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Navigating the political: An analysis of political calibration of integrated assessment modelling in light of the 1.5 °C goal

Lisette van Beek [a,b,*], Jeroen Oomen [b], Maarten Hajer [b], Peter Pelzer [c], Detlef van Vuuren [d]

[a] Copernicus Institute of Sustainable Development, Faculty of Geosciences Utrecht University, Utrecht, The Netherlands
[b] Urban Futures Studio, Faculty of Geosciences, Utrecht University, Utrecht, The Netherlands
[c] Department of Human Geography and Spatial Planning, Faculty of Geosciences, Utrecht University, Utrecht, The Netherlands
[d] PBL Netherlands Environmental Assessment Agency, The Hague, The Netherlands

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ABSTRACT

Some of the most influential explorations of low-carbon transformations are conducted with Integrated Assessment Models (IAMs). The recent attempts by the IPCC to look for pathways compatible with the 1.5 °C and 2 °C temperature goals are a case in point. Earlier scholarship indicates that model-based pathways are persuasive in bringing specific possible future alternatives into view and guiding policymaking. However, the process through which these shared imaginations of possible futures come about is not yet well understood. By closely examining the science-policy dynamics around the IPCC SR1.5, we observe a sequence of mutually legitimising interactions between modelling and policy making through which the 1.5 °C goal gradually gained traction in global climate politics. Our findings reveal a practice of 'political calibration', a continuous relational readjustment between modelling and the policy community. This political calibration is indicative of how modellers navigate climate politics to maintain policy relevance. However, this navigation also brings key dilemmas for modellers, between 1) requirements of the policy process and experts' conviction of realism; 2) perceived political sensitivities and widening the range of mitigation options; and 3) circulating crisp storylines and avoiding policy-prescriptiveness. Overall, these findings call into question the political neutrality of IAMs in its current position in the science-policy interface and suggest a future orientation in which modellers aim to develop additional relations with a broader set of publics resulting in more diverse perspectives on plausible and desirable futures.

1. Introduction

Delimiting climate change in line with the Paris Agreement (2015) implies the need for low-carbon transformations in energy, agriculture and transport systems (Geels, Berkhout and Vuuren, 2016). Model-based scenarios form an important tool to explore these low-carbon transformations. Such scenarios are typically made using Integrated Assessment Models (IAMs), computer simulations that couple socio-economic, technical and biophysical systems (Van Vuuren et al., 2011; Weyant, 2017). This modelling of complex interactions enables the systematic comparison of the costs and effectiveness of alternative climate mitigation strategies as well as the scope and timing of required emission reductions consistent with global temperature goals (Geels et al., 2016). Over the past decades, IAMs[1] have become increasingly prominent in the climate science-policy interface, co-evolving with global climate politics (McLaren and Markusson, 2020; van Beek et al., 2020; Bosetti,

Abbreviations: IAM, Integrated Assessment Model; IPCC, Intergovernmental Panel on Climate Change; NETs, Negative Emissions Technologies; ToF, Techniques of Futuring; SR1.5, Special Report on 1.5 ℃; STS, Science and Technology Studies; UNFCCC, United Nations Framework Convention on Climate Change; AOSIS, Alliance of Small Island States; COP, Conference of the Parties; SED, Structured Expert Dialogues; CLA, Coordinating Lead Author; CA, Contributing Author; LA, Lead Author; IIASA, International Institute for Applied Systems Analysis; SPM, Summary for Policymakers; BECCS, Bioenergy with Carbon Capture and Storage; WG, Working Group; LED, Low Energy Demand.

* Correspondence to: Princetonlaan 8a, 3584 CB Utrecht, The Netherlands.
E-mail address: l.m.g.vanbeek@uu.nl (L. van Beek).

[1] We use 'IAMs' to describe process-based Integrated Assessment Models, that include a detailed representations of the human and climate system and their interlinkages. These models are often used to assess cost-effective climate change mitigation pathways under global temperature targets. Cost-benefit IAMs constitute a different IAM type that are used to asses economically optimal levels of abatement given future climate impacts and typically include a simplified representation of both the human and climate system (Wilson et al., 2021 for more details on process-based IAMs).

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2021 on the history of IAMs). While scattered over different institutions, together the IAM modellers constitute a globally organised epistemic community with a leading role in scenarios underlying Working Group III of the Intergovernmental Panel on Climate Change (IPCC), which is dedicated to mitigation (Cointe et al., 2019). As such, IAMs provide a critical tool to explore mitigation pathways towards the 1.5 °C and 2 °C temperature goals in IPCC reports.

In recent years, the IPCC has moved from providing scientific evidence for climate change's cause and existence towards a more *solution-oriented* mode (Beck and Mahony, 2017; Guillemot, 2017). As such, the capacity of IAMs to explore mitigation options has become increasingly central to inform climate policy (van Beek et al., 2020). IAM scenarios quantify a range of alternative climate policy pathways (Edenhofer and Kowarsch, 2015). They can, however, only present a subset of possible climate actions due to their mathematical structures and bias towards technical feasibility and cost-effectiveness (Forster et al., 2020; Keppo et al., 2021). As such, IAM scenarios are influential in bringing specific alternatives into the imagination of policymakers while foreclosing other potentially crucial ways to mitigate climate change (Beck and Mahony, 2018b). For instance, alternatives that are not part of the IAM repertoire are 100% renewable energy scenarios (Hansen et al., 2019), degrowth scenarios (Keyßer and Lenzen, 2021) or relying strongly on ecosystem restoration (Roe et al., 2019; see Keppo et al., 2021 for overview of limitations). By rendering particular possibilities more thinkable or actionable, IAM pathways influence the imagined 'corridor of climate mitigation', structuring the deliberation of political actors on future climate action (Beck and Mahony, 2017, 2018a, 2018b; Beck and Oomen, 2021).

Given their central role in the climate science-policy interface, a detailed understanding of the practice of IAMs is critical to further both the scientific and societal debate. IAM pathways have been found to be influential in shaping policy commitments, such as in establishing the feasibility of the 2 °C degrees target (Lövbrand, 2011; Beck and Mahony, 2017, 2018a, 2018b; McLaren and Markusson, 2020). More recently, the 1.5 °C goal has become the new symbol for climate action – despite serious doubts about its feasibility (Livingston and Rummukainen, 2020). IAMs again played a significant role, as showcased by the world-wide adoption of policy commitments towards 'net-zero by 2050′ emissions targets and the deployment of negative emissions technologies (NETs), both originating from IAM-based 1.5 °C pathways (Thoni et al., 2020). Although these observations indicate an influential role of IAMs, we still have only a limited understanding of the pattern of science-policy interactions through which such policy commitments emerge and gain traction.

The current study aims to address this gap. We study integrated assessment modelling using the concept of 'Techniques of Futuring' (ToF; Hajer and Pelzer, 2018; Oomen et al., 2021), analysing the sequential and contextualised practices through which visions of possible futures become collectively shared. We analyse how the 1.5 °C goal increasingly gained traction by reconstructing the science-policy dynamics around the Special Report on 1.5 °C (SR1.5) (IPCC, 2018a). Our reconstruction captures the 2015–2020 period, from the adoption of the 1.5 °C in the Paris Agreement to a few years following the aftermath of the SR1.5. To this end, we conducted 22 semi-structured interviews with IPCC authors and policymakers (Appendix A and B), a quantitative literature analysis and reviewed IPCC and UNFCCC documentation (Appendix C and D). We selected interviewees based on ensuring a comprehensive view on science-policy dynamics from the diverse viewpoints of key actors, including IPCC authors, government representatives and expert reviewers (Appendix A and B). The selection of IPCC SR1.5 authors was based on their role in chapters relevant to climate mitigation (chapter 2, 4 and 5) as well as to ensure a balanced view on the role of IAMs, selecting IAM modellers as well as authors representing other scientific communities (e.g. bottom-up modelling). In the following paragraphs, we first elaborate on our conceptual approach (Section 2), which guides our reconstruction. We then provide background information on the emergence of the 1.5 °C target (Section 3). Section 4 presents our analysis on how and why the 1.5 °C gained traction. In Section 5, we reflect upon this analysis and discuss implications for the use of IAMs to explore low-carbon transformations.

2. Analysing the sequence of events through which images of the future gain traction

Taking a constructivist perspective on science-policy dynamics, our analysis is framed by a co-productionist approach of STS research (Latour, 1993; Jasanoff, 2004). This epistemological stance regards scientific practice not as neutral knowledge-making but as a performative endeavour that always 'co-produces' ideas about what to govern and how, whether intentionally or unintentionally. This means that we are particularly interested in the performative effects of projections. As revealed by a growing scholarship, collectively shared images and visions of the future influence political, economic, and technological decisions and developments. Scholarship on the collective imagination, for example, shows how "collectively shared, institutionally stabilised, and publicly performed visions of desired futures" animate future-oriented policy and technology development (Jasanoff and Kim, 2015, p. 4) and how 'fictional expectations' enable actors to make decisions under uncertainty based on the shared assumptions about some future state (Beckert, 2013, 2016).

In the context of environmental science and policy, model-based representations in authoritative scientific assessments such as the IPCC are powerful in shaping political deliberations about future climate action (Beck and Mahony, 2017; Beck and Oomen, 2021). However, little effort goes into understanding *how* and *why* particular images of the future become persuasive. To understand the relational process of science-policy dynamics through which such future visions become performative, we use the concept 'Techniques of Futuring' (ToF), defined as "practices bringing together actors around one or more imagined futures and through which actors come to share particular orientations for action" (Hajer and Pelzer, 2018, p. 225). Rather than taking IAMs or their pathways as the objects of analysis, the ToF lens brings into focus the relational process of mutually adjusting expectations among actors around the plausibility and desirability of possible futures (Oomen et al., 2021). As theorised by Oomen et al. (2021), this involves a "sequence of events [of] step- by-step braiding of knowledge, images of the future and legitimacy" (p. 12). This theoretical lens informed our detailed reconstruction of the sequence of events through which shared expectations around the 1.5 °C emerged. We took an interpretative approach to analyse the interviews and other data, revealing shifting perspectives and expectations regarding the 1.5 °C goal and the role of IAMs among different actors involved in the IPCC SR1.5 (Appendix A and B).

3. Background: the origins of the 1.5 °C degrees goal (2009–2015)

While science-policy discussions on the level of dangerous anthropogenic interference and long-term global goals can be traced back to the late 1980 s (Tschakert, 2015; Morseletto et al., 2017), the 1.5 °C goal first emerged at the UNFCCC negotiations during the 15th Conference of the Parties (COP) in Copenhagen in 2009. At that time, the Alliance of Small Island States (AOSIS) claimed that the projected sea-level rise related to a 2 °C warming implied that their islands would be wiped off the map (Guillemot, 2017; Tschakert, 2015; Livingston and Rummukainen, 2020). AOSIS and the Least Developed Countries (LDC) alliances emphasised the need to lower the global temperature goal to 1.5 °C (IISD, 2009). Although an international agreement could not be reached in Copenhagen, most countries supported the Copenhagen Accord, where the 2 °C was adopted in the negotiation document (UNFCCC, 2009). Under the pressure of the LDC and AOSIS, the Copenhagen Accord explicitly called for strengthening this goal: "consideration of *strengthening the long-term goal* [.] including in relation to *temperature rises of 1.5 degrees Celsius"* (UNFCCC, 2009, emphasis added). At COP16 in Cancun, the 'well below' 2 °C was formally agreed upon, but also to periodically review the long-term global goal (UNFCCC, 2010). Despite little response from the scientific community (Schleussner et al., 2016), a review process was initiated: so-called Structured Expert Dialogues (SEDs) involving face-to-face interactions between UNFCCC parties and experts addressing the adequacy of the temperature goal and the overall progress towards these goals (UNFCCC, 2011). The difference between 1.5 °C and 2 °C was a central topic during the SEDs. However, the meaning of this temperature difference was difficult to assess due to a lack of research (Tschakert, 2015). The final report of the SEDs in 2015 concluded: "While the 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). Shortly before COP21 in Paris, the Marshall Islands launched a High Ambition Coalition which demanded an explicit reference to 1.5 °C as a prerequisite for an agreement. Before and during COP21 in Paris, they rallied support from NGOs and more than 100 countries (Guillemot, 2017). A potential shift of the long-term global temperature goal from 2 °C to 1.5 °C was a key topic during the negotiations (IISD, 2015). The High Ambition Coalition managed to convince more and more countries of the need for a shift to 1.5 °C, whereas some countries remained sceptical and supported only a "well below 2 °C" goal (IISD, 2015b; Brun, 2016). Finally, in the Paris Agreement, countries compromised to: "Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels" (UNFCCC, 2015b, Art 2.1). Obviously, this compromise provided all parties with the ability to claim a victory. Many factors explaining the success of Paris are outlined elsewhere (e.g. Brun, 2016; Christoff, 2016; Guillemot, 2017). A key reason for the adoption of the 1.5 °C specifically was that it provided a bargaining chip for vulnerable countries who could not accept the 2 °C, while the agreement remained lenient regarding financial or legal obligations to developed countries for loss and damages of vulnerable countries (Guillemot, 2017; interviews 21 and 22, government representatives at COP21).

4. A reconstruction: how the 1.5 °C became the new guardrail of climate action (2015–2020)

This section starts from the adoption of the 'pursuing effort to 1.5 °C' goal in Paris to reconstruct the science-policy interactions around the IPCC SR1.5 between 2015 and 2020. We identify three phases through which the 1.5 °C goal gradually went from being perceived as unrealistic to becoming the new symbol of climate action. In each phase, this involved an iterative process between modelling and policy, in which model findings and policy targets legitimised each other (see Fig. 2):

- ***Phase 1 2015–2016 (4.1)***: the initial post-Paris emerging interaction between the modelling and policy shifted the 1.5 °C goal from being perceived as unrealistic towards 'achievable with NETs', relying on newly modelled 1.5 °C IAM pathways;
- ***Phase 2 2016–2018 (4.2):*** the IAM community then helped to further establish the perceived feasibility of the 1.5 °C through a series of readjustments of 'acceptable' levels of NETs and overshoot during the SR1.5 writing process;
- ***Phase 3 2018–2020 (4.3)***: finally, these published pathways shaped policy commitments to limit global warming to 1.5°Cin the aftermath of the IPCC SR1.5.

4.1. Phase 1: the 1.5 °C goal shifted from perceived as 'unrealistic' to 'achievable with NETs' (2015–2016)

In the Paris Agreement, the UNFCCC invited the IPCC "to provide a special report in 2018 on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways" (UNFCCC, 2015b, decision 1/21, para21). The initial idea was to invite the IPCC to draft a Special Report on the *impacts* of 1.5 °C vs. 2 °C, but during the negotiations the assessment of *how to achieve* this target was also emphasized. This focus on the 'how' was important to convince some governments on the feasibility of necessary actions to achieve the 1.5 °C (IISD, 2015a; interview 21 and 22, government officials attending COP21). Although the 1.5 °C target had been debated in previous negotiations, its adoption in Paris still came as a surprise to many scientists (Livingston and Rummukainen, 2020). Modellers, in particular, had previously considered 1.5 °C mitigation pathways irrelevant because they thought a 1.5 °C goal was not realistic, either politically or societally (interview 2, 6; cf. Livingston and Rummukainen, 2020). As stated by an IAM modeller *"We talked about [1.5 °C] but never seriously. It felt so unrealistic and infeasible that the models were not applied to this."* (interview 2, CA IPCC SR1.5).

Despite lingering doubts of the feasibility of this target, the focus of modelling studies shifted from 2 °C to 1.5 °C degrees after Paris (interview 2, 12, 20). According to one of the (non-IAM) CLAs of the SR1.5, *"the scientific debate was still centred around 2 °C degrees. […] Only after the target emerged during COP21, various modelling studies appeared that could solve for 1.5 °C degrees."* (interview 1).

Moreover, the explicit request of the IPCC report to show how to achieve the 1.5 °C target created a demand for research showing if and how the goal might be achieved. Being well-organized (cf. Cointe et al., 2019; van Beek et al., 2020), the IAM community could rapidly develop 1.5 °C pathways (see Fig. 1). As described by an IPCC Bureau member: *"[The IAM community] took the models […] and turned up the volume to 11 as it were, to run the models again with 1.5 °C."* (interview 5). This rapid increase in 1.5 °C pathways shows the ability of the IAM community to adjust the model focus towards a newly established target. The sheer size of the output and number of pathways from different IAM teams also helped to legitimise the achievability of this new goal.

This reveals an empirical example of 'calibrating' the model analysis in view of relevance: despite the personal conviction of realism of some of the modellers at the time, modelling efforts were redirected from exploring 2 °C pathways to those limiting warming to 1.5 °C. The alternative would have been to say that the 1.5 °C goal was infeasible according to modelling results. However, this would disregard small island states (interview 5, IPCC co-chair). In fact, if the IPCC would have concluded that the 1.5 °C was unrealistic, Paris negotiators might even have had to go back to the negotiation table (interview 22, COP21 negotiator). On the other hand, the shift from 2 °C to 1.5 °C implied faster emissions reduction, in which the rapidly appearing 1.5 °C scenario literature relied on NETs to an even more significant degree (interview 2,3,6,15). As explained by one modeller: *"I am not more confident that we can reach it, but I am more confident that we can model it. […] we would never have to say it would not be achievable, we just put more negative emissions in"* (interview 18).

Essentially, UNFCCC's knowledge demand to understand if and how the new target could be achieved was answered by IAM research with: "yes – using NETs". At the same time, NETs remain an issue of heated academic debate: their assumed scale in IAM scenarios is debated as well as the potential risks and ethical considerations (e.g. Vaughan and Gough, 2016; Forster et al., 2020). Others argue that counting on NETs in the future risks undermining near-term climate action (Markusson et al., 2018). Responding to UNFCCC's request for 1.5 °C pathways and showing it was 'feasible with NETs', IAMs came to play a legitimising role for the 1.5 °C target. This role was not inevitable. We observe three main reasons why IAMs could play this role: 1) the high degree of organization of the IAM community; 2) the more structural legitimacy of quantitative and system-wide future-oriented knowledge in the climate science-policy interface; and 3) the analytical qualities of IAMs.

4.1.1. Organization

First, modellers often work closely together in large-scale modelling

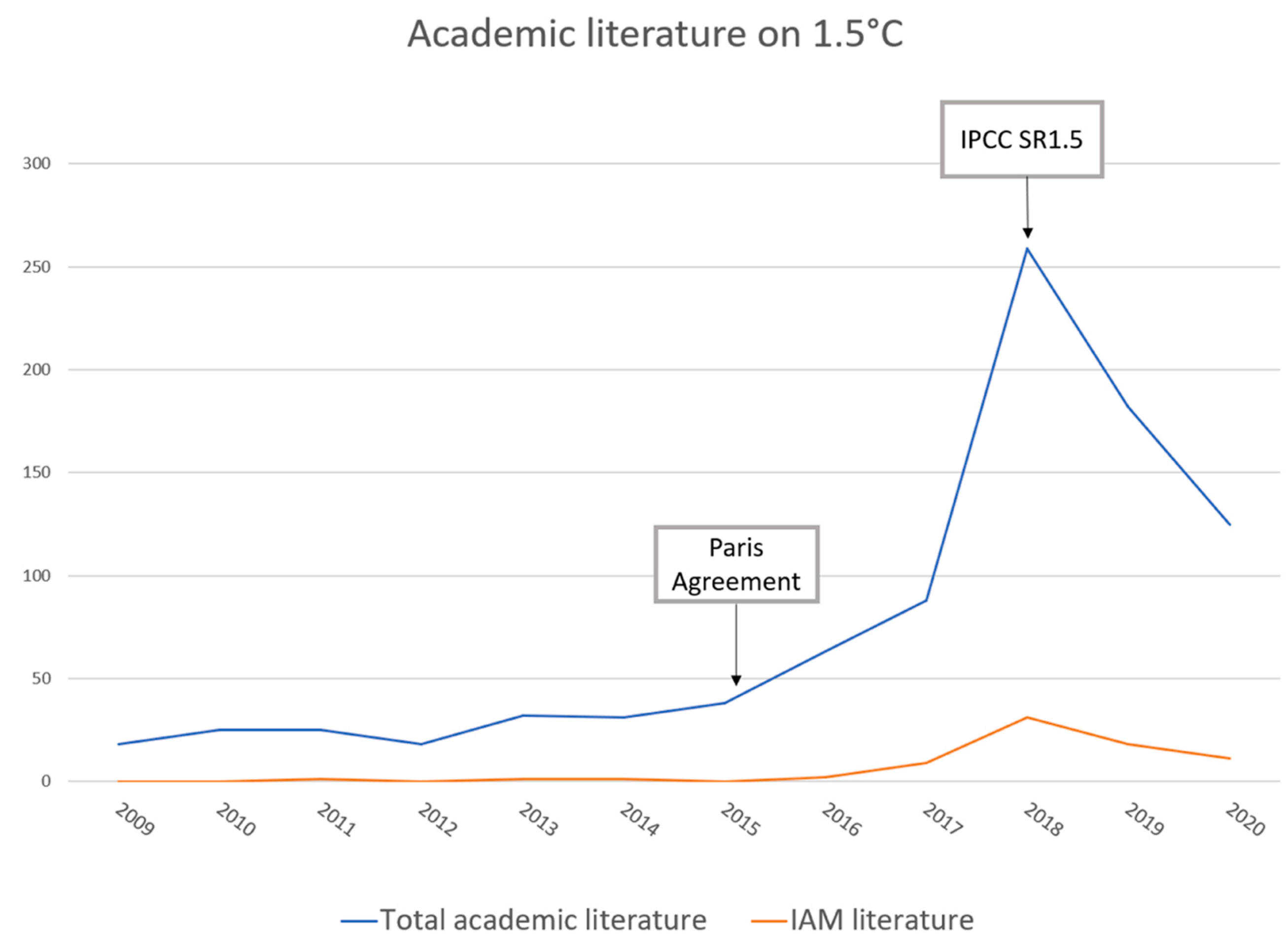

Fig. 1.. Number of academic peer-reviewed literature on 1.5 °C published over time between 2009 and 2020. Data derived from Scopus (Appendix D for methodology).

intercomparison projects, harmonise their assumptions through shared scenario frameworks and develop scenario databases to compare and analyse modelling outputs (Cointe et al., 2019). This high degree of collaboration and synchronisation in IAM research and the intimate ties between the major modelling groups facilitates the adoption of IAM outputs in IPCC reports (interview 1, 2, 12, 15, 18). These organizational capacities are exemplified by the 1.5 °C scenario database hosted by the International Institute for Applied Systems Analysis (IIASA). IIASA has served as IAM 'community hub' for decades (interview 3; Hughes and Paterson, 2017). The database resulted in a 'robust' set of scenarios assessed across different assumptions and models (interview 4), making IAM studies convenient to assess in an IPCC report compared to other types of literature that are more difficult to systematically compare (interview 1, 4, 7, 20). Although IIASA's call to submit 1.5 °C scenarios were meant to be "as broad as possible" (IIASA, 2017), the inclusion criteria of the database – e.g. covering all sectors and projecting towards 2100 – were such that it matched the usual model output of the six most established IAMs. As a result, these six IAM groups were at an advantage in getting their pathways assessed at the expense of less established IAM teams and bottom-up modellers (or other disciplines, for that matter):

> "If you start from zero, it takes some time to upload it, it might take a couple of months. The IAM community uses that format for their daily use and their models spit out the scenarios in that format. So the other modelling teams have a much higher hurdle to be included" (interview 4, CLA IPCC SR1.5, IAM modeller).

> "They are like a great football team. […] When you're playing against an IAM team, it becomes 5–0 very quickly before half-time. Because it's a consistent community." (interview 10, CLA IPCC SR1.5).

4.1.2. *Structural legitimacy*

Second, the reliance on IAMs to demonstrate the feasibility of the 1.5 °C goal relates to a more structural legitimacy of quantitative, global, and system-wide future-oriented knowledge in the climate-science policy interface. By default in environmental science and policy, the climate is approached as a global interconnected system, a view that has been shaped by the IPCC (Miller, 2004; Turnhout et al., 2016). Legitimacy of quantitative knowledge can be traced back to a much longer history of 'trust in numbers' among policymakers (Porter, 1995; cf. van Beek et al., 2020) as well as the emergence of computer modelling as the key epistemic approach to understand the past, present and future of the climate (Edwards, 2010). The privileged position of IAM analyses in the SR1.5 was not uncontroversial due to its biases, calling for more diversity in scientific disciplines in IPCC reports (Hansson et al., 2021; interview 5). Although the IPCC Bureau successfully brought in a much broader set of disciplines in the SR1.5 compared to previous reports, the Summary for Policymakers (SPM) – the most politically influential part of the report – still predominantly contained figures based on IAMs:

> "The main advantage of IAMs is their rigorous quantitative framing and systems perspective. This quantitative systems perspective helps you to illustrate points with numbers. […] And since the SPM is usually trying to assess and quantify the order of magnitude of

changes that need to happen they traditionally rely a lot on the IAM results" (interview 6, LA IPCC SR1.5).

4.1.3. Analytical qualities

Third, a key analytical strength of IAMs is to connect climatic (e.g. global temperature) and societal dynamics across sectors (e.g. energy supply and demand). The question of whether the 1.5 °C was a feasible global goal was thus tailor-made for an IAM approach, in contrast to for instance sectoral or nationally oriented approaches. As our interviews revealed, modellers as well as non-modellers struggle to identify viable alternative to IAMs:

> "If we did not have IAMs, we'd have to invent them because they are the only way of getting between human activity on climatic changes on a century scale" (interview 2, IPCC Bureau member).

> "Even when I am critical of IAMs and throw them all out of the window, if I sit tomorrow at my desk, I would still build a new IAM. One that understands how decisions in land use or building affect how much mitigation we need and how much land we need." (interview 4, CLA IPCC SR1.5, IAM modeller)

4.2. Phase 2: becoming persuasive: how the 1.5 °C gained traction despite emerging criticism on NETs (2017–2018)

In this second phase, covering the lead-up to the publication of the SR1.5, the 1.5 °C goal increasingly gained traction. At the same time, the *specific corridor* towards 1.5 °C projected by IAMs was highly controversial. This contention emerged already before Paris when IAMs asserted that 2 °C was possible (only) under the condition of substantial implementation of NETs. Several scholars warned in high-prestige academic journals that policymakers, unaware of the assumed scale and implications of NETs, may find "betting on negative emissions" more appealing than near-term emission reduction, risking a lock-in into a fossil-fuel-dependent society (Fuss et al., 2014; Anderson and Peters, 2016). We observe three key mechanisms through which the 1.5 °C as a feasible target could gain traction despite this criticism: 1) a tightening interdependence of modelling and policy around the acceptable level of overshoot in 1.5 °C pathways; 2) IPCC SR1.5 authors' attempts to harmonise cross-chapter discrepancies around the feasibility of NETs; and 3) efforts of the modelling community to expand their range of mitigation options towards demand-side mitigation.

4.2.1. Tightening interdependence

The first mechanism relates to science-policy negotiations around the acceptable level of "overshoot" in scenarios. In the First Order Draft of Chapter 2 (IPCC et al., 2017a): all 191 IAM scenarios compatible with the 1.5 °C were ones that temporarily exceeded 1.5 °C warming before returning to that level in 2100 – meaning that they all relied on NETs. The absence of non-overshoot scenarios in the first draft of the SR1.5 was fiercely criticised by expert reviewers and civil society organisations (IPCC, 2017b, 28 comments; interview 8). In response, the authors included non-overshoot scenarios in the subsequent draft (IPCC et al., 2017c), albeit very few (only 10 out of 578 scenarios). Again, critics commented on the extent to which scenarios exceeded the 1.5 °C, viewing high levels of overshoot as inconsistent with the Paris Agreement (interview 3, 4; IPCC, 2017d).

> "a lot of [scenarios] overshoot the target. Some delegations would then say: this is not what we would define as a 1.5 °C degree target as we have the water up to our necks by then." (interview 7, LA IPCC SR1.5).

Excluding all overshoot scenarios, however, would basically disqualify all the underlying scenario literature (interview 3) – and hence present the 1.5 °C goal as unrealistic. Eventually, it was agreed that overshoot to 2 °C degrees (but not higher) would be acceptable (interview 3,4). This compromise showcases the tightening interdependence between modelling and climate politics: the UNFCCC and IPCC relied on IAMs to present the 1.5 °C goal as realistic, and IAMs simply relied on NETs, resulting in an agreement on the acceptable *level* of overshoot – and hence accepting a significant use of NETs. Here we again observe a process of 'calibration' of the focus of analysis based on the societal debate: the acceptable level of overshoot and use of NETs in IAM pathways was readjusted to establish a sufficient number of pathways to hold the 1.5 °C goal attainable as well as avoiding high levels of overshoot that were feared by vulnerable countries.

4.2.2. Harmonizing discrepancies

A second mechanism through which 1.5 °C pathways attained their persuasiveness despite criticism was through resolving discrepancies between Chapter 2 and Chapter 4. These struggles involved the feasibility of Bioenergy with Carbon Capture and Storage (BECCS). Chapter 2, based on IAMs, assumed much higher potentials of BECCS (67–130 EJ/year) than Chapter 4, based on bottom-up studies (maximum of 100 EJ/year) (IPCC, 2018a). The significant use of NETs in IAM pathways was already under fire due to concerns about feasibility, land-use pressures and biodiversity loss. Again, it attracted fierce criticism from expert reviewers of the SR1.5, civil society organisations and government representatives (IPCC, 2017d, 2017c, interview 1; cf. Hansson et al., 2021). Despite agreement about Chapter 4 findings being more accurate, BECCS featured centrally in the SR1.5′s 'Illustrative Pathways', the four IAM-based archetype 1.5 °C scenarios that were highlighted visibly in the SPM (interview 1, 7):

> "Essentially in Chapter 4, we said: what is stated in Chapter 2 is impossible [...]. But no one really found this problematic. We knew that models are just one version of reality, which is not the real world. What is problematic, however, is that the Illustrative Pathways suggest it is possible, while in Chapter 4 we convey that it isn't" (interview 1, CLA IPCC SR1.5).

To harmonize discrepancies, the authors developed a feasibility assessment, crosschecking a range of mitigation options between Chapters 2 and 4 as a 'reality check' of IAM assumptions (interview 1, 10). Yet while this table was included in the report's final draft sent to governments for the line-by-line approval session, it did not make it into the final SPM (interview 9,10). Negotiations about the table were seen as jeopardising the approval of the full report (interview 10), as the country-specific information in the table might conflict with IPCC's mandate to provide 'non-policy-prescriptive' knowledge (interview 6, 10). In contrast, the Illustrative Pathways caused only minor disagreement among member states (IISD, 2018). As a result, only the Illustrative Pathways - some of which assuming high levels of NETs - were elevated in the SPM (Figure SPM.3b, IPCC, 2018a). IAM's quantitative, system-wide, and global orientation appeared crucial to align with IPCC's mandate to provide 'non-policy-prescriptive' information. Moreover, the overlap of IPCC WGIII authors and the IAM community blurs the distinction between *providing* and *assessing* literature (interview 5, cf. Corbera et al., 2016; Hughes and Paterson, 2017). This double role as both author and reviewer within the IPCC has also taught IAM modellers how to finetune their output and anticipate policymakers' knowledge questions:

> "the challenges that we encounter in the IPCC, we try to solve. The community learns from that and tries to anticipate and create knowledge that can be useful in IPCC reports that can be used for the arising questions" (interview 4, CLA IPCC SR1.5, IAM modeller).

4.2.3. Expand range of mitigation options

A third mechanism that rendered the 1.5 °C target persuasive despite criticism on NETs was that modellers expanded their range of options towards demand-side mitigation. Traditionally, the IAM community is more supply-side oriented. Changes in supply-side technology are easier to quantify in economic and mathematical equations than more complex choices in end-use regarding efficiency and lifestyle change that often involve a heterogeneity of people, perspectives, attitudes, and motivations (interview 2, 3, 4, 6). The IAM community had started to address this challenge in the context of the 2 °C goal (e.g. van Sluisveld et al., 2016), but the 1.5 °C goal gave a strong push to further expand their options in this direction (interview 2, 4, 6, 7, 8):

> "The 1.5 degrees made us think about other radical changes that we had not taken into consideration before, including radical lifestyle changes. [...]. So we went beyond what we would normally thought was possible" (interview 2, CA IPCC SR1.5, IAM modeller).

Notably, the emerging demand-side pathways could explicitly achieve the 1.5 °C with no or limited use of NETs, for instance, by assuming low energy use and dietary shifts (Grubler et al., 2018; van Vuuren et al., 2018). Even though the majority of 1.5 °C pathways still relied heavily on NETs, the 'Low Energy Demand' (LED) scenario (Grubler et al., 2018), was selected as one of the four illustrative pathways presented in the SPM, which appeared crucial to respond to growing criticism:

> "It was very exciting whether [the LED scenario] would be published in time. It came just in time, just a few days before the literature deadline. [...] The message was that it would be possible without BECCS, but it would then require behaviour changes much earlier." (interview 1, CLA IPCC SR1.5).

> "The LED scenario that came out right before the end and made a huge splash, being one of the Illustrative Pathways. The scenario made quite a career in a very short time." (interview 8, civil society representative).

The inclusion of this 'no NETs' scenario as one of the archetype scenarios was well received by critics, including civil society organisations (interview 8). This illustrates a recurring mechanism: motivated by criticism on NETs by experts and civil society organisations, modellers explored pathways that relied more on demand-side mitigation.

4.3. The 1.5 °C as the new guardrail for climate action: the uptake of IAM pathways in the aftermath of the SR1.5 (2018–2020)

In the third phase, the 1.5 °C goal became the new guardrail for climate action as IAM pathways in the SR1.5 became translated into policy commitments to limit global warming to 1.5 °C (cf. Hermansen et al., 2021). Interviewees indicated that the SR1.5 was 'incredibly influential' (interview 14) in policy and public debates, if not 'the most important report the IPCC ever produced' (interview 20). This is also reflected in its massive wave of media coverage (Boykoff and Pearman, 2019). This had various reasons. For one, the IPCC had changed their communication strategy, replete with visualisation experts and a head of communications (interview 5, 10). Secondly, the report was eagerly anticipated by a growing activist movement such as the #FridayforFutures movement (Hermansen et al., 2021), with Greta Thunberg imploring the world to 'listen to the science' (interview 10, 14). The impacts of climate change were also becoming increasingly visible (interview 14). Such contextual factors and charismatic spokespeople are what Morgan, 2011 calls 'good companions' that allow facts to 'travel well'. The (non-IAM) chapters on climate impacts between 1.5 °C and 2 °C raised the urgency of climate action (interview 7, 10,14). Regarding the chapters on mitigation, two IAM-based messages resonated in particular: 1) the need to reach net-zero emissions in 2050 and 2) the necessity of NETs to achieve the 1.5 °C target (interview 7, 8, 10, 12, 14, 16, 20).

The need to reach net-zero around mid-century already appeared in Article 4.1 of the Paris Agreement, albeit more ambiguously: *"to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century"* (UNFCCC, 2015b). The SR1.5 and the crisp and clear messaging from IAMs imprinted the necessity to reach 'net-zero in 2050′ on governments (interview 7, 14, 18, 20). This message was once more elevated by the IPCC co-chairs during the press release (IPCC, 2018b) and quickly became the new 'catchy number' reiterated in all government speeches in the following climate negotiations (interview 19, UNFCCC secretariat).

Apart from the contextual factors, two key reasons why IAM pathways resonated were the simplicity of their storylines and, as outlined in previous phases, their quantitative character:

> "The thing about pathways is that it is very simple. [...] at the end of the day, if Greta can't communicate your idea to half a million young people, then in the world of action, it is not very much used." (interview 10, CLA IPCC SR1.5)

> "We know that 1.5 is better than 2, even a kid would tell you that, but they could now justify this with some numbers." (interview 19, UNFCCC secretariat).

The simplicity of the message, however, can invite misunderstandings and have unintended effects. An obvious example is that the emissions reductions by 2030 were interpreted by influential media such as The Guardian, CNN and The Independent as 'we only have 12 years left' (Boykoff and Pearman, 2019). Although this 'climate deadlinism' has arguably raised urgency, it also risks opening the door for backstop technologies such as geoengineering and inducing fear and helplessness among the public (Asayama et al., 2019; Boykoff and Pearman, 2019). Moreover, there are many misconceptions about both the meaning of net-zero emissions as well as the scale and timing of the implementation of NETs among policymakers (McLaren et al., 2019). This dilemma between communicating clearly and becoming more prescriptive than intended was also visible with the Illustrative Pathways, which were interpreted as 'recipes for the future' (interview 7):

> "that pathways diagram is an incredibly useful communication device for me. Policymakers get it straight away." (interview 5, IPCC Bureau)

> "It was a lot of work to always say: it's just an illustrative pathway, it's just to demonstrate there are different pathways and we're not saying that one is superior to the other [...]. It was a key insight: how powerful those pathways are. It gives a lot of responsibility to the IAM community." (interview 7).

In all, in our reconstruction of science-policy interactions between 2015 and 2020 we identified three phases that were characterized by a tightened interdependence between modelling and climate policy and through which pathways towards the 1.5 °C became solidified (Fig. 2).

4.4. Political calibration

Throughout these phases, we observed that the 1.5 °C target gradually gained traction through a process of mutually legitimising interactions between modelling and policymaking, in terms of informing, cooperating and exploring pathways that had a fit to the policy deliberations at a particular time. We refer to this process as 'political calibration', given the analogy with the more formal 'model calibration'. We define political calibration as: *'a process of iterative readjustment between modellers and policymakers, in which the fit and focus of the model analysis and the requirements of the policy community are negotiated.* With this, we do not mean an adjustment based on the acceptability of model outcomes but rather on their policy relevance. Of course, the analogy with model calibration is only partial. The term calibration in modelling practices usually refers to a process of manipulating model parameters to obtain a match between observed historic data and model simulations in order to evaluate the 'epistemic adequacy' of models (Oreskes et al., 1994). The extent to which model behaviour reproduces historic or

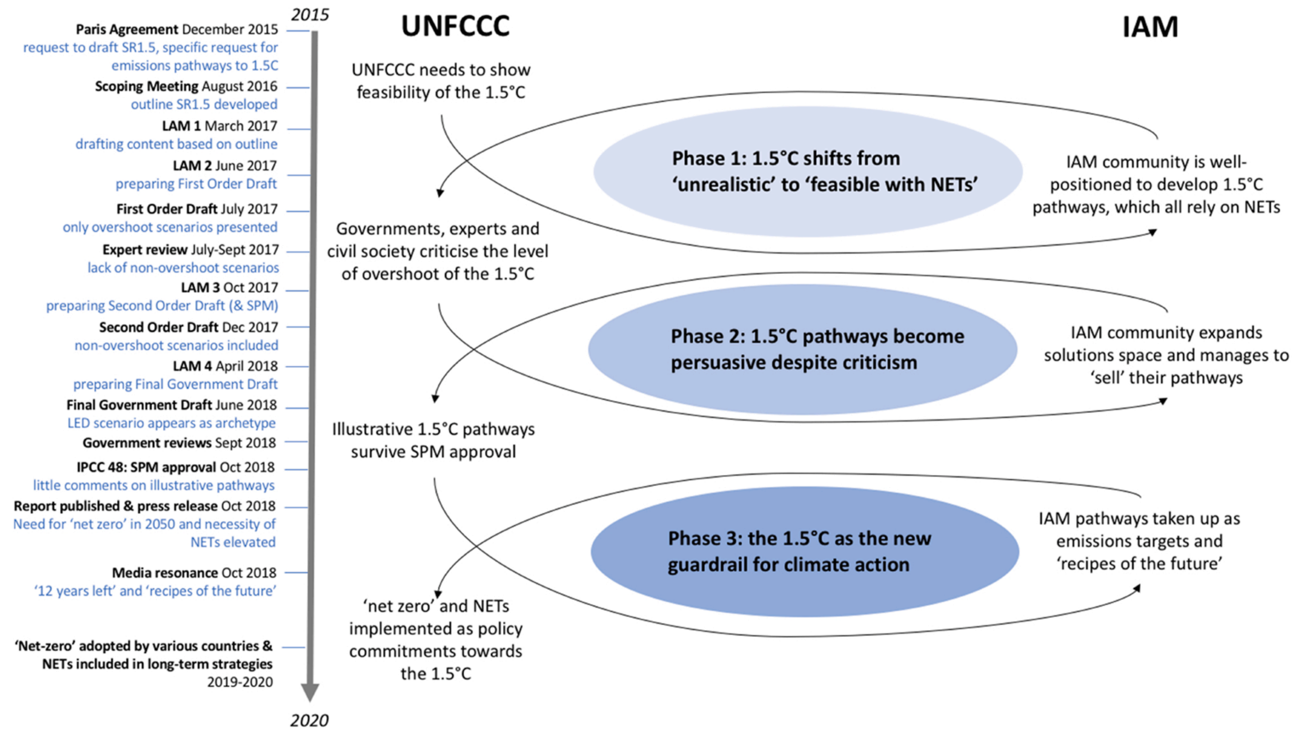

Fig. 2. Overview of the sequence of science-policy interactions around the IPCC SR1.5 between 2015 and 2020 through which the 1.5 °C goal increasingly gained traction.

near-term observations is one of the methods to evaluate process-based IAMs (Wilson et al., 2021). With 'political calibration', we refer not to the *epistemic* but to the *political* adequacy of models. As described by Oreskes et al. (1994), model calibration usually involves multiple steps of refinement until model simulations adequately reproduce observed data. Likewise, we see political calibration as a sequential process of continuously refining the fit between modelling and policy requirements. As we show in the final section below, this process of 'political calibration' is delicate and reflective, posing several dilemmas for modelers.

5. Reflection: understanding the role of IAMs in policy commitments to limit climate change to 1.5 °C

In our reconstruction we observed that IAMs played a key role in the shift of the 1.5 °C goal from an unrealistic target to the new guardrail for climate action. The role of IAMs in policy commitments was not inevitable. By analysing science-policy interactions through the Techniques of Futuring lens (Hajer and Pelzer, 2018; Oomen et al., 2021), we explained the role of IAM modelling in the (political) legitimation of the 1.5 °C goal. This analysis relies on relational, discursive and structural elements:

- the analytical qualities that rendered IAMs tailor-made for this particular policy question (phase 1);
- the advantageous material and organisational capacities of the IAM community for modellers compared to less experienced and more dispersed scientific communities, through which 1.5 °C pathways could rapidly be established (phase 1, cf. Cointe et al., 2019; van Beek et al., 2020);
- the legitimisation of global, system-wide quantitative projections over qualitative and country-specific future-oriented knowledge (phase 1 and 2, cf. Miller, 2004; Edwards, 2010; Turnhout et al., 2016; van Beek et al., 2020); and,
- the communicative power of concrete numbers and powerful visualisations that helped shape policy commitments (phase 3).

The continuous readjustment of modelling efforts to requirements of the policy community, the process of political calibration, was a key mechanism through which the 1.5 °C could gain traction in policy making and politics. Calibrating the focus of analysis based on ongoing political discussions appeared as an important strategy for modellers to remain policy relevant. However, the significant role of IAMs in climate politics also brings their political neutrality into question. We identified three key dilemmas that modellers face when navigating climate politics: 1) between the personal assessment of feasibility and the requirements of the policy process; 2) between respecting political sensitivities and widening the range of mitigation options; and 3) between furthering crisp storylines and avoiding policy-prescriptiveness. The three dilemmas are interrelated, reflecting a tension between policy relevance, and shaping policy commitments. The dilemmas have several implications for the usage of IAMs in the climate science-policy interface.

5.1. *Dilemma 1: policy relevance vs legitimising an unrealistic policy commitment*

With the adoption of the 1.5 °C goal in the Paris Agreement and the invitation to develop 1.5 °C pathways, the IPCC and IAM modellers faced a conundrum. Policymakers expressed interest in showing how to achieve 1.5 °C. Presenting 1.5 °C pathways, however, would automatically provide a perceived degree of feasibility – while many analysts at the time would assess the 1.5 °C to be infeasible (phase 1). The only possible route would imply large-scale deployment of negative emissions, possibly at a scale that would be hard to achieve in the real world. Moreover, concerns were raised regarding the risks of temporarily overshooting the 1.5 °C regarding potential impacts of NETs (phase 2). In other words, presenting the 1.5 °C as *infeasible* or presenting it as *feasible with NETs* both had direct policy implications. This shows how the often-reiterated boundary of 'policy-relevant' versus 'policy-prescriptive' is far more fluid in actual practice.

5.2. Dilemma 2: exploring radical solutions vs staying close to policy discussions

A second dilemma concerns the exploration of mitigation options. On the one hand, modellers aim to explore a wide range of policy options. The community refers to themselves as 'mapmakers' showing possible pathways that policymakers can use to navigate policy options (Edenhofer and Kowarsch, 2015; Beck and Oomen, 2021). On the other hand, modellers are aware of dominant discourses in international climate politics and avoid anticipated 'policy no-go's'. For instance, in the context of the IPCC SR1.5, modellers explored more demand-side mitigation options to reduce the use of NETs. However, more transformative changes such as radical lifestyle changes and discontinued economic growth were not part of this expansion. Modellers' continuous anticipation and adjustment to existing policy discourses contribute to their policy relevance but also implies that they explore their solutions space *within* the discursive context in which they are situated (cf. Ellenbeck and Lilliestam, 2019). Hence modellers face the risk of what political scientist Carl Friedrich (1937) once described as the power of the 'anticipated reaction'; actors refrain from raising an issue, assuming it will be refuted (cf. Lukes, 1974). A potential risk is that modellers exclude transformative pathways that contain politically challenging but potentially crucial low-carbon strategies.

5.3. Dilemma 3: quantitative and crisp storylines vs avoiding policy-prescriptiveness

Clear and consistent storylines, concrete numbers and visualisations help modellers to get their messages across. The quantitative nature of the storylines, such as 'net-zero by 2050′, aid the credibility of their projections (cf. van Beek et al., 2020; Porter, 1995). Moreover, the storylines are short, specific, and autonomous and hold a certain level of 'sturdiness' that explains their travels in policy and media (cf. Morgan, 2011). On the other hand, these characteristics also risk model-based results to become 'rounded off': they might lose important details or nuance during these travels (cf. Morgan, 2011). For instance, the communicative power of the illustrative pathways invited an interpretation as 'recipes for the future' and the 45% emissions reductions by 2030 resulted in the 'only 12 years left' narrative (phase 3). Their persuasiveness gives the IAM community a significant responsibility regarding their messaging and the range of options they explore.

6. Conclusion

Our findings reiterate that rather than a neutral knowledge practice, IAMs intrinsically shape ideas around how climate change should be governed (Edwards, 1996; Beck and Mahony, 2017; Beck and Oomen, 2021). On the one hand, the shift towards a solution-oriented mode of scientific assessments on climate mitigation implies that IAM analysis becomes increasingly policy-relevant given their capacity to explore the costs and effectiveness of mitigation options. On the other hand, the direct political implications of IAM analysis in political and public spheres brings the political neutrality of IAMs into question. Our analysis highlights that IAMs are not neutral 'map-makers' but are powerful in shaping the imagined corridor of climate mitigation (cf. Beck and Mahony, 2018b; Beck and Oomen, 2021). As such, IAM pathways may not be policy-*prescriptive* in a strict sense, but they are certainly policy-*shaping* to a degree beyond policy relevance. Importantly, our findings suggest that the boundaries of this imagined corridor of climate mitigation are not merely shaped by model capabilities or biases in expert judgments (see e.g. Beck and Krueger, 2016; Keppo et al., 2021). It is also the result of political calibration, the continuous readjustment of the focus of key model questions to maintain policy relevance.

The worldwide resonance of the IPCC SR1.5 indicates that IAM outputs have become relevant to inform deliberations on possible low-carbon transformations beyond the science-policy interface. Since Paris, non-state actors and substate actors such as civil society organisations, industry and local governments are increasing involved in the UNFCCC (Bäckstrand et al., 2017). Climate mitigation has become a central topic of public debate. This prominence implies the need broaden the constituency of IAM scenarios to a much more diverse set of actors. IAM modelling teams are mostly situated in the Global North and their projects are often funded by the EU (Cointe et al., 2019). This may hinder the diversification of relevant publics and may preclude more diverse and perhaps more radical perspectives on mitigation. In other words, there is a need to 'calibrate' to the needs of societal actors beyond policymakers. Perhaps IAMs should be shaped to function in the broader 'science-society interface' and be judged accordingly. In so doing, IAMs could explore a greater variety of possible pathways. Perhaps they could also correct for the bias that is inherent to the political calibration necessary for operating in close proximity of the policymaking world.

CRediT authorship contribution statement

Lisette van Beek: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Jeroen Oomen:** Conceptualization, Data curation, Writing – original draft, Writing – review & editing. **Maarten Hajer:** Conceptualization, Supervision, Writing – review & editing. **Peter Pelzer:** Conceptualization, Supervision, Writing – review & editing. **Detlef van Vuuren:** Conceptualization, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2022.03.024.

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