach not only facilitates dialogue but also helps to clarify points of convergence and divergence, making the court's task of weighing expert evidence more transparent and manageable. Nevertheless, the success of such initiatives depends on the willingness of both parties to engage constructively and on the court's capacity to navigate complex scientific discussions without favoring one side.

Hot-tubbing has been particularly effective in jurisdictions such as Australia, the United Kingdom, and Canada, where it is commonly employed in complex environmental and technical disputes.[259] The process typically begins with experts submitting individual reports, followed by a pre-hearing conference to identify common ground and isolate contentious issues. During the hearing, experts present their views concurrently, responding to questions from the judge and counsel while

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[257] EUROPEAN COMMISSION FOR THE EFFICIENCY OF JUSTICE, [3.2, 5.1.2]; EUROPEAN PARLIAMENT DIRECTORATE-GENERAL FOR INTERNAL POLICIES, [2.2, 4].

[258] EUROPEAN PARLIAMENT DIRECTORATE-GENERAL FOR INTERNAL POLICIES, [3.3.2, 3.3.3]; J.T. PERILLO, A.D. PERILLO, N. DESPODOVA, M. BULL KOVERA, *Testing the Waters: An Investigation of the Impact of Hot Tubbing on Experts From Referral Through Testimony*, in *Law and Human Behaviour*, 45(3), 2021, 229; D. CANALE, *Il conclave degli esperti: forme di soluzione dei disaccordi epistemici nel processo*, in *La consulenza tecnica d'ufficio: Funzione, oggetto, sindacabilità*, S. PATTI, R. POLI (ed.), 2024, 143-166.

[259] See, for example, U.K. CIVIL JUSTICE COUNCIL, *Concurrent Expert Evidence and 'Hot-Tubbing' in English Litigation Since the 'Jackson Reforms': a Legal and Empirical Study*, July 25, 2016, https://www.judiciary.uk/wp-content/uploads/2011/03/cjc-civil-litigation-review-hot-tubbing-report-20160801.pdf.

engaging in direct dialogue with each other.[260] This format not only clarifies technical disagreements but also reduces the potential for strategic obfuscation, as experts must justify their conclusions under immediate scrutiny.

In climate litigation, where scientific uncertainty and probabilistic reasoning often complicate the evaluation of evidence, hot-tubbing can be particularly valuable for examining climate attribution studies and future harm projections. The ICJ's use of concurrent expert evaluation in the *Dispute over the Status and Use of the Waters of the Silala* case reflects the method's potential at the international level. However, its effectiveness hinges on procedural safeguards, such as requiring experts to affirm their duty to the court rather than the appointing parties, and on judicial capacity to moderate discussions impartially.[261] Without such safeguards, there remains a risk that the process could reinforce existing biases rather than mitigate them.

Another aspect worth considering is the standardization of methodologies used for climate-related expert assessments. Requiring experts to adhere to established protocols, such as those outlined by the IPCC, could improve the consistency and reliability of expert testimony.[262] Peer review mechanisms, similar to those employed in scientific publishing, might further enhance quality control, ensuring that expert reports undergo scrutiny before being presented in court.[263] Yet, the question remains whether strict methodological uniformity might inadvertently exclude valid but less conventional scientific perspectives, thereby narrowing the scope of the debate.

Standardized methodologies, such as those outlined in the IPCC assessment reports and the Coupled Model Intercomparison Project (CMIP), provide a common

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260 *Ibid*.

261 *Dispute over the Status and Use of the Waters of the Silala* (Chile v. Bolivia), *Written statement of the experts of Chile*, Drs. Howard Wheater and Denis Peach, January 14, 2022; *Dispute over the Status and Use of the Waters of the Silala* (Chile v. Bolivia), *Written statement of the experts of Chile*, DHI, January 10, 2022; DEVANEY, 5 and ff.

262 IPCC reports undergo a structured review and endorsement process by IPCC member countries, which enhances their authority. Different levels of formal endorsement apply to various IPCC materials. The Summary for Policymakers (SPM), included in each IPCC report, is subject to line-by-line approval during an IPCC plenary session, ensuring detailed scrutiny and consensus. The main body of the report is only subject to acceptance – meaning it has not undergone line-by-line review – but is still recognized as a comprehensive, objective, and balanced assessment. For Synthesis Reports, which summarize key findings from an IPCC cycle, the SPM undergoes approval, while the body of the synthesis report is adopted section by section, rather than line by line, *Request for an Advisory Opinion submitted by the Commission of Small Island States on Climate Change and International Law*, [48].

263 HASANI, 25-27.

framework for climate modeling, attribution science, and impact evaluation. These protocols not only ensure scientific rigor but also facilitate comparability across expert assessments, allowing courts to identify inconsistencies and evaluate the credibility of competing claims.[264] This approach has already informed climate litigation, as seen in the *Verein KlimaSeniorinnen Schweiz v. Switzerland* case before the ECtHR, where the Court relied heavily on IPCC findings to assess national climate policies.[265] Similarly, peer review mechanisms, modeled after academic publishing standards, could further validate expert reports, ensuring they meet established scientific benchmarks before being admitted as evidence.

However, while standardization promotes consistency, it also raises concerns about flexibility. Climate science is inherently interdisciplinary and continuously evolving, with emerging methodologies sometimes challenging established paradigms.[266] Strict adherence to standardized protocols might risk excluding innovative approaches that, though less conventional, could provide valuable insights in complex litigation.[267] To balance scientific integrity with adaptability, courts could require experts to disclose and justify any deviations from standard methodologies, ensuring transparency while preserving room for methodological innovation.[268] This nuanced approach might help reconcile the need for robust evidence with the dynamic nature of climate science.

Scientific uncertainty adds another layer of complexity to the appointment and evaluation of experts. Divergent opinions are not uncommon in climate science, where projections often depend on assumptions about future scenarios and discount rates. Addressing such uncertainty might require the formation of interdisciplinary expert panels capable of offering a more holistic view of the issues at stake.[269] However, this solution raises its own challenges, particularly regarding the selection of disciplines to be represented and the potential for internal disagreements within the panel itself.

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264 L. TOUZÉ-PEIFFER, A. BARBEROUSSE, H. LE TREUT, *The Coupled Model Intercomparison Project: History, uses, and structural effects on climate research*, in *WIREs Climate Change*, 11(4), 2020, 648.

265 *Case of Verein Klimaseniorinnen Schweiz and Others v. Switzerland*, [107-120].

266 See *above*, Chapter I, [2].

267 HASANI, 19-20; HACKNEY, 264-268, 279-280, 287-293.

268 *Ibid*.

269 For an in-depth analysis of the interdisciplinary nature of climatology and its impact on climate litigation, see Chapter 1.

Interdisciplinary expert panels can enhance the evaluation of climate-related evidence by integrating diverse perspectives, including climate science, economics, public health, and environmental law. By synthesizing insights from multiple disciplines, these panels help courts assess not only the physical causes of climate change but also its broader socio-economic and legal implications.[270] The ability to incorporate diverse expertise ensures that expert testimony is not narrowly confined to a single methodological framework but instead reflects a more comprehensive view of the multifaceted nature of climate litigation.

However, forming and managing interdisciplinary panels presents several challenges. Differences in methodological approaches and epistemological assumptions can lead to disagreements, making it difficult to present unified conclusions.[271] Additionally, ensuring a balanced representation of disciplines is complex, as certain fields may exert disproportionate influence depending on the composition of the panel.[272] To mitigate these risks, courts and tribunals could establish standardized protocols for panel selection, ensuring diversity while maintaining procedural fairness. Transparency in the appointment process, clear mandates for panel members, and interdisciplinary peer review mechanisms could further enhance the reliability of expert findings. While interdisciplinary panels do not eliminate scientific uncertainty, they provide courts with a structured means of engaging with complex evidence, facilitating more informed decision-making in climate litigation.

Institutional reforms could also play a role in improving the expert appointment process. Creating centralized expert databases at the national and international levels, as proposed by the European Expertise and Expert Institute (EEEI), might facilitate the identification of qualified experts while ensuring transparency in selection.[273]

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270 R. BALSTAD, *The Interdisciplinary challenges of climate change research*, in UNESCO International Social Science Council, *World social science report, 2010: Knowledge Divides*, 2010, 210-212

271 J.R. BEEBE, M. BAGHRAMIAN, L. O'C. DRURY, F. DELLSEN, *Divergent Perspectives on Expert Disagreement: Preliminary Evidence from Climate Science, Climate Policy, Astrophysics, and Public Opinion*, in *arXiv*, 1802, 2018, 1889; T. KANHANGA, *Scientific Uncertainties: a Nightmare for Environmental Adjudicators*, in C. VOIGT (ed.), *International Judicial Practice on the Environment: Questions of Legitimacy*, Cambridge, 2019.

272 *Ibid*.

273 EUROPEAN PARLIAMENT DIRECTORATE-GENERAL FOR INTERNAL POLICIES, 28.

Additionally, the introduction of quality assurance mechanisms, such as certification programs and periodic evaluations, could help maintain high standards of expertise.[274] At the international level, the ICJ's underutilized option to appoint assessors under Article 30(2) of its Statute might offer an alternative to traditional expert appointments, although concerns about procedural fairness and party participation remain unresolved.[275]

The exploration of mechanisms to improve the appointment and evaluation of experts in strategic climate litigation highlights both the potential for reform and the persistent complexities of integrating scientific expertise into legal frameworks. While independent panels, hot-tubbing, standardized methodologies, and interdisciplinary expert groups offer promising avenues to enhance the quality and impartiality of expert testimony, they also introduce new challenges regarding procedural fairness, institutional capacity, and the dynamic nature of climate science itself.

Ultimately, the tension between ensuring scientific rigor and preserving the adversarial nature of litigation remains unresolved. Can the pursuit of neutral expertise ever be fully reconciled with the inherently strategic nature of legal disputes? How can courts maintain flexibility to accommodate emerging scientific approaches without compromising consistency and reliability? And perhaps most importantly, as climate litigation continues to evolve, will the legal system be able to adapt its evidentiary practices in step with scientific advancements? These questions suggest that while progress is possible, the search for an optimal balance between scientific integrity and judicial fairness is likely to remain an ongoing challenge.

2. Causal Link Challenges in Strategic Climate Litigation

2.1 The Importance of Establishing Causation in Climate Cases

274 EUROPEAN COMMISSION FOR THE EFFICIENCY OF JUSTICE, [3.2.6]

275 G. GAJA, *Assessing Expert Evidence in the ICJ*, in *The Law and Practice of International Courts and Tribunals*, 15, 2016, 417-418.

In strategic climate litigation, establishing causation is not just a legal requirement but a foundational element that determines the strength and impact of a case. Without a demonstrable link between the defendant's actions or omissions and the harm alleged, even the most compelling legal arguments risk losing their persuasive force. The very function of these lawsuits – whether aimed at securing emissions reductions, holding corporations accountable, or compelling governmental action – hinges on the ability to show that specific behaviors contribute, in a legally significant way, to climate change and its consequences. As climate-related cases become more frequent and ambitious, causation emerges as the crux upon which their success or failure depends.[276]

Causation operates on multiple levels within climate litigation. At its core, it is a fundamental legal condition for liability, whether in tort law, human rights-based claims, or actions grounded in constitutional and administrative law. Courts must be convinced that the harm suffered by individuals or communities is not merely an abstract consequence of global emissions but can be traced, at least in part, to the conduct of the defendant. This requirement is particularly pressing in cases where plaintiffs seek concrete remedies – such as damages for loss and destruction caused by climate-related events or injunctions compelling stronger mitigation policies. Without this link, claims are likely to falter, particularly in legal systems that apply strict tests for causation. The growing body of climate litigation illustrates the centrality of this issue, as seen in cases where courts have dismissed claims due to the perceived inability to attribute specific harms to specific actors. Conversely, in landmark decisions such as *Urgenda v. The Netherlands*, courts have begun to acknowledge the necessity of broadening traditional legal conceptions of causation to accommodate the systemic nature of climate harm.[277]

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[276] M. WILDE, *Causation and climate change litigation: 'bridge too far'?*, in *Austrian Law Journal*, 8, 2021, 268; N. NEDESKI, A. NOLLKAEMPER, *A guide to tackling the collective causation problem in international climate change litigation*, in *EJIL Talk*, 2022, https://www.ejiltalk.org/a-guide-to-tackling-the-collective-causation-problem-in-international-climate-change-litigation/; F.E.L. OTTO *ET AL.*, *Causality and the fate of climate litigation: The role of the social superstructure narrative*, in *Global Policy*, 13, 2022, 736 and ff.; T. PFROMMER *ET AL.*, *Establishing causation in climate litigation: admissibility and reliability*, in *Climatic Change*, 152, 2019, 67 and ff.

[277] *Ibid.*; V. STOYANOVA, *KlimaSeniorinnen and the Question(s) of Causation*, in *Climate Law: A Sabin Center Blog*, May 7, 2024,

Beyond its technical role in the legal reasoning of courts, the insistence on proving causation reflects an evolving legal landscape in which courts are increasingly called upon to grapple with complex scientific evidence. The role of climate attribution science in these cases is expanding, helping to bridge the gap between legal standards of proof and the inherently probabilistic nature of climate science. Advances in extreme event attribution, for instance, now allow scientists to quantify the extent to which human-induced climate change has increased the likelihood or severity of specific disasters.[278] These developments provide courts with stronger evidentiary foundations for causal reasoning, even if they do not fit neatly within traditional legal tests. The shift toward probabilistic causation – already recognized in fields such as toxic torts and environmental contamination – may increasingly shape judicial approaches to climate liability. This evolution underscores how the law adapts to new challenges, gradually integrating emerging methodologies to refine its understanding of harm and responsibility. As courts become more receptive to these scientific advances, the role of causation in climate litigation is likely to gain even greater significance.

Moreover, causation also functions as a powerful tool for advocacy and political accountability. Establishing a causal connection in court can transform diffuse responsibility into concrete legal liability, making the climate crisis more tangible in the eyes of the law and the public. A ruling that affirms causation does more than decide a case – it assigns blame, shapes narratives, and influences how governments and corporations perceive their own exposure to legal risk. Even unsuccessful cases can shift public discourse by forcing defendants to confront their role in climate change, a strategy that has been crucial in past environmental and public health

https://blogs.law.columbia.edu/climatechange/2024/05/07/klimaseniorinnen-and-the-questions-of-causation/.

[278] M. BURGER, J. WENTZ, R. HORTON, *The Law and Science of Climate Change Attribution*, in *Columbia Journal of Environmental Law*, 45(1), 2020, 60 and ff.; D.A. KYSAR, I. SOPARKAR, *Applying Attribution: Impacts of Climate Attribution Science on Tort Litigation, in Environmental Law Institute: Climate Judiciary Project*, January 2023, https://cjp.eli.org/curriculum/applying-attribution-impacts-climate-attribution-science-tort-litigation?utm_source=substack&utm_medium=email#:~:text=Climate%20attribution%20science%20can%20be,United%20States%20continues%20to%20grow; S.C. GOLD, *When Certainty Dissolves into Probability: A Legal Vision of Toxic Causation for the Post-Genomic Era*, in *Washington and Lee Law Review*, 70(1), 2013, 237 and ff.

litigation. For example, litigation against the tobacco industry in the 1990s, though initially unsuccessful, gradually built momentum by clarifying causal links between corporate conduct and public harm, eventually leading to landmark settlements.[279] A similar trajectory may unfold in climate litigation, where early legal struggles over causation lay the groundwork for more robust findings in the future.

The implications of establishing causation extend well beyond individual lawsuits. A legal finding that a government or corporation has caused or contributed to climate harm can set powerful precedents, influencing future litigation and shaping regulatory frameworks. The deterrent effect of such rulings can push policymakers toward more ambitious climate measures, while businesses may be compelled to reassess their practices in light of potential liability. Over time, the accumulation of judicial recognition of causation can contribute to the broader project of embedding climate responsibility into legal and governance structures. The influence of litigation on corporate and governmental behavior is already visible: in response to lawsuits, some fossil fuel companies have begun to adjust their public communications on climate change, and financial institutions are increasingly factoring climate-related legal risks into their investment strategies.[280]

At a societal level, the recognition of causation in court decisions plays a crucial role in reinforcing the legitimacy of climate governance. The law does not operate in a vacuum – it responds to social expectations and, in turn, shapes them. Judicial findings that establish a clear causal link between emissions and harm serve not only to apportion responsibility but also to strengthen the moral and political case for decisive climate action. As climate-related litigation continues to evolve, judicial determinations on causation will influence public perceptions of responsibility and fairness in the fight against climate change. They will also contribute to the ongoing

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[279] See, for example, the website https://oag.ca.gov/tobacco/msa; M. OLSZYNSKI, S. MASCHER, M. DOELLE, *From Smokes to Smokestacks: Lessons from Tobacco for the Future of Climate Change Liability*, in *The Georgetown Environmental Law Review*, 30(1), 2018; F. PONGIGLIONE, *The key role of causal explanation in the climate change issue*, in *Theoria*, 74, 2012, 175 and ff.

[280] Y. SI *ET AL.*, *Fossil fuel companies' climate communication strategies: Industry messaging on renewables and natural gas*, in *Energy Research & Social Science*, 98, 2023; S. DAYNE, *How fossil fuel companies are turning to influencers*, in *Global Landscape Forum: Think Landscape*, December 11, 2024, https://thinklandscape.globallandscapesforum.org/71249/how-fossil-fuel-companies-are-turning-to-influencers/.

dialogue about how legal systems should balance scientific uncertainty with the pressing need for accountability.[281]

Ultimately, causation is more than a procedural hurdle; it is a linchpin of strategic climate litigation, a mechanism through which legal, political, and moral responsibilities are articulated and enforced. Its successful establishment can serve as a catalyst for systemic change, reinforcing the role of law in addressing the climate crisis and ensuring that those who contribute to global warming are held to account. The significance of this issue will only continue to grow as courts, legislators, and societies confront the escalating impacts of a changing climate. If the legal system succeeds in refining its approach to causation in climate cases, it may provide one of the most powerful levers for driving climate action and shaping the policies of the future.

2.2 *Scientific and Legal Difficulties in Proving Causation*

Courts require proof that harmful conduct, such as greenhouse gas emissions, is causally linked to climate-related harm. However, establishing this link in climate litigation presents unique challenges, primarily due to the diffuse and cumulative nature of greenhouse gas emissions. Unlike traditional tort cases, where a single defendant's actions can be directly linked to the plaintiff's harm, climate change results from the collective actions of multiple actors over extended periods. This makes it difficult to attribute specific damages to individual emitters, a problem often referred to as the collective causation problem.[282] Given that climate change is caused by the

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[281] A. WONNEBERGER, *Climate change litigation in the news: litigation as public campaigning tool to legitimize climate-related responsibilities and solutions*, in *Social Movements Studies*, 3(1), 2023, 94–112; A.V. RYDBERG, *Climate Change Litigation: General Perspectives and Emerging Trends*, in *International Community Law Review*, 26, 2024, 346 and ff.; F.E.L. OTTO *ET AL.*, 2019.

[282] U.S. courts have consistently dismissed climate litigation cases due to challenges in establishing causation. In *Comer v. Murphy Oil USA*, plaintiffs argued that emissions from 34 major companies contributed to rising sea levels and temperatures in the Gulf of Mexico, which intensified Hurricane Katrina and caused property damage. The court rejected the claim, stating that the connection between the defendants' emissions and the hurricane was too remote and improbable to impose liability. Similarly, in *Native Village of Kivalina v. ExxonMobil Corp.*, an Alaskan community sought damages from 24 oil and energy companies for the loss of protective sea ice, which increased their vulnerability to storms and erosion. The court ruled that climate change results from numerous actors over centuries,

cumulative emissions of states, corporations, and individuals worldwide, courts must determine whether a single entity can be held liable for harm that is the result of complex, interdependent factors.[283]

The legal standards for proving causation vary across jurisdictions and depend on the type of case. In civil litigation, plaintiffs are generally required to meet the "balance of probabilities" standard, meaning they must show that it is more likely than not that the defendant's actions contributed to the harm. In criminal or regulatory cases, a higher standard of proof, such as "beyond a reasonable doubt," may apply, making it even more difficult to establish liability. Traditional causation tests, such as the but-for test – requiring proof that the harm would not have occurred but for the defendant's conduct – are particularly ill-suited for climate litigation. Since greenhouse gases disperse globally and contribute cumulatively to climate change, no single entity's emissions can be identified as the sole cause of a particular impact. This has led courts in some jurisdictions to explore more flexible approaches to causation, particularly in mass tort and environmental cases.[284]

A landmark example of this shift is *Urgenda v. Netherlands*, in which the Dutch Supreme Court ruled that the government had a duty to reduce emissions based on a risk-based approach to causation. The court did not require proof that the Dutch government's specific emissions had caused particular climate harms. Instead, it acknowledged that failing to take sufficient mitigation measures increased the risk of future harm, which was deemed sufficient to establish liability.[285] This decision aligns with broader trends in environmental law, where courts have sometimes relaxed

making it impossible to trace specific harm to individual defendants. Outside the U.S., courts have applied similar reasoning. In *Smith v. Fonterra* (New Zealand), the Supreme Court dismissed a claim against industrial and agricultural entities, concluding that the alleged harms resulted from too many indirect and cumulative factors to hold specific defendants accountable. These cases illustrate that causation remains one of the biggest legal hurdles in climate litigation, as courts remain reluctant to attribute climate-related damages to individual emitters.

283 M. WILDE, 281-282; N. NEDESKI, A. NOLLKAEMPER, 2022, who note that examples of this defensive argument can be found in cases such as *Billy et al. v. Australia* and *Sacchi et al. v. Argentina*, where States emphasized the complexity of the causal chain to deny liability.

284 M. WILDE, 274-276, 281-283; N. NEDESKI, A. NOLLKAEMPER, 2022; F.E.L. OTTO *ET AL.*, 2019; T. PFROMMER *ET AL.*, 68-70.

285 M. WILDE, 270-273; N. NEDESKI, A. NOLLKAEMPER, 2022.

causation requirements to accommodate the unique challenges posed by large-scale, cumulative harms.[286]

Scientific advancements in climate attribution studies have played a crucial role in supporting this evolving legal approach. Attribution science seeks to determine the extent to which human-induced climate change influences specific weather events or broader climatic trends. One of the primary methodologies used in this field is the Fraction of Attributable Risk (FAR), which quantifies the likelihood that a particular event – such as a heatwave, hurricane, or flood – was made more severe or more probable due to anthropogenic greenhouse gas emissions.[287]

To reach these conclusions, climate scientists use counterfactual analysis, in which they compare observed climate conditions with hypothetical scenarios in which human emissions are removed.[288] This allows researchers to estimate how much of an event's intensity or frequency can be attributed to human influence. For instance, studies have found that the 2013–2014 Argentinian heatwave was made 400% more likely due to human-induced climate change.[289] However, despite their growing sophistication, these models rely on probabilistic reasoning rather than deterministic proof, making them fundamentally different from the kind of direct causation evidence traditionally expected in courts.

Several challenges remain in integrating attribution science into legal proceedings. First, as seen in the First Chapter, extreme weather events are inherently rare, making it difficult to establish statistically robust trends. Second, different climate models yield varying estimates of climate sensitivity and event probability, leading to debates about the reliability and consistency of findings. Third, there is no universally accepted legal framework for incorporating attribution science into litigation, leading to variability in how courts interpret and weigh this evidence. These scientific uncertainties complicate the task of demonstrating causation under traditional legal

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286 *Ibid*.

287 T. PFROMMER *ET AL.*, 70-72.

288 A. HANNART, P. NAVEAU, *Probabilities of Causation of Climate Changes*, in *Journal of Climate*, 21, 2017, 5507.

289 M. WILDE, 274-276, 281-283; N. NEDESKI, A. NOLLKAEMPER, 2022.

standards, prompting some courts to consider probabilistic causation instead of demanding absolute certainty.[290]

Another complicating factor is the delayed effect of greenhouse gas emissions. Unlike pollution cases where exposure and harm occur within a short time frame, climate change unfolds over decades or even centuries. The thermal inertia of the oceans means that some climate impacts from past emissions are only beginning to materialize now, while emissions released today will continue to affect the climate for generations. This temporal disconnect creates evidentiary hurdles, as plaintiffs must link present-day harms to emissions that may have occurred many years ago. Moreover, climate-related disasters often result from a combination of natural variability and human-induced changes, making it difficult to assign definitive responsibility to any single entity.[291]

These complexities raise fundamental legal questions about the standard of proof required in climate cases. As observed, while courts have traditionally relied on deterministic causation models, some have begun to accept risk-based and probabilistic causation approaches. In the United States, the *Daubert* standard governs the admissibility of scientific evidence in court, requiring expert testimony to be based on reliable methodologies that have been tested, peer-reviewed, and widely accepted within the scientific community. Climate attribution studies meet some of these criteria, but they also face challenges in terms of reproducibility, error margins, and the inherent uncertainties involved in modeling complex climate interactions. As a result, different courts have reached different conclusions about whether and how to admit attribution science as evidence.[292]

To address these challenges, some legal systems have begun adapting their causation standards for climate cases. Courts handling mass tort litigation, such as asbestos lawsuits, have sometimes allowed plaintiffs to rely on risk-based causation theories, rather than requiring direct proof of individual harm.[293] Similarly, in climate

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290 See M. WILDE, 277-278, who notes how case law has developed the concepts of "material contribution" and "material increase in risk" to overcome evidentiary difficulties in cases of exposure to harmful substances.

291 E. BIBER, *Climate Change, Causation, and Delayed Harm*, in *Hofstra Law Review*, 37, 2009, 975.

292 T. PFROMMER *ET AL.*, 75-77.

293 M. WILDE, 279-280, 281-282; F.E.L. OTTO *ET AL.*, 238; E. BIBER, 977.

litigation, some scholars and advocates argue for a shift away from traditional causation doctrines toward frameworks that focus on systemic risk assessment.[294] Recognizing that climate harms result from cumulative contributions rather than isolated acts could make it easier for plaintiffs to hold major emitters accountable.

However, courts around the world have taken inconsistent approaches to these issues. The European Court of Human Rights' ruling in *KlimaSeniorinnen v. Switzerland* highlighted the difficulties of applying traditional human rights principles to climate litigation, acknowledging the complexities of climate causation and the need for new legal frameworks.[295] In *Lliuya v. RWE*, a German court considered whether a single polluter could be held proportionally liable for climate damages, even though it was only one of many contributors. These cases illustrate the ongoing evolution of climate litigation, as courts attempt to reconcile legal principles with the realities of climate science.[296]

Despite the lack of a universally accepted legal framework, climate litigation continues to evolve, driven by advancements in attribution science, growing public awareness, and shifting legal interpretations. Courts are increasingly recognizing the need for flexible approaches to causation, particularly as scientific methodologies improve. As litigation strategies continue to develop, the role of climate attribution

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294 *Ibid*.

295 V. STOYANOVA, 2024, who notes that, in order to establish a link between the harm suffered by the applicants and the action (or inaction) of the State, the Court introduces a criterion of "sufficient proximity" between the climate risk and the affected individual, as well as a "threshold of severity," requiring the risk to be sufficiently serious to trigger the State's obligations. To then determine Switzerland's share of responsibility, the Court applies the "real prospect" test, assessing whether the omitted action by the State would have had a real possibility of altering the outcome or mitigating the harm [444]; however, the way this test is applied remains ambiguous in the judgment.

296 In *Lliuya v. RWE*, Peruvian farmer Saúl Luciano Lliuya sued German energy giant RWE in 2015, claiming the company's greenhouse gas emissions contributed to the melting of glaciers near Huaraz, Peru, increasing the risk of flooding from Lake Palcacocha. He sought compensation for 0.47% of flood protection costs, proportional to RWE's estimated share of historical global emissions. The District Court of Essen dismissed the case, citing the complexity of climate causation. However, in 2017, the Higher Regional Court of Hamm admitted the case into the evidentiary phase, marking a legal milestone by recognizing that a private company could potentially be held liable for climate damages abroad. After pandemic-related delays, a site visit took place in May 2022, and court-appointed experts are now assessing the flood risk and RWE's role. The case could set a precedent for corporate accountability in transnational climate litigation. See M. WILDE, 270-273, who also highlights that, in general, lawsuits against governments have achieved significant success, whereas those against private companies face greater obstacles, particularly in terms of causation; N. NEDESKI, A. NOLLKAEMPER, 2022.

science in legal proceedings is likely to become more prominent, shaping the future of climate accountability and governance.

2.3 *Strategies for Addressing Causal Uncertainty*

The issue of causation represents one of the main barriers in climate litigation, hindering claims for compensation for damages caused by climate change. However, in recent years, various legal and scientific solutions have emerged to overcome this challenge. Notably, some courts have shown greater flexibility in their approach to causation, recognizing the responsibility of states and corporations even in the absence of direct proof of a causal link. Cases such as *Urgenda* in the Netherlands and *Neubauer* in Germany illustrate how courts have affirmed that liability does not depend solely on demonstrating that a single actor's emissions directly caused a particular harm, but also on the obligation to take preventive measures to mitigate foreseeable risks. In this sense, responsibility is no longer solely based on causing damage but also on contributing to a context that has made such damage more likely.

At the same time, legal scholarship has proposed alternative frameworks to adapt the concept of causation to the complexity of climate change. One significant approach is the NESS test, a legal framework designed to establish causation in complex cases where multiple factors contribute to harm. Unlike the traditional but-for test, which requires proving that a single action was indispensable to the outcome, the NESS test considers whether a factor was a necessary component within a broader set of conditions that together were sufficient to cause harm.[297] This approach is particularly useful in climate litigation, where no single emitter can be identified as the sole cause of climate-related damages, but each contributes to the overall problem. If a defendant's emissions were a necessary part of the total set of conditions that intensified an extreme weather event or environmental damage, then liability can still be assigned.

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[297] T. BURMAN, *A New Causal Pathway for Recovery in Climate Change Litigation?*, in *Environmental Law Reporter*, 52, 2022, 10042.

The application of the NESS test in climate litigation is strengthened by climate attribution science, which quantifies how much specific emissions have contributed to rising global temperatures and related climate events. Scientific models can estimate the percentage of global warming attributable to a corporation's or state's emissions and determine whether those emissions played a role in increasing the severity of climate-related disasters.[298] This allows courts to move beyond the traditional causation model and acknowledge that climate change is a cumulative phenomenon in which multiple actors bear responsibility. If removing a particular defendant's emissions would have reduced the probability or severity of a specific harm, then those emissions are causally relevant under the NESS framework.

This approach has precedents in other areas of law, particularly in toxic torts and product liability cases. Courts have previously assigned liability to multiple contributors when their actions collectively resulted in harm, even if no single actor was the exclusive cause. The market share liability doctrine, which has been applied in cases involving asbestos and defective pharmaceuticals, distributes damages proportionally to each actor's contribution to the harm.[299] A similar logic can be applied in climate litigation, ensuring that large polluters cannot evade responsibility by arguing that their emissions alone did not directly cause a specific event.

Despite its advantages, the NESS test faces practical and legal challenges. Defining the sufficient set of conditions that led to a specific harm requires careful scientific and legal assessment, and courts must determine how much contribution is enough to establish liability. Some jurisdictions may be hesitant to adopt a more flexible causation standard, preferring the stricter requirements of traditional tort law. However, as climate litigation evolves, the NESS test offers a powerful tool for assigning responsibility in a way that reflects the collective nature of climate change,

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298 T. BURMAN, 10038-10041.

299 T. BURMAN, 10060-61, who mentions *Warren v. Parkhurst* (1893), where the New York Supreme Court held multiple industrial polluters liable for contaminating a river, even though no single entity alone had caused significant harm. The court ruled that since each polluter contributed to a cumulative environmental impact, they could all be held responsible. This reasoning closely aligns with the NESS test, as each polluter's actions were necessary components of a sufficient set of conditions that led to the harm.

preventing major polluters from escaping liability simply because their individual emissions are not the sole cause of harm.[300]

Other solutions are proportional liability and market share liability, two legal frameworks that help distribute responsibility among multiple contributors in cases where harm results from cumulative actions rather than a single identifiable cause. Proportional liability assigns responsibility based on the degree to which each defendant contributed to the harm, often using scientific attribution models to determine the percentage of damage caused by a specific actor. In climate litigation, this approach allows courts to hold major emitters accountable by linking their emissions to global warming and extreme weather events.[301] If a corporation's emissions account for 3% of global CO_2 levels, for example, it could be required to compensate for 3% of the climate-related damages. This model is particularly valuable in cases where scientific evidence can quantify the role of individual actors in worsening climate change, ensuring that liability is fairly distributed.

By contrast, market share liability is a concept that originated in product liability cases, where victims could not prove which specific manufacturer was responsible for their harm but could establish that multiple companies produced a harmful product. Instead of requiring plaintiffs to trace harm to a single defendant, liability is assigned based on each company's share of the market for the product in question.[302] In climate cases, this approach could be applied to fossil fuel companies, with damages distributed according to their historical share of global emissions. For example, if a company was responsible for 15% of fossil fuel production over a given

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300 T. BURMAN, 10038.

301 T. BURMAN, 10054-10056.

302 R. STUART-SMITH, A. SAAD *ET AL.*, *Attribution science and litigation: facilitating effective legal arguments and strategies to manage climate change damages*, Summary report for FILE Foundation, 2021, https://www.smithschool.ox.ac.uk/sites/default/files/2022-03/attribution-science-and-litigation.pdf; R.F. STUART-SMITH *ET AL.*, *Filling the evidentiary gap in climate litigation*, in *Nature Climate Change*, 11, 2021, 651–652; T. BURMAN, 10056-10057, who refers to *Sindell v. Abbott Laboratories*, where the California Supreme Court ruled that it would be unfair to hold a single defendant fully liable under an alternative causation theory, given the large number of manufacturers that could have caused the harm and the fact that they were following industry practices and regulatory standards. However, the court recognized that policy considerations justified relaxing the strict causation requirement, as the defendants' actions created a risk of harm to innocent victims, and they were in a better position to absorb the costs and prevent defects. The court established the market share liability doctrine, allowing plaintiffs to recover damages proportionate to each defendant's share of the product sold on the market when the exact manufacturer responsible for the injury could not be identified; N. NEDESKI, A. NOLLKAEMPER, 2022.

period, it could be required to cover 15% of the damages linked to climate change. This framework is particularly useful when direct causation is difficult to establish but historical emissions data provide a basis for determining responsibility.

While both models aim to circumvent the causation challenge in climate litigation, they differ in their legal foundations and methods of calculation. Proportional liability relies on scientific attribution to quantify the impact of specific emissions, making it a preferred approach in cases involving direct climate-related harm. Market share liability, on the other hand, is based on economic market distribution, making it more applicable to cases where historical responsibility for emissions needs to be allocated across multiple actors. Each framework presents challenges, such as defining the threshold for liability or ensuring courts accept scientific models of attribution, but both offer viable paths for holding major polluters accountable in an era where climate litigation is becoming a crucial tool for environmental justice.[303]

Alongside these legal innovations, climate attribution science has taken on a central role in litigation, providing tools to establish scientific links between greenhouse gas emissions and specific climate change impacts. Event attribution techniques help determine whether and to what extent climate change has increased the probability or severity of extreme weather events such as hurricanes, wildfires, and floods. Impact attribution quantifies the extent to which a climate-related event has affected a particular community or individual, distinguishing between climate and non-climate factors. Finally, source attribution identifies the major responsible emitters and measures their contribution to specific climate-related events. These scientific methodologies are increasingly being accepted in courtrooms, where they are used to demonstrate that a defendant's emissions have contributed to harmful events in a statistically significant way.[304]

The integration of these emerging legal and scientific approaches is gradually reshaping the landscape of climate litigation. On one hand, national and international

303 T. BURMAN, 10054-10057.

304 N. NEDESKI, A. NOLLKAEMPER, 2022; R. STUART-SMITH, A. SAAD, 3-6; R.F. STUART-SMITH *ET AL*., 654; P. MINNEROP, *Climate Causality: From Causation to Attribution*, in M. WEWERINKE SINGH, S. MEAD (eds.), *Cambridge Handbook on Climate Change Litigation*, Cambridge, 2024.

courts are starting to acknowledge the validity of scientific evidence in attributing climate-related harm. On the other, there is a shift in legal criteria for evaluating the liability of emitters, with a growing openness to less rigid normative standards. An emerging trend is the willingness of courts to apply liability standards that do not require absolute proof of causation but instead consider the broader complexity of climate change and the principle of shared responsibility.

Looking ahead, one of the key challenges will be developing more effective compensation mechanisms for victims of climate change. International organizations and arbitration courts could play a crucial role in establishing funds or reparative mechanisms based on principles of equity and proportionality.[305] Additionally, further legal developments could facilitate the use of attribution science in legal proceedings, enabling a more precise assessment of the responsibility of both public and private actors.[306]

These transformations mark an important step toward climate justice. The problem of causation, which for years has been an insurmountable obstacle to compensation claims, is now finding innovative solutions through the convergence of science and law. If this trend continues, climate litigation could become an increasingly powerful tool for holding polluters accountable and securing justice for those suffering the consequences of climate change.

3. Interconnected Challenges and Proposed Solutions

3.1 *The Relationship Between Expert Evidence and Causation*

The relationship between expert evidence and causation in climate change litigation is complex and dynamic, shaped by both scientific advancements and judicial constraints. The role of expert testimony is crucial in establishing causation, yet it also creates challenges that courts must navigate. On one hand, expert evidence serves as

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305 A. NOLLKAEMPER, *Causation Puzzles in International Climate Litigation*, in *Amsterdam Center for International Law*, 3, 2024, [6].

306 *Ibid*.

the backbone for proving the link between greenhouse gas emissions and specific climate-related harms. On the other, disagreements among experts, methodological uncertainties, and legal standards of proof contribute to a feedback loop that complicates the determination of causation.

A fundamental issue in climate litigation is the requirement to establish both general causation and specific causation. General causation involves demonstrating that climate change can, in principle, cause certain harms – such as an increase in the frequency and intensity of extreme weather events or the progressive rise in sea levels. Specific causation, on the other hand, requires the claimant to prove that a particular harm they have suffered can be attributed, at least in part, to the emissions of a specific defendant or to a particular act or omission.[307]

This dual requirement is particularly challenging in mass tort cases and environmental liability claims, where causation is often contested due to the complexity of climate change. While general causation can be supported by well-established scientific evidence (such as IPCC reports that demonstrate the link between greenhouse gas emissions and global warming), proving specific causation is far more difficult. As observed, climate change results from the cumulative emissions of countless actors over long periods, making it extremely challenging to isolate the contribution of a single entity and establish that, without its specific conduct, the harm would not have occurred or would have been less severe.[308]

Complicating matters further is the fact that the admissibility of expert testimony, which is crucial for establishing specific causation, depends on the legal evidentiary standards applied by courts. Different jurisdictions adopt different approaches to evaluating scientific evidence, influencing the extent to which probabilistic methodologies – such as probabilistic event attribution – can be used to establish causation in legal proceedings.[309]

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307 E.M. TAGER, C.J. SUMMERS, *2 Helpful Cases On Specific Causation Expert Testimony*, in *Law 360*, March 2, 2016, https://www.law360.com/articles/765115/2-helpful-cases-on-specific-causation-expert-testimony; C.R.J. PACE, *Admitting and Excluding General Causation Expert Testimony: The Eleventh Circuit Construct*, in *American Journal of Trial Advocacy*, 37, 2013, 47-48.

308 I. KAMINKSI, *How scientists are helping sue over climate change*, in *The Lancet*, 6, 2022, 386; C.R.J. PACE, 47.

309 P. MINNEROPT, F. OTTO, *Climate Change and Causation: Joining Law and Climate Science on The Basis of Formal Logic*, in *Buffalo Environmental Law Journal*, 17, 2020, 49; I. KAMINKSI, 386-387.

In some legal systems, particularly in the United States, courts apply the Daubert standard, which imposes strict requirements for the admissibility of expert testimony. Under this standard, an expert's methodology must (i) be based on valid scientific principles and techniques, (ii) be subjected to peer review and publication, (iii) have a known and acceptable error rate and (iv) be generally accepted within the relevant scientific community.[310]

This high threshold poses a significant challenge for claimants in climate litigation because the methodologies used to establish specific causation, such as climate attribution studies, are inherently probabilistic and do not provide absolute certainty.[311] For example, attribution models may conclude that a heatwave was made twice as likely due to climate change, but they cannot definitively state that without the defendant's emissions, the heatwave would not have occurred.

If a court applies the Daubert standard strictly, it may exclude expert testimony on these grounds, making it extremely difficult for the claimant to prove specific causation. This creates a vicious cycle: if courts reject expert testimony due to its probabilistic nature, claimants lose the only scientific tool available to demonstrate the causal link between a defendant's emissions and the damage suffered.[312]

Conversely, other legal systems adopt more flexible standards, such as the Frye standard, which primarily considers whether the methodology is generally accepted within the scientific community. Courts following this approach are more likely to admit probabilistic models, recognizing them as valid scientific tools despite their lack of absolute certainty. However, they often remain hesitant to fully rely on such models, demanding a higher degree of certainty than climate science can provide.[313]

One major challenge in admitting expert testimony on causation is judicial skepticism toward novel scientific methodologies. Courts tend to exclude expert opinions that lack a clear causal chain or rely on uncertain extrapolations. In toxic tort litigation, for example, courts have frequently rejected expert testimony where causation was inferred primarily from statistical associations rather than direct

310 C.R.J. PACE, 47-52.
311 P. MINNEROPT, F. OTTO, 70-72.
312 C.R.J. PACE, 49-50.
313 *Ibid*.

evidence.[314] This reflects a broader concern in climate litigation, where establishing causation is complicated by the multiplicity of contributing factors and the long temporal scale over which climate impacts unfold. The presence of alternative causes, such as natural climate variability or localized environmental changes, further complicates the ability of plaintiffs to demonstrate that a specific defendant's emissions were a substantial contributing factor to their harm.

A reinforcing feedback loop emerges when courts' high evidentiary thresholds influence how experts frame their testimony. Legal expectations of certainty may lead scientists to present overly cautious assessments, limiting the impact of their findings in litigation.[315] At the same time, when experts disagree on methodologies or conclusions, courts may perceive scientific uncertainty as a reason to reject causation claims altogether. This dynamic was evident in *In re Lipitor (Atorvastatin Calcium) Marketing, Sales Practices and Products Liability Litigation (MDL 2502)*, where the U.S. District Court for the District of South Carolina excluded expert testimony on the grounds that it relied too heavily on temporal associations – the fact that patients developed diabetes after taking Lipitor – rather than demonstrating a scientifically validated causal mechanism. Applying the Daubert standard, the court deemed the expert evidence insufficiently reliable to establish specific causation, leading to the dismissal of numerous claims. This case illustrates a broader challenge in litigation where causation must be established through probabilistic or inferential reasoning.[316]

Similar obstacles arise in climate litigation, where courts evaluate probabilistic event attribution studies that assess the likelihood that climate change contributed to an extreme weather event but do not offer deterministic proof of causation. Just as the Lipitor court rejected expert testimony due to a lack of definitive causal evidence, courts in climate cases may exclude scientific findings that rely on statistical probability, complicating efforts to hold specific actors accountable for climate-related harms. A notable example is Lliuya v. RWE, where the Essen Regional Court initially dismissed the case, citing insufficient legal causality, as it was difficult to trace a direct link between RWE's emissions and the specific harm alleged. However, the Higher

314 E.M. TAGER, C.J. SUMMERS, 2016.
315 *Ibid*.
316 *Ibid*.

Regional Court of Hamm later admitted the case, recognizing new expert evidence quantifying RWE's proportional contribution to global emissions.[317]

The broader implications of this feedback loop extend beyond individual cases, influencing both legal and scientific developments. As courts continue to demand more precise causal connections, scientific research may adapt by refining methodologies and enhancing attribution models. However, if legal standards remain rigid, they risk excluding valuable scientific insights that, while not offering absolute certainty, provide a robust probabilistic basis for linking emissions to climate-related harms.[318] International litigation, particularly cases before human rights tribunals and transnational courts, may help establish precedents that accommodate probabilistic causation models, paving the way for more effective integration of climate science into legal reasoning.

Ultimately, expert evidence plays a pivotal yet contested role in climate litigation. While courts rely on scientific testimony to establish causation, the standards they apply can create barriers to its acceptance. The tension between legal demands for certainty and the inherently probabilistic nature of climate science generates a recursive challenge, in which expert disagreement reinforces judicial skepticism, and vice versa. Moving forward, a more adaptive legal approach that acknowledges the evolving nature of scientific evidence may be necessary to ensure that climate litigation remains a viable mechanism for accountability in the face of global environmental change.

3.2 *Ensuring Fairness and Effectiveness in Climate Litigation*

Ensuring fairness and effectiveness in climate litigation is a pressing challenge as courts increasingly adjudicate cases involving complex scientific and legal issues. Climate change litigation has emerged as a crucial mechanism for holding governments and corporations accountable for their role in global warming, yet its

317 I. KAMINKSI, 386; P. MINNEROPT, F. OTTO, 62-65.

318 EXPERTSDIRECT, *Expert Evidence in Landmark Climate Change Litigation*, https://expertsdirect.com/expert-evidence-in-landmark-climate-change-litigation/.

success depends on the judiciary's ability to navigate scientific uncertainty, integrate legal and scientific reasoning, and enhance judicial expertise through training and specialization. Addressing these challenges requires a comprehensive approach that balances the need for legal certainty with the evolving nature of climate science while ensuring that judges have the necessary tools to interpret and apply scientific evidence effectively.

As observed, one of the primary obstacles in climate litigation is the fundamental difference between the way science and law operate. Climate science relies on probabilistic models and evolving research, making it inherently uncertain, whereas legal systems demand clear standards of proof and responsibility. This divergence can create difficulties when courts are asked to rule on liability for climate-related harm or the adequacy of government policies based on scientific predictions. Judges, who are often not trained in scientific methodologies, may expect definitive answers that scientists cannot provide, leading to a misinterpretation of uncertainty as a lack of evidence.[319] This can affect the credibility of climate litigation and hinder the enforcement of climate-related legal obligations.

Courts have adopted different approaches to addressing scientific uncertainty. Some take a deferential stance, giving significant weight to the decisions of regulatory agencies and expert bodies, particularly when scientific issues fall within their domain. In the U.S., for example, this is common in cases involving environmental regulations under statutes such as the National Environmental Policy Act and the Endangered Species Act, where courts assume that agencies possess the necessary expertise to evaluate climate science.[320] However, other courts adopt a more skeptical approach, scrutinizing agency decisions for inconsistencies, incomplete analyses, or undue

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319 R.L. GLICKSMAN, D. KIM, K. GROTH-TUFT, *Judicial Review of Scientific Uncertainty in Climate Change Lawsuits: Deferential and Nondeferential Evaluation of Agency Factual and Policy Determinations*, in *Harvard Environmental Law Review*, 46, 2022, 2-10; K. SULYOK, *Scientific Uncertainty as a Key Obstacle to Efficient Legal Protection of the Environmental Interests of Future Generations*, in M.C. CORDONIER SEGGER, M. SZABÓ, A.R. HARRINGTON, *Intergenerational Justice in Sustainable Development Treaty Implementation: Advancing Future Generations Rights through National Institutions*, Cambridge, 2021, 302; T. WETZER, R. STUART-SMITH, A. DIBLEY, *Climate Risk Assessments Must Engage with the Law: Legal actions determine the allocation and magnitude of climate-related financial risk exposures*, in *Science*, 383, 2024, 152.

320 R.L. GLICKSMAN, D. KIM, K. GROTH-TUFT, 35-42.

political influence.[321] In these cases, courts may reject agency findings if they find that the reasoning lacks a sound scientific basis. While deference can prevent courts from overstepping their role, excessive reliance on agency determinations can also lead to weak enforcement of environmental protections.

To reconcile scientific uncertainty with the need for legal certainty, courts have increasingly relied on principles such as the precautionary principle, which allows judges to take preventive action even in the absence of complete scientific certainty. This approach recognizes that waiting for absolute proof of harm before implementing climate measures could result in irreversible environmental damage.[322] Additionally, courts are encouraged to enhance transparency in their reasoning, explicitly outlining how they interpret and weigh scientific evidence. By doing so, they can improve the consistency of climate litigation outcomes and provide clearer guidance for policymakers and litigants.[323]

Another essential aspect of improving climate litigation is fostering coherence between legal and scientific reasoning. One of the biggest challenges courts face is how to evaluate and interpret scientific data without a standardized framework. Scientific testimony often varies in reliability, and judges must determine which findings are credible and legally relevant. As seen in paragraph 1, the lack of clear guidelines for assessing expert testimony can lead to inconsistent rulings and undermine the integrity of climate litigation. To address this, legal scholars and policymakers have called for standardized criteria for evaluating scientific evidence, ensuring that courts apply consistent methods when assessing climate science.[324] Increasing judicial engagement with scientific experts is also crucial. In some jurisdictions, courts have begun to establish expert panels that assist judges in interpreting climate data, helping them make more informed decisions.

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321 *Ibid*.

322 K. SULYOK, 311-312; L.A. OMUKO, 52; M. HARITZ, *Climate change liability and the application of the precautionary principle*, in P. MARTENS, C.T. CHANG, *The Social and Behavioural Aspects of Climate Change*, London, 2010.

323 R.L. GLICKSMAN, D. KIM, K. GROTH-TUFT, 44-45; J.M. CHIN, J.B. BAKER, *Transparency and diversity to advance legal-scientific communication*, in *Forensic Science International: Synergie*, 9, 2024, 100557; THE PEW CHARITABLE TRUSTS, *How Organizing, Sharing Data Can Boost Court Transparency: Steps for making civil courts more open*, September 2013, https://www.pewtrusts.org/-/media/assets/2023/09/courts/how-organizing-and-sharing-data-can-boost-court-transparency.pdf.

324 R.L. GLICKSMAN, D. KIM, K. GROTH-TUFT, 2-10.

Several innovative approaches have been proposed to strengthen the integration of science into legal decision-making. Some courts have experimented with the creation of judicial science panels, composed of independent experts who provide neutral assessments of scientific issues in litigation. These panels help bridge the gap between the scientific and legal communities, ensuring that judges base their decisions on accurate and up-to-date scientific knowledge.[325] Additionally, legal institutions have started developing guidelines specifically for judges on how to assess climate science.[326] Programs like the Climate Judiciary Project offer training to judges, equipping them with the knowledge needed to navigate climate-related cases effectively. These initiatives can help reduce the risk of judicial misinterpretation of scientific evidence and improve the overall quality of climate litigation.[327]

Given the increasing complexity of climate-related disputes, judicial training has become essential. Climate litigation requires judges to understand not only legal doctrines but also the scientific principles underlying climate change. Training programs designed specifically for judges aim to enhance their ability to assess expert testimony and apply legal doctrines effectively. Initiatives such as the Climate Judiciary Project and the European Judicial Training on Corporate Climate Litigation have played a key role in equipping judges with the necessary tools to handle climate cases with greater competence.[328] By improving judicial literacy in climate science, these programs contribute to the fairness and effectiveness of climate litigation.[329]

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325 Some environmental courts incorporate scientific expertise directly into their institutional design, for example by appointing judges with scientific training alongside legally trained judges. This model, found for instance in India's National Green Tribunal, as well as in Kenya, Sweden, and Denmark, aims to enhance judicial capacity to handle complex environmental disputes involving technical or scientific evidence. These mixed benches represent a structural response to the challenge of integrating scientific knowledge into adjudication processes; see J.M. ANGSTADT, M.S. SCHINK, *Specialist environmental courts and tribunals: A systematic literature review and case for earth system governance analysis*, in *Earth System Governance*, 18, 2023, 100192.

326 See *above* paragraph 1.

327 See https://www.eli.org/climate-judiciary-project; https://www.youtube.com/watch?v=vP9xNwMpsmE; https://www.youtube.com/watch?v=3coQy_S5NYA.

328 See also https://www.biicl.org/events/11996/european-judicial-training-on-corporate-climate-litigation.

329 CLIENTEARTH, *Training judges in a triple planetary crisis*, January 2024, https://www.clientearth.asia/latest/news/training-judges-in-a-triple-planetary-crisis/; ENVIRONMENTAL LAW ALLIANCE WORLDWIDE, *Judicial Training to Protect the Climate*, November 2021, https://elaw.org/judicial-training-protect-climate.

Beyond training, the establishment of specialized environmental courts has proven to be an effective way to improve climate litigation outcomes. These courts concentrate judicial expertise on environmental and climate-related issues, ensuring that cases are adjudicated by judges with a deep understanding of scientific and legal complexities. Specialized environmental courts also streamline dispute resolution processes by tailoring procedural mechanisms to environmental cases.[330] Some of the most successful examples include the National Green Tribunal in India, which has jurisdiction over a wide range of environmental disputes, and the Land and Environment Court of New South Wales, which integrates scientific expertise into legal proceedings. The presence of specialized courts allows for more consistent and informed rulings, reducing the risk of judicial errors in climate litigation.

Despite these advancements, challenges remain in ensuring the effectiveness of climate litigation. One key issue is the need for greater international coordination in judicial training and specialized courts. Climate change is a global issue, yet legal approaches vary significantly across jurisdictions. Efforts to harmonize judicial training programs and establish best practices for climate litigation could improve the consistency of rulings across different legal systems.[331] Additionally, ensuring public trust in judicial expertise is crucial. Courts must maintain their credibility by demonstrating that their rulings are based on sound scientific reasoning and transparent legal processes. Strengthening judicial independence and ensuring that climate cases are decided based on objective legal and scientific criteria will be essential for the continued effectiveness of climate litigation.

Ensuring fairness and effectiveness in climate litigation requires a multifaceted approach. Courts must balance scientific uncertainty with legal certainty, develop mechanisms to align scientific reasoning with legal principles, and invest in judicial training and specialized courts. By adopting these strategies, climate litigation can become a more robust tool for enforcing environmental accountability and advancing climate justice. As climate litigation continues to shape environmental governance, the

330 J.M. ANGSTADT, M.S. SCHINK, 100192.
331 *Ibid*.

judiciary's ability to integrate science and law will be crucial in determining its success.

4. Conclusions

The integration of scientific expertise into climate litigation is no longer a peripheral concern but a decisive factor in the effectiveness of judicial intervention in climate governance. The need for courts to assess complex climate science in disputes over liability and causation underscores the limitations of traditional legal frameworks. Climate litigation is uniquely positioned at the intersection of legal reasoning and scientific evidence, requiring courts to adapt in ways that preserve both procedural fairness and substantive justice.

While procedural refinements such as expert registers, hot-tubbing, and standardized methodologies are crucial, they must be supplemented by institutional reforms that redefine the role of scientific expertise in judicial proceedings. Courts must move beyond a passive reliance on party-appointed experts and consider the integration of judicial scientific panels – multidisciplinary bodies tasked with assessing climate evidence in a neutral and transparent manner. Such panels, operating under the authority of national or international courts, could ensure consistency in the interpretation of climate data while mitigating the adversarial distortions inherent in expert testimony.

Moreover, a certification system for climate experts, akin to accreditation bodies in forensic science, could help regulate the quality of expert testimony. Courts could impose mandatory adherence to peer-reviewed methodologies, with independent review mechanisms ensuring that perverse incentives to manipulate data in favor of litigants are minimized. This would shift the balance of credibility in climate litigation from rhetorical persuasion to empirical rigor.

Yet, judicial capacity remains a bottleneck. Judges must be equipped with the necessary tools to assess technical evidence effectively. Training programs in climate science for members of the judiciary, as well as the inclusion of scientific advisors within court systems, would improve the ability of courts to handle scientific

uncertainty without either undue deference or unwarranted skepticism. The risk of climate science being either misinterpreted or sidelined in legal reasoning is too great to be ignored.

The greatest structural challenge in climate litigation is causation. Traditional legal standards – particularly the but-for test – are ill-suited to assess multi-causal, probabilistic phenomena like climate change. The rigidity of these frameworks has led to the dismissal of claims that fail to establish a direct, singular causal link between a defendant's emissions and a plaintiff's harm, even where the scientific consensus affirms significant contributory responsibility.

To reconcile legal reasoning with scientific complexity, courts must adopt causation frameworks that reflect cumulative responsibility. The NESS test provides a promising approach by acknowledging that while no single emitter is exclusively responsible for climate harms, each contributes to a broader set of necessary conditions that together cause the damage. This model allows liability to be established even in cases where emissions from multiple sources interact to produce a climate-related impact.

However, shifting to a NESS-based approach requires clear legal thresholds for material contribution. Courts must define standards for when an emitter's contribution is significant enough to warrant liability, balancing the need for accountability against the risk of overextending legal responsibility. This could be achieved through proportional liability models, where responsibility is distributed among defendants based on the measurable impact of their emissions. Such an approach would prevent large emitters from escaping liability simply because their emissions constitute only a fraction of global totals, while avoiding undue burdens on smaller actors whose contributions are marginal.

A further refinement is the market-share liability model, adapted from toxic tort litigation, where liability is assigned based on historical emissions data. By linking responsibility to quantifiable shares of total greenhouse gas contributions, this approach provides courts with a systematic method to allocate damages without requiring an exact causal chain between an individual emitter and a specific harm.

The evolution of climate attribution science has significantly improved the evidentiary basis for establishing liability in climate litigation. Advanced models now

allow researchers to quantify the extent to which anthropogenic emissions have intensified specific climate events, providing probabilistic assessments of causation that courts can use to assign responsibility.

The integration of such evidence into legal reasoning requires courts to accept probabilistic proof as legally sufficient – a departure from the traditional demand for deterministic certainty. This shift is already evident in landmark cases such as *Lliuya v. RWE*, where a German court accepted attribution science as a legitimate basis for assessing corporate liability. However, this approach must be refined to prevent excessive reliance on statistical correlations that lack robust scientific validation.

A possible solution is the creation of evidentiary presumptions based on well-established attribution findings. For instance, if a court recognizes that human-induced climate change has made a certain type of extreme weather event twice as likely, it could shift the burden of proof onto the defendant to demonstrate that their emissions did not significantly contribute to the harm. This inversion of the evidentiary burden aligns with the precautionary principle and acknowledges the inherent uncertainties in climate science without allowing them to obstruct justice.

The judicial adaptation to climate science has consequences beyond individual lawsuits. A coherent and science-informed approach to liability can reshape corporate behavior, state policies, and international legal norms. Companies facing increased litigation risks are already shifting toward enhanced climate disclosures, and some jurisdictions are integrating liability considerations into regulatory frameworks. Courts must recognize their role not merely as arbiters of past misconduct but as agents of normative transformation, capable of influencing the trajectory of climate governance.

However, judicial action alone is insufficient. The risk of fragmented legal interpretations across jurisdictions could create inconsistencies in how liability is assigned, undermining legal certainty. To address this, international judicial cooperation on climate litigation – through cross-border legal dialogues, shared precedents, and the harmonization of causation standards – should be actively pursued. The establishment of specialized climate courts or an international tribunal for climate-related claims could provide a forum for more coherent adjudication.

Further, climate litigation must remain accessible to those most affected by climate change. Current procedural barriers, including restrictive standing rules and the high costs of expert testimony, disproportionately disadvantage vulnerable communities. Strengthening collective litigation mechanisms, expanding legal aid for climate cases, and ensuring that climate liability frameworks integrate environmental justice considerations will be essential to maintaining litigation as an equitable tool for climate accountability.

The intersection of science and law in climate litigation demands an adaptive legal system that evolves alongside scientific advancements. Procedural reforms to expert testimony, flexible causal frameworks, and the integration of climate attribution science are crucial steps toward a litigation system that effectively reflects the realities of climate change. However, these developments must be accompanied by deeper structural changes, including judicial specialization, liability models that align with scientific complexity, and stronger international coordination.

Ultimately, climate litigation will succeed as an instrument of accountability only if courts can balance legal certainty with scientific integrity. The continued evolution of legal doctrines to incorporate cumulative and probabilistic causation will determine whether courts can meaningfully contribute to climate governance. If successful, this shift could transform climate litigation from a reactive measure into a proactive force – one that not only adjudicates past harms but also helps shape the legal and institutional architecture for a sustainable future.

CONCLUSION

The inquiry undertaken in this thesis reveals a persistent epistemological gap between legal reasoning and scientific reasoning in the context of strategic climate litigation. Law and science operate on fundamentally different epistemic wavelengths: legal adjudication demands definitive, binary outcomes grounded in normative standards, while scientific knowledge is inherently probabilistic, evolving, and contingent on empirical uncertainty. Climate litigation forces these divergent modes of reasoning into direct contact, exposing tensions in how courts handle evidence and proof. The core findings confirm that challenges surrounding expert evidence and causation in climate cases are not isolated procedural hiccups, but symptoms of this deeper law-science mismatch. In courts from the international to the national level, scientific facts and methods do not seamlessly translate into legal proof. This gap has concrete consequences: it can impede the success of legitimate claims and strain the judicial capacity to deliver climate justice in an informed, credible way.

One key insight is how courts struggle with expert evidence. Judges often lack specialized scientific expertise, yet they must evaluate complex climate data and expert testimony under adversarial conditions. The adjudicatory process tends to treat scientific input as just another piece of evidence, subject to partisan interpretation, rather than as a distinct form of knowledge with its own standards of validity. Divergent scientific testimony underscores the need for procedural innovations, reminding us that without adequate tools, judges are left navigating complex disputes in a zone of uncertainty. The thesis found that courts sometimes respond by minimizing engagement with the science – for example, by deferring to formal legal doctrines or burdens of proof to sidestep scientific uncertainty – which can lead to judgments that do not fully reflect scientific reality. This undermines the epistemic legitimacy of outcomes. In short, when judges are unable to effectively discern reliable climate science from less credible claims, the impartiality and accuracy of climate adjudication are at risk.

A parallel challenge arises with causation, the linchpin of liability in many climate cases. Climate change is a diffuse, global process with numerous contributors, which does not fit neatly into the proximate, linear causation models familiar to tort law. The thesis documented how traditional legal tests for causation – requiring proof that a defendant's emissions "caused" specific climate-related harm – clash with the probabilistic nature of climate science. Courts in several jurisdictions have held that while greenhouse gas emissions in general cause climate change, plaintiffs failed to prove that a particular defendant's emissions were the direct cause of a particular injury. Often judges pointed to the small share of global emissions attributable to any one actor, the multiplicity of contributors, or the lack of a single causal chain, as grounds to deny relief. Notably, the evidence presented in these cases frequently lags behind the state-of-the-art climate science, impeding causal claims. In many lawsuits studied, the scientific evidence submitted was not sufficient to satisfy even relatively flexible causation standards, let alone stricter "but for" tests. This is not because climate science is incapable of attributing specific impacts – indeed, modern attribution science can quantify the contribution of anthropogenic climate change to extreme weather events or damages – but because litigants and courts have been slow to integrate these cutting-edge methodologies. The result is an evidentiary gap: courts are often unconvinced of causation not due to scientific impossibility, but due to the legal system's inertia and discomfort in handling probabilistic evidence.

These findings carry a normative imperative. If courts are to fulfill their role in addressing the climate crisis, they must adapt their procedures and standards to more responsibly integrate scientific knowledge. The growing body of climate litigation has made one thing clear: judicial decisions in this domain are a co-production of legal and scientific rationality. Courts can no longer treat science as external or ancillary to legal reasoning; instead, they should embrace approaches that are epistemically robust – that is, grounded in the best available science and sound scientific reasoning – while still upholding fairness and due process. An important normative conclusion of this thesis is that judges have an "epistemic duty" to educate themselves about the scientific dimensions of the disputes they handle and to maintain cognitive control over scientific aspects of the case. In practice, this means a judge should not simply defer to experts or, conversely, dismiss technical evidence out of hand; rather, the judge should strive

to understand the core scientific concepts at stake (for example, the basics of climate models or probability of causation) well enough to evaluate the evidence in a reasoned way. By discharging this duty, judges can rely on scientific authority in a non-arbitrary manner, knowing why and how a piece of science is being accepted or rejected.

Encouragingly, recent developments demonstrate that such a bridging of legal and scientific epistemologies is both possible and already underway. The year 2025 has seen landmark moves at both international and domestic levels that exemplify a more science-literate judiciary. The ICJ's advisory opinion on climate change (July 2025) stands out as a symbol of progress. In that unprecedented proceeding, the Court explicitly acknowledged that tackling climate change "requires the contribution of all fields of human knowledge, whether law, science, economics or any other",[332] and it grounded its legal conclusions in the findings of the IPCC. The ICJ affirmed that the IPCC reports represent the best available science on climate change and treated those scientific conclusions as a factual baseline for its legal reasoning. For example, the Court unequivocally accepted that anthropogenic greenhouse gas emissions are the primary cause of global warming and associated climate impacts, citing robust scientific consensus. This marks a sea change in judicial epistemology: an international tribunal integrating scientific evidence at the foundation of its legal opinion, rather than treating science as an external matter. By doing so, the ICJ not only clarified states' legal obligations but also set a powerful example of how courts can engage with science openly and responsibly on issues of planetary importance.

At the national level, the Italian Supreme Court (Corte di Cassazione, Sezioni Unite) in July 2025 issued a pivotal order that similarly reflects the judiciary's evolving role in climate governance. In that decision (No. 20381/2025), Italy's highest court settled a jurisdictional question in favor of claimants, allowing a climate lawsuit against a major energy company (ENI) to proceed in Italian civil courts. The Court affirmed that Italian courts have jurisdiction to hear climate tort claims – including those involving harm linked to emissions from a company's foreign operations – thereby dismantling a key procedural barrier that had often stymied climate plaintiffs. Environmental groups hailed the ruling as "historic," confirming that climate justice

[332] *Obligations of States in respect of Climate Change*, [456].

is possible in Italy. Beyond the immediate procedural point, the symbolic significance is considerable: the judiciary signaled its willingness to hold powerful actors to account for contributions to climate change, implicitly recognizing that courts can and should adjudicate complex global harm when fundamental rights and public interests are at stake. This mirrors a broader trend of courts stepping into a climate governance role – from the Dutch Supreme Court's *Urgenda* ruling enforcing emissions targets, to the German Constitutional Court's 2021 decision tying climate action to human rights, to ongoing cases in the ECtHR pressing states on their duty of care to the climate. Such developments underscore that the judiciary is becoming an important forum for climate accountability, complementing (or catalyzing) legislative and executive action. The growing judicial role in climate governance is a double-edged sword: on one hand, it reflects judges' recognition of the urgent moral and legal imperatives at play; on the other, it places a burden on courts to elevate their fact-finding and reasoning processes so that outcomes are not only just but also seen as scientifically credible and legitimate.

In light of these findings and developments, the thesis advances several forward-looking recommendations to improve the epistemic robustness of judicial decision-making in climate disputes. These proposals aim to bridge the science-law gap so that courts can fulfill their adjudicative duties without compromising on truth or justice:

1. *Enhance Impartiality of Expert Evidence*: Courts should reform how expert knowledge is brought into the courtroom to reduce bias and partisanship. Rather than relying solely on adversarial experts hired by each party (whose testimony can be diametrically opposed), courts can make greater use of independent or court-appointed experts, neutral expert panels, or *amicus curiae* briefs from scientific bodies. For instance, the ICJ's engagement with IPCC scientists offers a model of institutionalizing neutral scientific input. Domestic courts might develop rosters of accredited climate scientists available to serve as neutral experts or commission joint expert reports agreed upon by all parties. By improving the impartiality of scientific evidence, judges will be better equipped to ascertain factual truths. Additionally, clearer *criteria* for evaluating scientific testimony should be established, akin to Daubert standards in U.S.

law, to ensure that any expert opinion admitted in a climate case meets basic thresholds of methodological soundness and relevance. This thesis argues for transparent judicial reasoning on scientific issues: judgments should openly explain how expert evidence was assessed and why certain scientific claims were credited or dismissed. Such transparency not only improves the quality of the decision but also builds public trust by showing that the court's treatment of science was reasoned rather than arbitrary.

2. *Adapt Causation Standards to Climate Science*: To deal with the unique causal complexity of climate harms, courts should consider more flexible doctrines of causation and burden of proof. Rigid "but-for" causation is often ill-suited to injuries resulting from cumulative global emissions. Instead, legal systems can embrace probabilistic and risk-based causation approaches that align with scientific evidence. There is growing scholarship suggesting that courts can accept attribution science findings as proof of causation on a probabilistic basis – for example, if a defendant's emissions increased the risk or intensity of a flood that damaged the plaintiff's property, that should suffice to establish causation even if one cannot prove the flood would not have occurred "but for" those emissions. Indeed, analogies from toxic tort litigation (such as asbestos cases) show that probabilistic causation has been judicially managed before: courts have, at times, imposed liability based on epidemiological statistics and contributions to risk when direct proof was impossible. Climate cases could follow suit. Concretely, legal standards like "material contribution to harm" or "substantial contribution" can lower the causation threshold to a level consistent with climate science, requiring the plaintiff to show that the defendant's emissions contributed significantly to the risk or magnitude of the harm, rather than proving sole causation. In some jurisdictions, we already see movement in this direction: for example, Italian courts in non-compensatory (preventive) climate actions have relaxed the requirement of direct proof of causation, allowing judges to order protective measures based on broader scientific evidence and consensus about risk. Similarly, other legal systems have invoked the precautionary principle to favor preventive action in the face of scientific uncertainty. This thesis supports such evolutions. It also suggests

shifting burdens of proof in appropriate cases: where defendants control relevant information or where harm would be catastrophic, the onus could be on major emitters to prove their emissions are not causing harm, rather than on plaintiffs to prove they are. Strategies like these would help align legal causation with the collective, probabilistic causation that climate science recognizes, thereby closing the evidentiary gap that has so far hampered effective redress.

3. *Build Judicial Capacity and Structural Reform*: Bridging epistemologies requires investment in the capacity of the judiciary itself. This thesis advocates for systematic judicial education programs on climate science and more generally on scientific literacy for judges. Judges handling climate cases should have access to training workshops, interdisciplinary conferences, or bench guides that distill key scientific concepts (such as carbon budgets, climate attribution techniques, uncertainty quantification, etc.). A better informed judiciary will be less likely to feel out of its depth when faced with technical evidence. Additionally, there is merit in exploring specialized forums for climate litigation. Just as some countries have environmental courts or tribunals, the complexity of climate science might justify specialized climate benches or the consolidation of climate cases before judges with scientific expertise. Even within generalist court systems, procedural rules could be modified to allow judges more leeway to appoint technical advisors or to pose questions to expert witnesses directly (rather than only through party cross-examination). Another forward-looking idea is to develop "climate evidence toolkits" – essentially protocols or best-practice guidelines – that courts worldwide can draw on when managing scientific evidence. These could be living documents created by jurists and scientists collaboratively, providing checklists for evaluating climate models, standards for admitting climate studies, and guidance on articulating findings in judgments. Finally, further research and interdisciplinary dialogue should be encouraged. Academia, including future doctoral research, can support courts by mapping how innovative evidentiary approaches are working, by refining attribution science to better meet legal standards, and by studying the impact of climate judgments

on policy. Continuous feedback between the scientific community and the legal community will be crucial to refine the methods by which courts absorb scientific knowledge and to ensure that each climate case contributes to a stronger jurisprudence for the next.

In sum, the conclusion of this thesis is both cautionary and hopeful. The cautionary element lies in recognizing that without conscious adaptation, judicial processes risk epistemic failure in the face of scientific complexity – either by misinterpreting climate evidence or by excluding it in the name of legal formality, potentially leading to unjust outcomes. The hopeful element is grounded in the belief, reinforced by the examples and reforms discussed, that law is capable of evolution. Courts are learning institutions as well as dispute-resolvers. Through incremental changes in practice and bold normative shifts, they can better align legal truth-seeking with scientific truth. Persuasive, just climate judgments will increasingly be those that manage to harmonize scientific and legal rationality, demonstrating that the findings are both legally sound and scientifically informed. Ultimately, bridging the epistemological gap between science and law is not a luxury or an academic abstraction – it is a practical necessity for the judiciary in an age of climate change and other science-driven challenges. A court that can engage with climate science in an open, informed, and methodologically transparent way will not only do justice in the cases before it, but will also bolster its own legitimacy in the eyes of the public. Furthermore, innovations developed for climate litigation may have ripple effects across other domains where science and law intersect (such as public health, technological risks, or pandemic response), helping to modernize legal systems for the complexities of the 21st century.

The growing wave of strategic climate litigation is, in effect, putting "science on trial" – but this need not pit science against law. Instead, as this thesis has argued, it is an opportunity to build a more epistemically robust justice system. By responsibly bridging scientific and legal ways of knowing, courts can rise to the challenge of climate change. They can ensure that as our planet's prognosis is debated in courtrooms, the outcomes are not only legally sound but scientifically grounded. Such a transformation, the thesis concludes, is essential if the rule of law is to contribute meaningfully to addressing one of the most profound and urgent issues of our time.

The judiciary's responsibility in the climate crisis is clear and growing – and so too is its capacity, given the right reforms, to deliver informed and principled justice for a warming world.

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