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A history of the 1.5°C target

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Abstract

The 1.5°C target is now widely considered as the maximum acceptable limit for global warming. However, it is at once recent and, as it appears increasingly unreachable, already almost obsolete. Adopted as an aspirational target in the Paris Agreement in 2015, the 1.5°C objective originated with a political impetus within UNFCCC negotiations. The Intergovernmental Panel on Climate Change (IPCC) endorsed this policy-driven target when it produced the Special Report on 1.5°C. This article highlights the continuity of the history of the 1.5°C target with that of the 2°C target, but also the differences between the two. Because the 1.5°C target considerably raises the bar on mitigation efforts, it exacerbates political tensions and ambiguities that were already latent in the 2°C target. This article retraces the emergence of the 1.5°C in diplomatic negotiations, the preparation of the IPCC Special report on 1.5°C, and the new kinds of debates they provoked among climate scientists and experts. To explain how an unreachable target became the reference for climate action, we analyze the "political calibration" of climate science and politics, which can also be described as a codependency between climate science and politics.

This article is categorized under:

- Integrated Assessment of Climate Change > Integrated Assessment Modeling
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KEYWORDS

1.5°C target, climate policy target, IPCC Special Report, Paris Agreement, science-policy interface

1 | INTRODUCTION

An increase of 1.5°C in average global temperatures compared to preindustrial levels is now widely entrenched as the maximum acceptable limit for global warming, although it is at once fairly new in climate discussions and almost obsolete.[1] The "1.5°C target" first appeared discreetly during the preparation of the 2009 Copenhagen conference, gradually gained support over the following years, and was eventually adopted as an aspirational target in the 2015 Paris Agreement. Meanwhile, the world moves closer to overshooting it every year: with current warming since 1850 estimated at between 0.8 and 1.3°C (Intergovernmental Panel on Climate Change [IPCC], 2021) and greenhouse gas emissions continuing to rise, the target appears increasingly unattainable. And yet calls to "Keep 1.5°C alive," to use the phrase put forward by the COP26 Presidency (UK Government, 2021, cited in Schenuit, 2022), have been growing louder. How did an almost impossible target become the point of reference for climate action? How does it maintain its legitimacy despite the incompatibility between ambitions and actions that it makes evident?

This article retraces the short but eventful history of the 1.5°C target. It is a direct extension of the literature on the 2°C target (Aykut & Dahan, 2014; Cointe et al., 2011; Morseletto et al., 2017; Randalls, 2011), because the emergence and establishment of the 1.5°C target is itself an extension of the history of the 2°C target. This history also invites us to question the relations between climate science and politics in the light of the contradictions and ambiguities behind the 1.5°C target. Previous analyses have emphasized the co-production of climate science and policy (Miller, 2004) and, more recently, described the effect of mitigation pathways as performative (Beck & Mahony, 2018b). We argue that the history of the 1.5°C target is better described in terms of a codependency of science and policy. On the one hand, science—especially as mediated by IPCC reports, but also by Structured Expert Dialogues under the UNFCCC—informs and shapes climate negotiations, giving legitimacy to targets and/or highlighting their inconsistencies with current policies. On the other hand, the quest for policy relevance influences scientific research agendas to some extent. This generates tensions and difficulties on both sides of the science-policy interface. These are further exacerbated in the case of the disciplines featured in Working Group III (WGIII) of the IPCC, which grapple directly with the societal, political and economic logic of emissions reductions objectives.

Our history of the 1.5°C target is based on our previous work on climate negotiations, climate scenarios, the IPCC, and integrated assessment models (IAMs). It builds on a diversity of empirical material collected in several projects between 2015 and 2021: a set of interviews with integrated assessment modelers, an ethnographic study of COP21, and a master's thesis.[2] We complemented this material with a review of the literature on post-Copenhagen climate negotiations, as well as on the evolution of climate science–policy interactions.

Histories of the 2°C target highlight its co-production by science and politics over several decades. By contrast, the 1.5°C target originated in climate negotiations, and scientists only really started to consider it (somewhat reluctantly) once it was politically approved. The target remains a source of discomfort among scientists, as shown in November 2022 by the call from Scientist Rebellion to admit that "there is no plausible pathway to 1.5°C".[3] We thus begin by retracing the emergence of the 1.5°C target in UNFCCC negotiations ahead of COP21. We then analyze the preparation of the IPCC Special Report on 1.5°C (SR1.5), and the debates and criticisms that the target provoked among climate experts. To put this history in perspective, we continue with a flashback to the time of the production of the first 2°C mitigation scenarios, which allows us to discuss the "political calibration" of climate targets (van Beek et al., 2022) and to account for some of its contradictions.

2 | THE IRRUPTION OF THE 1.5°C TARGET AT THE NEGOTIATING TABLE

While the 2°C target has a relatively long, intricate and entwined political-scientific history, the 1.5°C target emerged relatively rapidly, and its origins are clearly on the diplomatic side. The 2°C long-term temperature target was constructed in long and complex exchanges between climate science and policy (Cointe et al., 2011; Randalls, 2011). After the adoption of the UNFCCC in 1992, the literature focused on what was to be stabilized: greenhouse gas emissions, atmospheric concentrations or global temperature. In 1996, Germany adopted the 2°C temperature target, associated with a target for greenhouse gas concentrations, soon followed by the European Union. However, at the international level the IPCC focused on emissions and concentrations, and negotiations were concerned with short-term emissions reduction objectives, which were the focus of the Kyoto Protocol. This changed in 2007, when the Bali Action Plan referred to a long-term global goal. Over this period, the success of the "burning embers" diagram, first published in 2001 in the IPCC Third Assessment Report, established the increase in global temperatures as a measure of climate risks (Mahony & Hulme, 2012).[4] As a result, during the 2000s the 2°C temperature threshold became increasingly prominent in the scientific literature and in global politics.

The 1.5°C target has a shorter and more overtly political history. It first appeared in the lead-up to the 2009 COP15 in Copenhagen, as part of discussions on the long-term global goal that were converging toward a 2°C limit (Cointe et al., 2011; Guillemot, 2017; Livingston & Rummukainen, 2020).[5] The Alliance of Small Island States (AOSIS) considered 2°C an unacceptable level of warming and an existential threat (Livingston & Rummukainen, 2020, p. 11; Tschakert, 2015). In 2009, they engaged in diplomatic work to advocate for 1.5°C instead, building an alliance with the Least Developed Countries (LDC) group and rallying the support of heads of states and ministers in the Climate Vulnerable Forum (ICCCAD, 2016). They viewed the 2°C target as the objective of the rich countries, and 1.5°C as the only safe limit for poor and vulnerable countries. The Copenhagen Accord set 2°C as the limit to the increase in global temperature, while concluding on an invitation to consider "strengthening the long-term goal... including in relation to temperature rises of 1.5 degrees Celsius" (UNFCCC, 2009, para. 12).[6] One year later in Cancun, the COP adopted the objective of "hold[ing] the increase in global average temperature below 2°C above pre-industrial levels" and decided on a periodic review of the adequacy of this goal, confirming the possibility of strengthening it to 1.5°C (UNFCCC, 2010, paras. 4 and 138).

The first review took place from 2013 to 2015 and included a Structured Expert Dialogue (SED) between parties to the UNFCCC and over 70 scientific experts (UNFCCC, 2015a). The implications of limiting global warming to 1.5°C versus 2°C were a central topic in all four sessions of the SED (Tschakert, 2015; UNFCCC, 2015a). One of the 10 messages put forward in the SED report was that "while science on the 1.5°C warming limit is less robust, efforts should be made to push the defence line as low as possible" (UNFCCC, 2015a, p. 33). This temperature was in fact outside the range considered in the IPCC's AR5, the most recent assessment of the literature available at the time. Only a handful of emissions scenarios among the 1200 in the AR5 WGIII scenarios database had explored the likelihood of staying below 1.5°C of warming (UNFCCC, 2015a, p. 92 para. 132). Regarding impacts, experts in the SED repeatedly noted that the literature was too scarce to robustly assess the difference between 1.5°C and 2°C (UNFCCC, 2015a, p. 67 para. 27, p. 73 para. 53). All the same, as Tschakert (2015, p. 8) noted about the fourth session of the SED, the "consensus... was that a 2°C danger level seemed utterly inadequate."

The output of the SED helped AOSIS make the case for 1.5°C. Indeed, the SED itself was part of their negotiating strategy and among their achievements. As noted by Benjamin and Thomas (2016, pp. 2–3) and Ourbak and Magnan (2017, p. 2203), it was AOSIS that pushed the initiative to hold a Structured Expert Dialogue that would consider strengthening the long-term global goal and conclude before the Paris negotiations, and that later advocated for the SED's report to be put before the COP. In parallel, they garnered support for the 1.5°C target from NGOs and from other countries, especially within the so-called High Ambition Coalition (Fry, 2016; Ourbak & Magnan, 2017). The eventual adoption of 1.5°C as an aspirational goal in the Paris Agreement (UNFCCC, 2015a, 2015b, art. 2) was nonetheless the result of intense and difficult negotiations (Benjamin & Thomas, 2016; Brun, 2016; Ourbak & Magnan, 2017).

Scientists and politicians are not alone in the game. Other groups of actors—think tanks, NGOs, philanthropic foundations, etc.—interact with researchers and political negotiators through networking, coordination, capacity building, lobbying and financing. These other actors played a central role in the inclusion of the 1.5°C objective in the negotiations and in the Paris Agreement, as shown by Morena (2017). From 2010, several foundations involved in climate discussions sought to change their strategy after what they saw as the failure of the Copenhagen COP. At the instigation of the European Climate Foundation (ECF), international groups, NGOs and think-tanks (Climate Analytics, Ecofys, PIK, CAN, and WRI, to name a few) came together in the International Policies and Politics Initiative (IPPI) to pool resources and strategies to build positive "momentum" around COP 21 in Paris (Morena, 2017). Think tanks and foundations from developed countries thus provided support to negotiators from AOSIS and LDCs to promote the 1.5°C target.

In the immediate aftermath of COP21, the adoption of the 1.5°C target was met with surprise and skepticism (Livingston & Rummukainen, 2020; Guillemot, 2017; Hulme, 2016). Many climate scientists considered it unrealistic, especially since it came without proportionate commitments to reduce global greenhouse gas emissions. Despite this reluctance from scientists to support a politically driven target, the key role of the SED shows that science was instrumental in the process, identifying pockets of consensus and large areas of insufficient research.[7]

3 | THE SPECIAL REPORT ON 1.5°C: FROM SKEPTICISM TO OWNERSHIP

In December 2015, alongside the Paris Agreement, the COP requested that the IPCC provide a Special Report on global warming of 1.5°C, to be delivered in 2018 to inform the political negotiations toward the first revision of the NDCs. In its April 2016 plenary, the IPCC decided to prepare three special reports: one on land, one on oceans and the cryosphere, and one on the 1.5°C target, described (and ultimately titled) in full as "a Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways... in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty." This broadened the scope of the Special Report to encompass sustainable development and poverty eradication, which was necessary to get all countries on board (interview with Masson-Delmotte, 2018). In this section we will see that SR1.5, initially met with reluctance by scientists, has been an unprecedented success, with scientific, methodological and conceptual innovations and record media coverage.

Responding to government requests is part of the IPCC's mandate. Nevertheless, the request for a report on the 1.5°C target was first met with concern or discontent among most scientists. As this report was obviously responding to a political demand, many saw it as a political instrumentalization of the IPCC, "a form of hypocrisy, raising false hopes for the public and the most vulnerable countries" (Boucher et al., 2016). Many, for whom the 1.5°C target was a "lost battle," saw this research as a waste of time and resources. Moreover, producing the report in such a short timeframe, when very little work existed on impacts or trajectories corresponding to 1.5°C, was a real challenge. The WGI co-chair in charge of SR1.5 therefore had reasons to fear that few researchers would want to get involved (interview with Masson-Delmotte, 2018).

However, the opposite happened: 560 researchers applied to be authors and 42,000 comments were sent in during the review phases—a record for IPCC reports (although some scientists refused to participate). Just as with the mention of the 1.5°C target in the Paris Agreement, scientists' position on the SR1.5 report evolved very quickly, from outrage to acceptance and ownership.[8] The 1.5°C target's official status changed the situation, giving it an authority that legitimized research. Many researchers wanted to participate in the political process, and to avoid cutting themselves off from the developing countries (Renaudin, 2019). Finally, just as European Union funding encouraged IAM modelers to produce pathways limiting warming to 2°C (Cointe et al., 2019; Lövbrand, 2011), funders have begun to support research on the 1.5°C objective.[9]

In August 2016, a scoping meeting was organized by the co-chairs of the IPCC's three working groups to produce a first outline. The new IPCC Bureau, appointed just before COP21, intended to take advantage of this request in order to establish the target as a topic for scientific inquiry, and to correct some of the shortcomings pointed out in previous reports, such as the importance of carbon dioxide removal (CDR) (see below). The innovations generated by SR1.5 illustrate scientists' ability to reformulate questions to make them scientifically interesting and show that, as is often the case, their ability to align to political expectations opens up new scientific perspectives (Lövbrand, 2011) and provides an "innovation boost" (Cointe et al., 2019). One of the main novelties of the report lies in the organization of the work behind its production. While in previous IPCC reports the three working groups worked separately, scientists from all three WGs participated in the preparation of the five chapters of SR1.5, which were conceived as complementing and responding to each other (Renaudin, 2019). The social sciences, in particular, played a more important role than before. One of the authors' ambitions was to better link climate change with other environmental and social issues such as poverty, health and inequality.

The request in the Paris Agreement for a special report inspired calls for papers and dedicated research programs that rapidly increased the amount of work on the impacts and implications of 1.5°C of warming (Livingston & Rummukainen, 2020). The first task of the report was to document the difference between the impacts of 1.5°C and 2°C of warming. A large body of new work showed very significant differences in a variety of areas, particularly for ecosystems. The second message of SR1.5 concerned the pathways to reach this objective: not exceeding 1.5°C of warming before the end of the century implies reaching CO_2 neutrality by 2050. The 1.5°C objective is thus associated with the "net zero emissions" objective: CO_2 neutrality is physically necessary in order to stabilize global temperatures, and the deadline for achieving it gets closer as the temperature target gets more ambitious. Another outcome of SR1.5 is the establishment of a close connection between the target and the short term: "1.5°C compatible" trajectories require CO_2 emissions to be halved by 2030.

To what extent should the pathways provided by integrated assessment models be allowed to rely on CDR to achieve such drastic decarbonization? This question was hard-fought in the SR1.5 writing process (van Beek et al., 2022). In AR5, all scenarios that achieved warming below 2°C by 2100 relied on a temporary overshoot of atmospheric CO_2 concentrations, followed by the removal of CO_2 from the atmosphere in the second half of the 21st century through CDR (also referred to as negative emission technologies, or NETs)—the form most used in the models being bioenergy with carbon capture and storage (BECCS). This large-scale use of BECCS, a type of technologies that do not exist on the required scale and that may have negative side effects, provoked heated debate and criticism (Anderson & Peters, 2016). In the months and years following the release of AR5, many articles and reports have been published on CDRs, analyzing their potential, limitations and risks (Fuss et al., 2018). One issue with BECCS was the huge areas of arable lands it requires for bioenergy production, at the expense of food production and biodiversity. With its inclusion of questions of ecology, development and poverty, SR1.5 provided a more critical perspective on BECCS. It introduced different categories of CDR, highlighting "nature-based solutions" (e.g., afforestation or soil carbon sequestration). However, the issue of finding "an acceptable level of overshoot" gave rise to intense science–policy negotiations (van Beek et al., 2022, p. 197). A few "no overshoot" scenarios reaching 1.5°C without CDR (10 out of 578) were published just before the SR1.5 deadline. These scenarios, responding to the criticism from experts and civil society that most scenarios favored technological solutions without questioning the dominant economic growth paradigm, made very strong assumptions of global decrease in energy consumption and demand, along with large-scale afforestation.

The report could not avoid the delicate question of whether it is in fact feasible to limit warming to 1.5°C at all. Several IPCC meetings were organized to address this issue. Asked to answer what was "not a scientific question" (interview, SR1.5 author, 2019), the SR1.5 authors responded by dividing feasibility into six dimensions (geophysical, environmental, technological, economic, sociocultural, and institutional) that "interact in complex and place-specific ways" (IPCC, 2018, pp. 71–72). Dealing with feasibility in several chapters as well as in a dedicated box, SR1.5 claims that limiting global warming to 1.5°C is "geophysically feasible" (since past emissions do not yet exceed the limit) and specifies the associated feasibility conditions. Through this new example of boundary work, the report confirms the geophysical feasibility of the goal while drawing a boundary between this and more political forms of feasibility. This "geophysical feasibility" allowed SR1.5 to maintain policy neutrality while conveying the message that it was not too late to stay below the 1.5°C threshold—depending on technological, economic, social and political choices that do not lie within the "policy neutral" remit of the IPCC.

SR1.5 received remarkably extensive, high-profile and long-lasting media coverage, far beyond previous IPCC reports (Boykoff & Pearman, 2019). Several factors probably contributed to this success. The IPCC Bureau devoted a great deal of effort to communication (careful illustrations, media training for the authors, etc.), and wanted the report to reach a wide audience beyond policymakers (interview with Masson-Delmotte, 2018). NGOs and foundations were deeply involved in promoting the report and its conclusions (Morena, 2017). Its publication coincided with the rise to fame of Greta Thunberg and the proliferation of school strikes and climate movements in 2018, contributing to its success. However, headlines and slogans were often limited to very simple watchwords—essentially "only 12 years left to save the climate." This claim has been criticized as not reflective of the substance of the report (Asayama et al., 2019), and the scientists involved preferred to emphasize the message that "every tenth of a degree counts." By contrast, some of the report's messages, particularly the considerable changes needed to limit warming to 1.5°C—including carbon removal—were scarcely discussed. NGOs refer to the report to claim that the target is still achievable and that "the blockage is not technical, but political,"[10] without mentioning that almost all pathways to limiting global warming to 1.5°C require large amounts of CDR (Renaudin, 2019).

4 | THE IMPOSSIBLE 1.5°C TARGET: HYPOCRISY OR PUSH TO ACTION?

In terms of the failure to focus clearly on its concrete implications, the 1.5°C target fared no better than the 2°C target, which has been analyzed as a "disembedded object" (Morseletto et al., 2017) or as part of a "schism of reality" (Aykut, 2016; Aykut & Dahan, 2014). Ahead of COP21, the discrepancy between ambition and action was the main cause of criticism of the 2°C target and, a fortiori, of skepticism about raising the ambition to 1.5°C. SR1.5 reaffirmed the need for rapid and radical action and the inadequacy of existing policies, but at the same time it gave scientific legitimacy to the 1.5°C target. It also clarified some debates, especially on CDR and feasibility (see above). Despite the overall shift in climate scientists' attitudes toward the 1.5°C target, some criticisms persisted, especially with regard to the ambiguous character of such an aspirational target. These debates were initially largely confined to academic publications, but made their way into the media during COP27 in 2022.[11]

Climate scientist Kevin Anderson has denounced the "duality" and hypocrisy of keeping targets that currently cannot be achieved without massive amounts of negative emissions while not recognizing the revolutionary nature of the transformations that this implies (Anderson, 2015). This line of criticism reflects the still-controversial status of CDR and negative emissions, which are sometimes denounced as a way of delaying action and preserving the status quo (Carton, 2020). The IAMs that produce mitigation pathways with high negative emissions have been subjected to lively academic debate (Anderson & Jewell, 2019), although their reliance on NETs was somewhat moderated following SR1.5.

Questioning the political usefulness of the target, climate policy expert Oliver Geden has argued that, given that models always seem able to produce emissions pathways that are compatible with increasingly ambitious targets using devices such as NETs or overshoot, the "doomsday clock" is stuck at "five minutes to midnight" (Geden, 2016a). In other words, the urgency remains but it is never too late, so ambitions can be preserved while action is postponed. This recalls what Aykut et al. (2020) call "incantatory governance": the ambition of climate mitigation targets acts not as a binding limit, but as a signal that is supposed to set relevant actors in motion in the right direction. It is thus imperative that the target appears urgent, but within reach. In a less confrontational fashion, there have also been calls to not let the long-term global target obscure discussions on short-term, local or national transformations—including the production of expertise and scenarios relevant to short-term, local-scale action (Boucher et al., 2016).[12]

These criticisms coexist with another position on the role of the 1.5°C target, which recognizes the "incantatory" character of the target but considers that character as its *raison d'être*. In this view, whether the target is reached or overshot is secondary; the purpose of the 1.5°C target is to meet the demand of poor and vulnerable countries, to give them diplomatic weapons (Tschakert, 2015) and to raise global ambition. As a SR1.5 author who worked on the box on feasibility puts it: "In fact [1.5°C] is a way of reinforcing the climate objective more than a climate objective as such."

Finally, the tensions and contradictions of the 1.5°C target have drawn attention to potential changes in the relations between climate science and politics, and in particular to the role of the IPCC. Some scholars have suggested that these tensions challenge the IPCC's "policy neutrality" (Lahn, 2022) and called for reflection on the future role of the IPCC (Beck & Mahony, 2018b). All the same, following SR1.5, the IPCC's framing of the boundary between policy relevance and policy prescription was reaffirmed: "We have delivered the message to governments, we have provided them with the evidence, and it is up to them to decide on the final feasibility step," the co-chair of WGIII, Jim Skea, said at a press conference on the report.

5 | THE "POLITICAL CALIBRATION" OF IAMs TO PRODUCE LOW-CARBON PATHWAYS

To understand the 1.5°C target and the science-politics interactions that hold it together, it is useful to look back to the 2°C target. Many of the ambiguities and contradictions of the 1.5°C objective were already present with the 2°C target, only not as glaringly so. These ambiguities and contradictions were made manifest in the development of low emissions pathways that are compatible with increasingly ambitious temperature limits. These pathways are a keystone of IPCC reports, and are also used to assess mitigation options. They are instrumental in bringing climate policy targets into existence and maintaining them over time. Since the mid-2000s, a small but growing research community has emerged to develop the integrated assessment models that are used to explore long-term mitigation options (Cointe et al., 2019; van Beek et al., 2020).[13]

van Beek et al. (2022, p. 198) proposed the concept of "political calibration" to analyze the interplay between IAM research and climate policymaking. They define it as "a process of iterative adjustment between modelers and policymakers, in which the fit and focus of the model analysis and the requirements of the policy community are negotiated." It was through this process of political calibration, they show, that the 1.5°C target made its way into the range of explored futures.

Before the Paris Agreement, the 1.5°C limit was outside the range of explored pathways. It was deemed unrealistic, and thus irrelevant (Livingston & Rummukainen, 2020; van Beek et al., 2022). After the Paris Agreement, pathways compatible with 1.5°C became widespread in the literature. A similar process had occurred for the 2°C target a decade earlier. Prior to 2007, there were hardly any scenarios compatible with a 2°C target. Among 177 stabilization scenarios assessed in IPCC AR4, only six fell in the range of 2.0–2.4°C warming, and none below 2°C (IPCC, 2007, p. 20). IAM researchers really started to explore pathways likely to limit global warming to 2°C after the IPCC Expert Meeting on New Scenarios held in Noordwijkerhout in 2007 (Moss et al., 2008). At this meeting, a new suite of reference emissions scenarios was selected from the available literature to replace the scenarios defined in the Special Report on Emissions Scenarios (or SRES): the "Representative Concentration Pathways" (RCPs). Among the contenders was RCP2.6, a recent scenario published by van Vuuren et al. (2007) where GHG concentrations peak and decline before stabilizing at 400 ppm CO_2 equivalent, and which was considered compatible with a "below 2°C" goal.

At the time, this was the lowest stabilization scenario in the literature. As one IAM modeler explained us in an interview, this scenario was developed precisely to remedy the lack of modeling studies on the conditions needed to meet the 2°C target advocated by the EU, following a discussion between this modeler and Bert Metz, then the head of IPCC Working Group III. Studies considering response strategies had until then focused on stabilization at 550 ppm, which was increasingly seen as insufficient to meet a 2°C target (interview, Modeler 2, 2015). The scenario required drastic and rapid emissions reductions in all sectors, as well as BECCS to enable so-called "negative emissions" later in the century. Despite the exploratory character of this scenario, participants in the Noordwijkerhout meeting, including researchers, government officials, international organizations and NGOs, favored it as the low-end option. Ahead of the meeting, a position paper prepared by Malte Meinshausen and Bill Hare made the case for the RCP2.6 scenario based on two main arguments: its consistency with the long-term objectives considered in political discussions, and the scientific interest of using its "peak-and-decline" shape to study the climatic response to declining greenhouse gas concentrations (Moss et al., 2008, Appendix 4).[14] The meeting's final report reflects this position and uses the same arguments (Moss et al., 2008, p. xix).[15]

To confirm the selection of this scenario, other IAM teams were asked to try and reproduce it with other models (Weyant et al., 2009). Gradually, 2°C-compatible scenarios became common in the literature, even though they could be extremely challenging to model (Guivarch & Hallegatte, 2013, p. 188). Despite their optimistic assumptions and drastic emissions reductions requirements, they contributed to ascertaining the feasibility in principle of the 2°C target (Lövbrand, 2011; van Beek et al., 2022).[16] This established negative emissions as an all but indispensable element in the portfolio of climate action (Beck & Mahony, 2018a). In a way, BECCS and NETs expanded the so-called "possibility space."

What happened following the adoption of the 1.5°C target was similar. IAM teams developed pathways compatible with 1.5°C to meet the demand, relying on temporary overshoot and negative emissions, but also expanding the range of mitigation options they considered (van Beek et al., 2022, p. 198). Back in 2017, one modeler explained that when he started, for him "2°C was impossible, but as I kept seeing it, it has become something very common. The same thing is happening with 1.5°C even if there are many arguments against it" (interview, Modeler 3, 2017). All the same, it is no secret that these scenarios are very challenging to produce: they stretch models to their limits. The same modeler explained: "For us, 1.5°C is very difficult, very costly. When we model, we open up a spectrum of possibilities, and this one we had not anticipated at all. We are working at the limits of the model, of the equations, of the production functions, with substitution effects that drive us to extreme cases, and we have asked ourselves whether our model is really credible for this kind of scenarios" (interview, Modeler 3, 2017). In other words, in order to achieve 1.5°C pathways, modelers have needed to use such strong assumptions that it put to the test their ability to control or trust their models. This was already the case for 2°C pathways: for instance, Guivarch and Hallegatte (2013, p. 188) note that "van Vuuren et al. (2010a, b) indicate that the low stabilization levels compatible with the 2°C target are close to the maximum achievable emissions reduction potential in their model." A similar caveat is expressed in Annex III to the WGIII contribution to IPCC AR6, which remarks that "overshoot was particularly allowed for low concentration and temperature targets as many models could not find a solution otherwise" (IPCC, 2022, p. II-55).

Modelers' persistence in "working at the limits" in order to model pathways to 1.5°C may appear paradoxical, but it can be explained by the fact that policy relevance is a constitutive dimension of IAM research (Cointe et al., 2019; Lövbrand, 2011; van Beek et al., 2020, 2022), and indeed of "WGIII science" more broadly. In fact, the multiplication of 1.5°C scenarios spurred by SR1.5 has made it possible to correct some of their initial excesses, particularly on CDR; and the debates around NETs and IAMs have opened up new directions of research, for instance on feasibility, no-overshoot scenarios and, more recently, post-growth scenarios.

6 | CONCLUSION

The 1.5°C objective for climate policy action is a continuation of the 2°C objective and is subject to the same ambiguities, especially regarding the use of negative emissions. With its origins in a political impetus provided by a broad coalition of vulnerable states, NGOs and philanthropic foundations in UNFCCC negotiations, this objective is even more unattainable than 2°C. And because it is considerably more demanding, it intensifies and brings to the fore political tensions and inconsistencies that were already present.

Faced with these contradictions, scientists initially reacted with surprise, concern or skepticism when the target was adopted in 2015. This changed with the preparation and publication of IPCC SR1.5: by producing this report, the IPCC endorsed this policy-driven target. The report increased knowledge and clarified some debates, but it could not resolve the inconsistency between the long-term global goal and actual mitigation commitments. This gave rise to two coexisting positions among scientists and experts: some take the target literally and denounce its hypocrisy, while others see it as an aspirational target meant to raise ambition. The political realism of the latter position assumes an "inherent inconsistency" between discourse, decisions and action (Geden, 2016b).

The process that has allowed the 1.5°C target to exist and be sustained has been analyzed as "political calibration" (van Beek et al., 2022). Like that of many concepts developed to understand and address climate change, the history of the 1.5°C target has been marked by the continuous mutual adjustments of "scientific knowledge, policy goals and expectations about policy relevance" that Lahn (2022, p. 6) emphasized in the history of the carbon budget. But these adjustments do not always follow the same pattern. While the 2°C target is usually analyzed as the result of the co-production of science and politics, the history of 1.5°C is rather one of codependency: political objectives require scientific backing to be legitimate, and research needs to attune to political discussions if it is to remain policy-relevant. The question remains whether the exacerbation of contradictions brought by the 1.5°C objective serves the fight against climate change, and whether it is tenable.

AUTHOR CONTRIBUTIONS

Béatrice Cointe: Conceptualization (equal); investigation (equal); writing – original draft (equal). **Hélène Guillemot:** Conceptualization (equal); investigation (equal); writing – original draft (equal).

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CONFLICT OF INTEREST

No conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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RELATED WIREs ARTICLES

History of the 2°C climate target
A history of the global carbon budget

ENDNOTES

[1] The first version of this article was written in the spring and summer of 2022, and it was revised during COP27 in November 2022. We have attempted to take into account the latest developments, while acknowledging that the climate debate is in a state of flux.

[2] This article is based on fieldwork and interviews conducted during several projects in which the authors participated. As part of the collaborative research project ClimaCOP on COP 21, Hélène Guillemot conducted eight interviews with scientists at and around the Paris COP in 2015 and 2016 (Guillemot, 2017). As part of a collaboration with Christophe Cassen, Béatrice Cointe conducted 15 interviews with integrated assessment modelers in 2015–2016, as well as observation in meetings of the Integrated Assessment Modeling Consortium (IAMC) (2015, 2021) (Cointe et al., 2019). The materials used to prepare this article also include 10 interviews conducted in 2019 by Audrey Renaudin for her master's thesis on SR15 (Renaudin, 2019).

[3] Scientist Rebellion, "A united academia can fight climate failure," https://signon.scientistrebellion.com/ [accessed on November 23, 2022]

[4] The phrase 'burning embers' refers to a figure entitled "reasons for concern," which was first published in IPCC TAR (IPCC, 2001, p. 5, Figure SPM-2), and was updated in subsequent IPCC reports. It uses a color scale from yellow to purple to indicate levels of threat on different dimensions, according to increases in global temperatures.

[5] As one anonymous reviewer pointed out, in a 1993 paper William Nordhaus referred to a policy proposal to "stabili[ze] climate so that the change in global average temperature is limited to no more than 0.2 degrees C per decade with an ultimate limitation of 1.5 degrees C" (Nordhaus, 1993, p. 21), suggesting that the 1.5°C limit was already on the table, if only briefly, in the 1990s. However, Nordhaus does not source this proposal, and we have not been able to retrace it to its origin(s).

[6] The Copenhagen Accord was not formally adopted by the COP, but only "take[n] note of."

[7] As an example of the process of joint agenda setting for climate research and negotiations, during the SED an expert suggested that the scarcity of research on the impacts of 1.5°C of warming "may also be due to the fact many

scientists are unaware of the fact that a 1.5°C warming is being discussed by policymakers" (UNFCCC, 2015a, p. 73 para. 53).

[8] As expressed, for instance, by an author of SR1.5 in an interview in 2019: "Honestly, as a scientist, I thought it was a bad idea to produce a report on 1.5°C, but in fact, after having done so, I think it was a good idea. So, even though it was very much driven by political motivation, I think that there was still an intuition behind it that was quite powerful."

[9] The vast majority of research projects on pathways to 1.5°C are Horizon 2020 projects funded by The European Commission. Other funders of research projects involving IAMs include JPI Climate, DG CLIMA, and the German and UK governments, as well as foundations such as ECF, Ikea, Hewlett and the Children's Investment Fund. See the website of the Integrated Assessment Modeling Consortium: https://www.iamconsortium.org/resources/projects/ (accessed on August 25, 2022)

[10] See the press release about SR1.5 from French NGOs (including Greenpeace, WWP, Oxfam, etc.) posted on the Climate Action Network website (in French): http://reseauactionclimat.org/wp-content/uploads/2018/10/dossier-giec-15.pdf

[11] For example: "Say Goodbye to 1.5°C", *The Economist*, November 5, 2022; Chelsea Harvey, "The World Will Likely Miss 1.5 Degrees C – Why Isn't Anyone Saying So?", *Scientific American*, 11/11/2022; Bill McGuire, "The 1.5°C target is dead – to prevent total failure, GOP27 must admit it", *The Guardian*, November 12, 2022; Audrey Garric, "Faut-il déclarer qu'il n'est plus possible de limiter le réchauffement climatique à 1,5°C?", *Le Monde*, November 15, 2022.

[12] This is reflected in the IPCC AR6 WGIII report, which includes both a chapter on long-term transformation pathways and a chapter on short-term and national pathways.

[13] The field is dominated by a dozen models and research groups, the majority of which are now based in Europe. Currently, the three biggest IAM teams are at IIASA in Austria, PIK in Germany and PBL-RIVM in the Netherlands.

[14] Bill Hare is a climate scientist, but also the founder and CEO of the NGO Climate Analytics. He has advised small island states and Least Developed Countries in climate negotiations, especially during the negotiations toward the Paris Agreement. The position paper was supported by 26 climate scientists and experts.

[15] The position paper makes the case for the policy relevance of RCP2.6 in somewhat stronger terms than the report: excluding the lowest mitigation pathways from the scientific debate would be policy-prescriptive, because scientists would then be making "decisions about what are feasible mitigation pathways and what aren't" (Moss et al., 2008: 105).

[16] Guivarch and Hallegatte (2013, p. 188) further note that "failed experiments tend not to be published," so that infeasible pathways do not appear in the literature, which tends to reinforce the apparent feasibility of stringent targets: for each possible 2°C or 1.5°C pathway that was identified and published, we do not know how many modeling attempts failed.

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