Persuasive Pathways

The Practice of Integrated Assessment Modelling in Climate Politics

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ISBN 978-90-393-7600-3
https://doi.org/10.33540/2017

Designed by Ekaterina Volkova
Printed and bound at Jan van Eyck
Printing & Publishing Lab, Maastricht

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The Practice of Integrated Assessment Modelling in Climate Politics

Richtinggevende Routes

De praktijk van Integrated Assessment Modellering in de klimaatpolitiek

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor
aan de Universiteit Utrecht
op gezag van de rector magnificus,
prof.dr. H.R.B.M. Kummeling, ingevolge het
besluit van het college voor promoties
in het openbaar te verdedigen op
vrijdag 15 december 2023
des middags te 12:15 uur

door

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geboren op 11 mei 1993
te Amersfoort

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Dit proefschrift werd (mede) mogelijk gemaakt met financiële steun van de Swedish Research Council for Sustainable Development (FORMAS)

‘Although we are computer modellers much of the time, sometimes we are decision makers too.’

Groping in the Dark – Meadows et al. 1982 (p. 287)

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https://doi.org/10.1016/j.gloenvcha.2020.102191

II. Van Beek, L., Oomen, J., Hajer, M., Pelzer, P., & Van Vuuren, D. (2022). Navigating the political: an analysis of political calibration of integrated assessment modelling in light of the 1.5 C goal. *Environmental Science & Policy, 133*, 193-202.

https://doi.org/10.1016/j.envsci.2022.03.024

III. Van Beek, L. & Versteeg (2023). Plausibility in models and fiction: What Integrated Assessment Modellers can learn from an interaction with climate fiction. *Futures. 151,* 103195.

https://doi.org/10.1016/j.futures.2023.103195

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V. Van Beek, L., Mouter, N., Pelzer, P., Hajer, M., Van Vuuren, D. Experts and expertise in practices of citizen engagement in climate policy: a comparative analysis of two contrasting cases. *(under review at Climatic Change)*

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I. LB, MH, DV and PP developed the design and conceptualisation of the paper. LB drafted the manuscript and performed the data collection and analysis with input from MH, DV and PP. CC contributed to the data collection, analysis and writing at a later stage.
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III. LB initiated the research. LB and WV contributed equally to research design, data collection and analysis, developing, writing and revising the manuscript.

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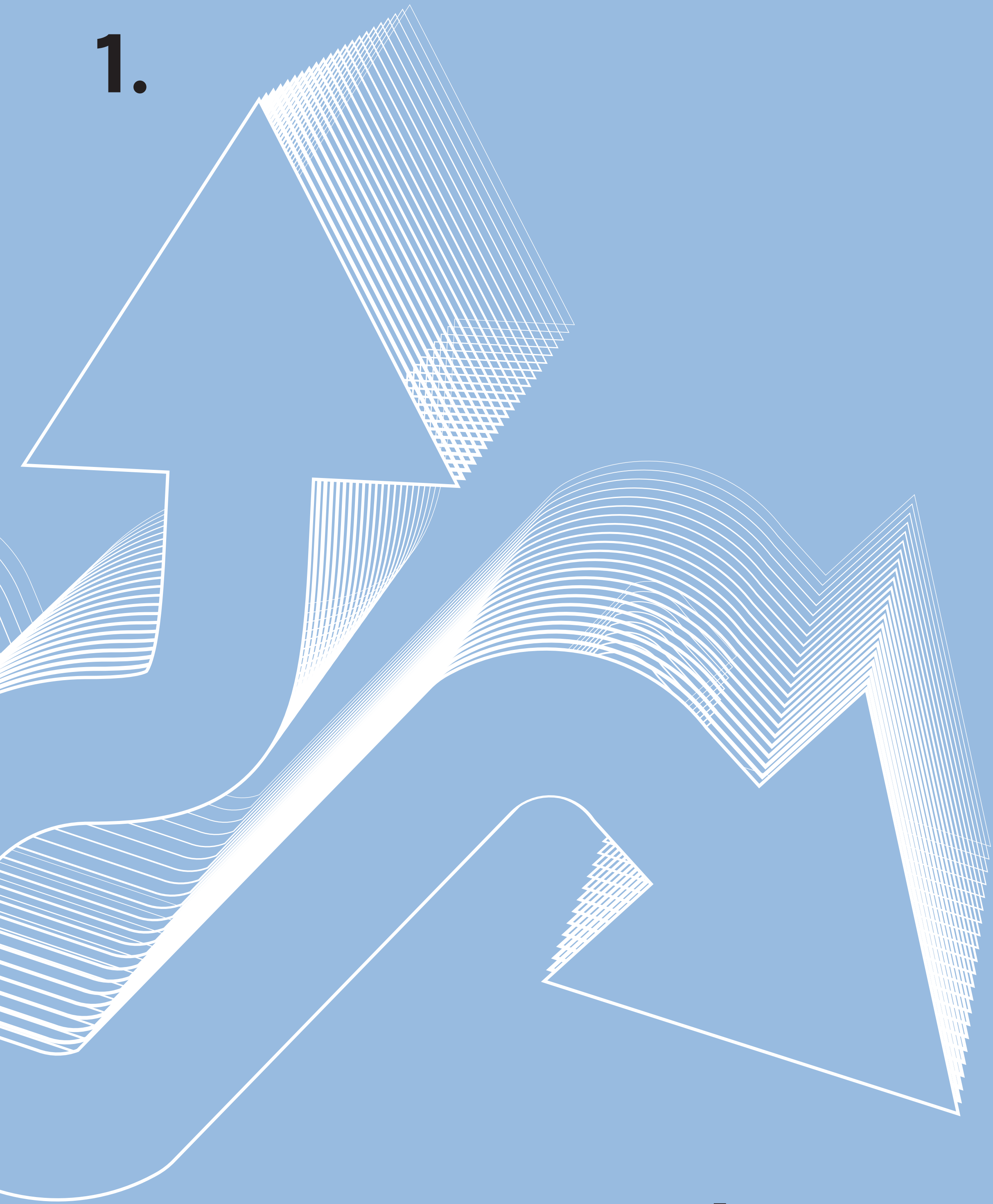
List of acronyms

BECCS	bioenergy with carbon capture and storage
CBA	cost-benefit analysis
CDR	carbon dioxide removal
COP	Conference of the Parties
ESM	Earth System Model
EPA	Environmental Protection Agency
GCM	General Circulation Model
GHG	greenhouse gas
IAM	Integrated Assessment Model
IIASA	International Institute for Applied Systems Analysis
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change
MIP	Modelling Intercomparison Project
NDC	Nationally Determined Contribution
NET	Negative Emissions Technology
RCP	Representative Concentration Pathway
SSP	Shared Socio-economic Pathway
SPM	Summary for Policymakers
SR	Special Report
SRES	Special Report on Emissions Scenarios
STS	Science and Technology Studies
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WG	Working Group

1.



Introduction

1.1 The prominence of Integrated Assessment Modelling in climate policy

As I am writing down the first words of this introduction in late 2022, it is fifty years ago since the *Limits to Growth* (Meadows et al., 1972) report was published. The report, commissioned by the Club of Rome, sold millions of copies worldwide and was translated into over thirty languages. Its powerful and straightforward message, that exponential population and economic growth would end in societal collapse, resonated all over the world. The conclusions of the report were based on calculations of the 'World 3' model. It was the first time that a computer model simulated interactions between human activities and ecological impacts on a global scale. The report not only caused a true paradigm shift, setting in motion a worldwide environmental movement, it was also the first time global modelling had been used to understand environmental problems. Whereas in the early 1970s the use of computer models to project long-term futures was hardly imaginable, global modelling had gained worldwide recognition a mere ten years later (Ashley, 1983).

Today, fifty years later, a lot has changed. Whereas the term 'climate change' did not even feature in the *Limits to Growth* report,[1] it is now broadly recognised that we are in the midst of a climate crisis. In an effort to combat the rising temperatures, ambitious climate targets have been set, such as the 1.5 and 2°C degrees temperature goals in the Paris Agreement in 2015 and, more recently, the mid-century emissions targets. The UN declared the 2020s as the 'decade of action' to advance the necessary speed and scale of transformative change to meet the globally agreed climate and sustainability targets. The debate in climate politics is no longer about the causes and existence of climate change, but rather about finding pathways towards a low-carbon future. What has not changed however, is the central role that global models play in this debate. Global models have become the primary approach amongst scientists and policymakers to understanding environmental problems, most notably climate change. The historian Paul Edwards (2010) even states that 'Everything we know about the worlds' climate – past, present and future – we know through models' (p. xiv).

The global climate targets, as well as the pathways to achieving them, are strongly based on Integrated Assessment Models (IAMs). IAMs[2] are in essence computer models that represent the complex interactions

1 The *Limits to Growth* did report on the rising CO2 concentrations and refers to it as thermal pollution alongside other forms of pollution and states that 'It is not known how much CO2 can be released without causing irreversible changes in the earth's climate' (p. 81)

2 A wide range of IAMs exist, which differ in their structure, detail and purpose. A common distinction is made between detailed process-based IAMs, which are used to develop mitigation scenarios and aggregate cost-benefit IAMs that used to establish optimal levels of climate targets (Weyant, 2017). In thesis, I refer to the former category when using the term 'IAMs' given the focus on exploring pathways towards a low-carbon future.

between human activities such as land and energy use and changes in the climate system such as global temperature. These capacities enable the simulation of the causal chain from causes of climate change to impacts to possible responses. Although contemporary IAMs are much more complex due to advancements in computing power and data availability, their roots can be traced back to the first global modelling efforts that appeared in the 1970s (Parson & Fisher-Vanden, 1997; Rotmans, 1998). As illustrated in Figure 1, over the past five decades IAMs and their predecessors have largely co-evolved with global environmental politics. IAMs provide input critical to the assessments of the Intergovernmental Panel on Climate Change (IPCC), most notably by producing mitigation scenarios, as well as more indirectly via emission scenarios used by climate models[3] and impact studies. Many of the IAMs that are in use today were built in the early 1990s, when climate change had just appeared on the global policy agenda (Rotmans & Van Asselt, 1996). IAMs have played a variety of roles in setting targets and agendas by producing successive sets of IPCC scenarios (McLaren & Markusson, 2020; Pedersen et al., 2022). For example, IAM scenarios were foundational in obtaining political support for the 2°C target by demonstrating its credibility and technical feasibility (Lövbrand, 2011). Today, IAMs are the primary means to explore possible pathways towards the globally agreed climate targets.

3 Climate models usually refer to General Circulation Models (GCMs) or Earth System Models (ESM). While both climate models and IAMs are global models that are prominent in the science-policy interface, a key difference is that GCMs and ESMs represent the climate system whereas IAMs represent climate-society interactions.

While one could view the co-evolution of IAMs and climate policy as a successful case of policy-relevant research, the reliance on IAMs can be problematic. Scholars in Science and Technology Studies (STS) have argued that the prominence of modelling in climate policy forecloses alternative ways of knowing and governing climate change (Beck & Oomen, 2021; Beck & Mahony, 2017, 2018a; 2018b; Lövbrand, 2011; Miller, 2004; Shackley & Wynne, 1995; Turnhout, Dewulf, & Hulme, 2016). Already three decades ago, Shackley and Wynne (1995) argued how climate modellers and policymakers 'mutually construct' the presumption of a top-down and centralised governance structure, excluding other more local or decentralised forms of governance. Lövbrand (2011) later showed how modellers oriented their modelling efforts towards exploring 2°C scenarios in response to the demands of EU policymakers. While this close interaction between IAM modelling EU climate policy resulted in policy-relevant research, modellers' orientation towards policy-relevance may also limit their capacity to challenge existing policy agendas (Ibid.). Furthermore, IAMs typically explore pathways towards a quantified emissions or temperature target by finding a cost-effective combination of policy measures and technologies. While cost-effective pathways are easy to model, the prominence of IAMs in climate policy risks that alternative futures and other social, ethical and political questions become overlooked (Beck & Oomen, 2021).

I identify three recent shifts in climate science and politics that challenge the position of IAMs in the coming years (see also Figure 1).[4] First, following the Paris Agreement, the IPCC announced a shift in focus from causes and impacts to identifying strategies and solutions (Guillemot, 2017; Beck et al., 2022). This solution-oriented mode immediately implies the need to engage with the variety of perspectives on desirable low-carbon futures, which challenges the seemingly apolitical nature of IAM scenarios. Second, because of the lacklustre response to the climate crisis, there is a growing call for radical transformations towards a sustainable future. The notion of 'transformation', which emphasises structural and systemic changes of current systems, has become gradually institutionalised since the early 2010s (Feola, 2015). However, global climate science and policy seem to be concentrated on techno-economic rationalities and lack the 'radical imagination' of transformative change (Hammond, 2021; Stoddard et al., 2021). Third, climate governance has expanded from globally binding agreements towards a 'polycentric' climate governance where climate action is taken on the national and substate level and by non-state actors (Bäckstrand et al., 2017; Jordan et al., 2015). This polycentric character of climate governance brings the prominence of IAMs into question, as it is unclear how IAMs and the IPCC more generally could cater to the emerging plurality of actors with diverse knowledge needs.

4 With 'identify' I do not mean I am the first one to observe these shifts, but recognise these as particularly crucial with regard to IAMs in climate politics.

While the interaction (and associated challenges) between global modelling and climate policy is clear, it is less clear *why* they closely interact and *how* their interaction shapes the imagination of low-carbon futures. This is crucial to understand because these collectively imagined futures largely shape climate actions and decisions that are taken in the present. Moreover, while the three shifts point to the need to 'open-up' the imagination of low-carbon futures towards wider sets of actors and viewpoints (cf. Stirling, 2008) as well as radical transformative change, what this would mean for the current position of IAMs remains uncertain. Therefore, this thesis is concerned with how and why IAMs and climate policy have co- evolved, and how the imagination of low-carbon futures may be pluralised and democratised.

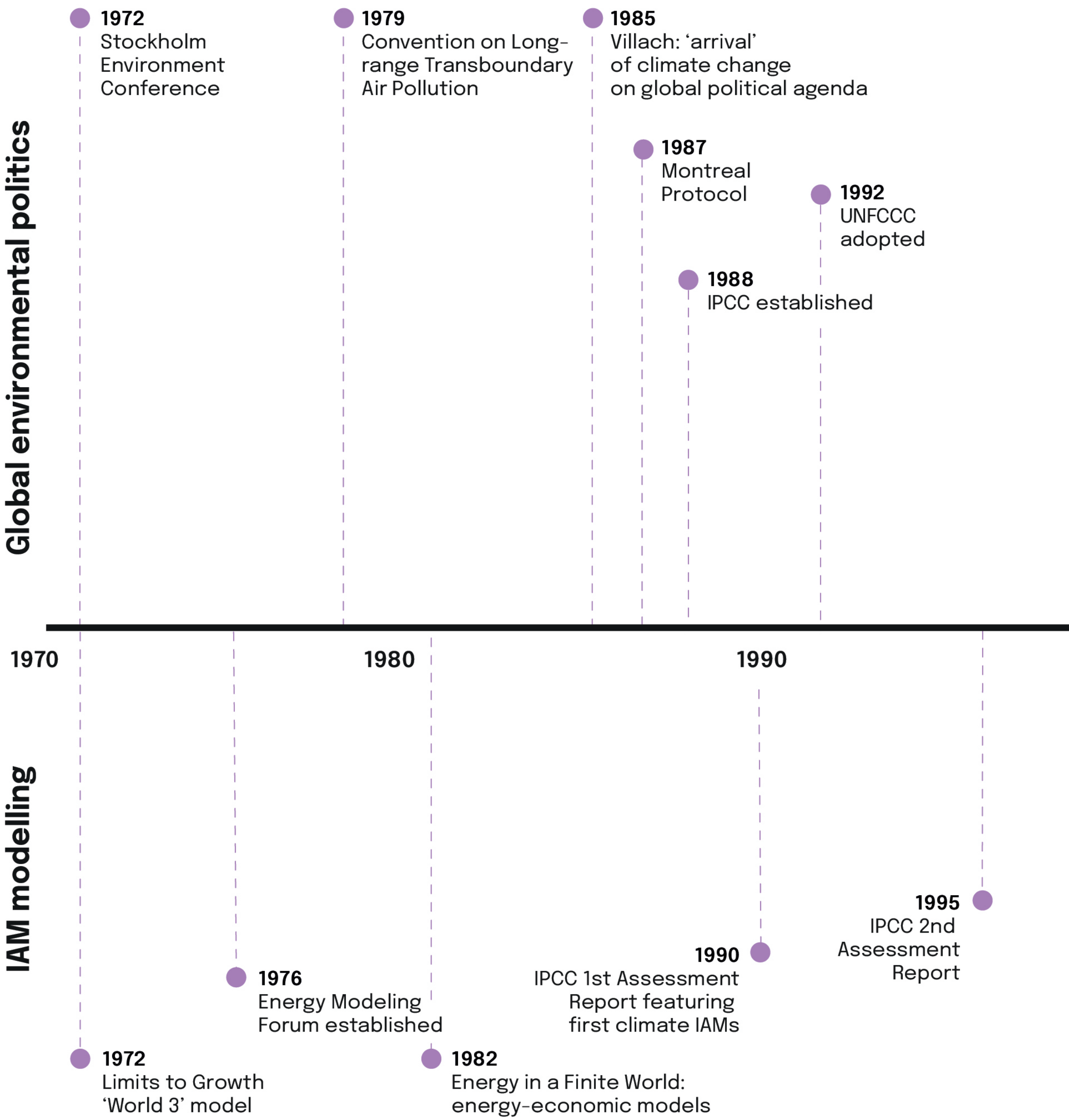
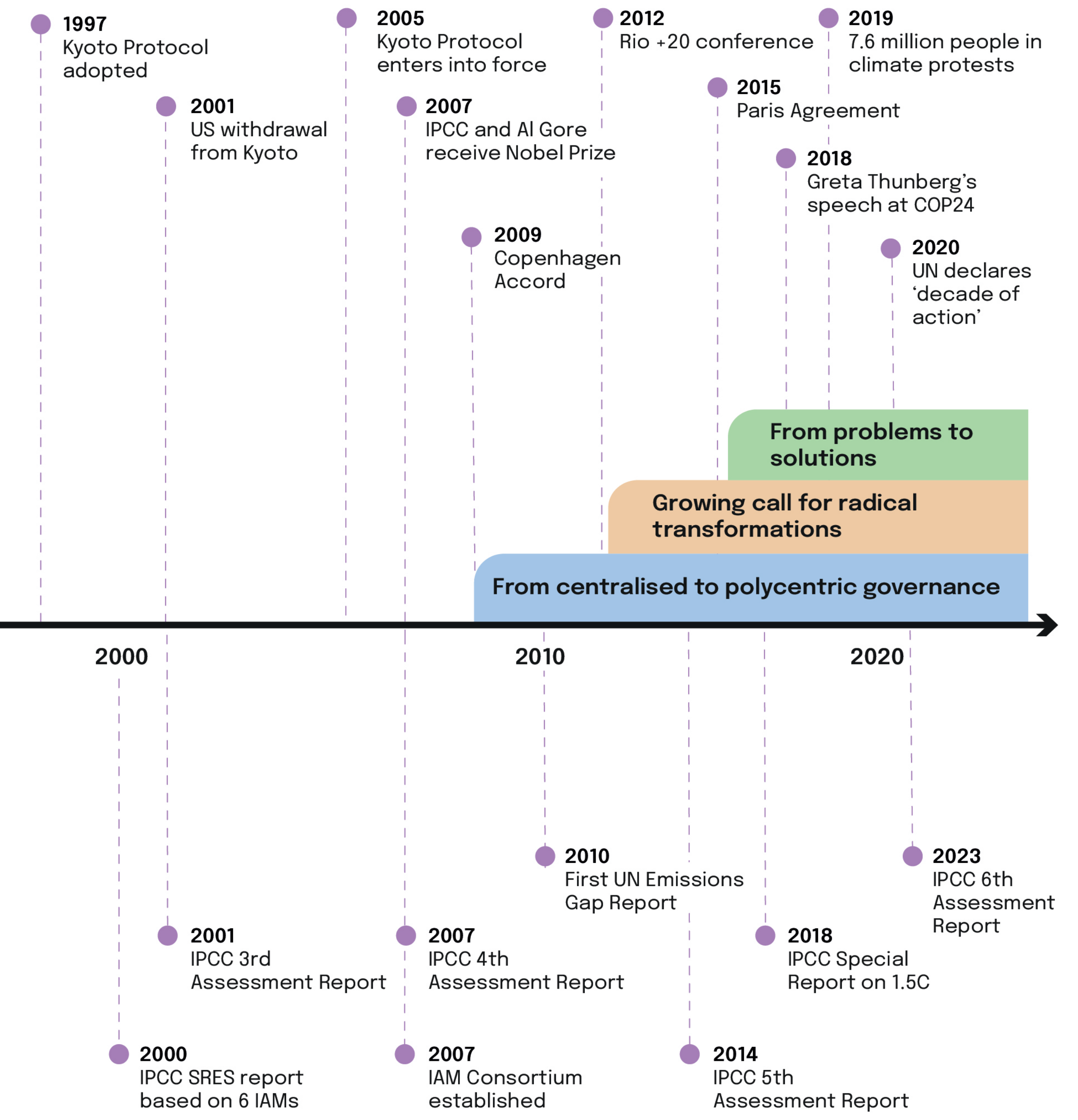


Figure 1. Timeline of the interaction between IAMs and environmental politics over the past 50 years.



Timeline showing key events in global environmental politics (upper), most notably major international environmental agreements, as well as key events in IAM modelling (lower), including scenarios in successive IPCC assessments.

1.2 Three shifts in climate science and politics

1.2.1 From problems to solutions and the need to engage with diverse perspectives

Between the 1990s and 2020s, the IPCC has gone through six cycles of producing assessment reports, which over time have come to be regarded as the world's most authoritative assessments of scientific evidence on climate change. Since the Paris Agreement in 2015, the IPCC is increasingly shifting towards a more 'solution-oriented' mode (Beck et al., 2022; Guillemot, 2017). This move has directed the attention from IPCC's Working Group (WG) I on physical climate science to WG III on response strategies. Yet transformations are likely to have unequal distributive effects across geographical and temporal scales and are associated with a plurality of perspectives on what a low-carbon and sustainable future looks like and how we might get there (Scoones et al., 2015). In other words, transformations are deeply political. This political nature challenges the IPCC's mandate, which is to provide 'policy-relevant but not policy- prescriptive' assessments (IPCC, 2021). Recognising this challenge, IAM modellers introduced the metaphor of cartography to describe their role: modellers are 'mapmakers' who identify various policy 'pathways' and associated consequences, which can help the 'navigators' (policymakers) to decide on which path to take (Edenhofer & Kowarsch, 2015; Edenhofer & Minx, 2014; IPCC, 2014). This model of science-policy interaction presupposes that the pathways represent diversity in political standpoints and narratives, that the assumptions are transparent and that the pathways are defined in collaboration with stakeholders (Edenhofer & Kowarsch, 2015). To some extent, IAM pathways indeed reflect this model. In the Sixth Assessment Report (IPCC, 2022), IAM pathways presents five illustrative mitigation pathways which vary in the assumed ambitiousness of climate policy, the type of mitigation strategies, the timing of mitigation and the combination of climate policy with other sustainability objectives. Modellers involved in IPCC reports are also addressing the issue of transparency, the alleged lack of which formed a point of critique ever since the first IPCC reports in the 1990s (e.g. Schneider, 1997; Van der Sluijs, 2002), by making data and source code publicly available and developing open-access scenario databases (although the 'openness' of these databases can be questioned given their technical language). IAM modellers also deploy stakeholder engagement, most notably with policymakers

5 Early efforts of stakeholder engagement by the IMAGE modelling group include for instance the 'Delft dialogue' (Van Daalen et al., 1998) which included dialogues with policymakers to support the climate negotiations and more recently the SHAPE project to develop sustainable development pathways (https://shape-project.org/) ↗

and more recently also with other societal stakeholders including civil society organisations.[5]

Yet, I would argue that the challenge of engaging with divergent perspectives on desirable futures still remains unresolved. IAM modellers are organised in a relatively close-knit community, with institutions and networks situated predominantly in the Global North (Corbera et al., 2016; Hughes & Paterson, 2017). The most established IAM teams which traditionally contribute substantially to IPCC reports are located in the Netherlands, Germany, Japan, Austria and the US.[6] It is therefore questionable whether non-Western worldviews are represented. Moreover, while the strong organisation of the IAM community facilitates the efficient synthesis of thousands of scenarios, their close collaboration and mutual learning also results in common assumptions around the relevant problem and solution- orientations, such as the search for cost-effective pathways. The metaphor of the mapmaker becomes problematic here, as it suggests that IAMs map out all possible paths that could be taken, whereas in reality IAM teams make choices about what futures to explore and what futures to ignore. In the latest IPCC assessment (2023), the majority of the scenarios seem to focus mostly on techno-economic solutions. While IAMs also explore alternative pathways, these are still a minority of the full set. An example of a critical model decision is the choice of the discount rate,[7] which is rarely made explicit, but has profound inter- and intragenerational justice implications as it shifts the burden of mitigation to future generations (Krznaric, 2020; Stern, 2006). The discount rate also has implications for timing and type of mitigation strategies in scenarios: the higher the discount rate, the higher the overshoot of the carbon budget and assumed need for carbon removals (Emmerling et al., 2019). Although modellers do engage with distributive justice concerns in their practice, IAMs still account for a limited set of these principles (Jafino et al., 2021; Rubiano Rivadeneira & Carton, 2022). These value-based judgments are not *arbitrary*, however, as some critics argue (e.g. Pindyck, 2013). Rather, the assumptions shape and are shaped by the discursive structures in which IAMs are situated (Ellenbeck & Lilliestam, 2019); the discount rate that the IAM community typically uses is in line with market interests and government investments (Emmerling et al., 2019).

What is problematic however, is that IAM pathways are typically presented and interpreted as apolitical, while modellers make value-based choices in the mitigation pathways they explore. The authoritative nature of IAM scenarios can thereby obstruct a political debate on

6 Over the past six successive IPCC reports, IAMs that were most often used to develop scenarios were IMAGE (PBL, the Netherlands), MESSAGE (IIASA, Austria), AIM (NIES, Japan), REMIND (PIK, Germany), MERGE (Stanford University, US) and GCAM/MiniCAM (PNNL, US). The two most recent assessments (AR5 and AR6) included a more diverse set of models, for example WITCH, (CMCC, Italy), IMACLIM (CIRED, France) and COFFEE (COPPE/UFRI, Brazil).

7 Process-based IAMs typically use a discount rate of about 5-6% per year (in line with market interests and government investments) in order to select cost-effective mitigation pathways (Emmerling et al., 2019). The choice of the discount rate is a long-debated issue in climate economics, most notably in relation to cost-benefit IAMs. The Stern Review for instance, suggested a discount rate of 1.4%, which would favour earlier mitigation (Stern, 2006).

desirable low-carbon futures. An example of this are the IAM pathways in the Special Report on 1.5°C (IPCC, 2018), which projected that the 1.5°C target would require net-zero emissions around 2050 and a reduction of about 45% of emissions by 2030. The four 'illustrative' policy pathways all relied to varying degrees on carbon dioxide removal (CDR), such as afforestation and carbon capture and storage. CDR is subject to ongoing academic debate, most notably around the feasibility of its large-scale deployment that is often assumed in IAM scenarios (e.g. Forster et al., 2020; Low & Schäfer, 2020; Vaughan & Gough, 2016) as well as their potential ecological and social consequences (e.g. Buck, 2016; Dooley et al., 2021). This debate on the feasibility and desirability of CDR was precisely what modellers intended. In fact, modellers themselves argue for the need of such a debate to avoid getting locked into an undesirable future (Van Vuuren et al., 2017). Instead of purely stimulating a debate on CDR, however, the IAM scenarios also contributed to its normalisation. At the time of writing, CDR is seen as an inevitable mitigation strategy and have been adopted in many national long-term mitigation plans (Carton et al., 2020; Thoni et al., 2020). It is important at this point to emphasise the distinction between the *intention* of scenarios and their *interpretation*. Shackley and Wynne (1996) have observed that climate models are often viewed as predictive truth machines rather than as the heuristic tools they are intended to be. MacKenzie (1990) referred to this phenomenon as the 'certainty trough': while knowledge producers are generally well aware of uncertainties and shortcomings of their findings, these uncertainties are often lost in translation by users who tend to interpret this knowledge with much more certainty.[8] A problem underlying this misunderstanding and misinterpretation seems to be the assumption of a linear model from science to policy and society, whereas in reality this interaction is much more complex and dynamic (cf. Turnhout, Tuinstra and Halffman, 2019). Altogether, the inherent political nature of transformations suggests that political questions can no longer be avoided. Yet, given the seemingly apolitical character of IAM scenarios, it is not self-evident *how* IAMs should engage with such questions.

1.2.2 The growing call for radical transformations

Despite ambitious global targets on climate and sustainability, the world is still not on track to meet these targets (UNEP, 2022; IPCC, 2023). It is now widely acknowledged that 'a stepwise approach is no longer an option. We need system-wide transformation' (UNEP, 2022, p. xv). As noted by Feola (2015), the term 'transformation' has become gradually

8 Based on an ethnographic fieldwork, Lahsen (2005) has argued that MacKenzie's distribution of uncertainty did not reflect the complexity of uncertainty perceptions of different actors around climate models. She found that GCMs are not produced in a single site, the distinction between users and developers is blurred, modellers are not necessarily aware of all inaccuracies and modellers are not always capable of keeping a critical distance given the emotional and professional investment in their models. Nevertheless, she confirms that in general 'atmospheric scientists are better judges than, for example policy-makers, of the accuracy of model output' (p. 917)

institutionalised in climate science and politics since the early 2010s (as illustrated in Figure 1). There is a growing scholarship on transformations using diverse terms, such as socio-technical transitions and socio-ecological transformations (Feola, 2015; Hölscher et al., 2018; Patterson et al., 2017).[9] In this thesis, I align with the definition by Patterson et al. (2017) in understanding transformations as 'fundamental changes in structural, functional, relational, and cognitive aspects of socio-technical-ecological systems that lead to new patterns of interactions and outcomes' (p. 2). IAMs have considerable strengths in exploring potential transformations, most notably the capacity to conceive of changes across multiple subsystems (transport, industry, energy and land-use) and across different geographical scales (Geels, Berkhout, & Vuuren, 2016). They also provide information on the necessary speed and scope of low-carbon transformations. The Emissions Gap Report (UNEP, 2022) exemplifies this contribution, as the gap between countries' pledges and the necessary emissions reductions to achieve global climate targets could arguably not be understood without IAMs.

9 Some scholars make a distinction between 'transitions' and 'transformations' (Hölscher et al., 2018; Stirling, 2022). However, as the terms are often used interchangeably and are not mutually exclusive, I follow Patterson (2017) in using 'transformations' as a broad term that refers to fundamental shifts in systems.

However, concerns have been raised that IAMs do not adequately capture deep transformative change. Anderson (in Anderson & Jewell, 2019), for instance, argues that IAMs' assumption of marginal changes within the current economic system is misaligned with the radical and immediate transformations that the stringent global climate targets imply. The reliance of IAMs on CDR (see 1.2.1) also features as a prominent example in such arguments. Because CDR may not deliver on the scale assumed in IAMs, critics argue that the assumption of large-scale deployment of CDR creates a false technological promise, in which the need for radical and near-term emission reduction is potentially undermined (Anderson & Peters, 2016; Carton et al., 2020; 2023; Grant et al., 2021; Markusson et al., 2018; McLaren et al., 2019). However, not all IAM pathways rely strongly on CDR. Already around 2007, IAM modelling teams started exploring the climate benefits of dietary change (Stehfest et al., 2009) and the community is increasingly exploring lifestyle scenarios (see e.g. Grubler et al., 2018; Van den Berg et al., 2019; Van Sluisveld et al., 2016; Van Vuuren et al., 2018). Nevertheless, IAMs' predominantly techno-economic framing and focus on cost-effectiveness still moves the attention away from deeper-level, more fundamental societal transformations.

One way of understanding the depth of system change is the 'leverage point' framework developed by system thinker and *Limits to Growth* modeller Donella Meadows (1999). Her framework distinguishes nine places to intervene in a system, ranging from 'shallow' leverage points such as material stocks and feedbacks to 'deeper' leverage points such as goals and paradigms. When applying this framework to low-carbon transformations, it indeed appears that the deeper the leverage points the weaker its representation. IAMs most strongly represent material stocks (e.g. building stocks, trees, electric vehicles) and feedbacks (e.g. improving energy efficiency, reducing waste in value chains). Change in social structures is represented mostly in the form of consumer behaviour (e.g. Van den Berg et al., 2019; Van Vuuren et al., 2018), but IAMs do not describe diverse collective and political forms of agency such as social movements (Otto et al., 2020) and institutional change, such as shifts in governance architectures (Hickmann et al., 2022). Transformations also imply shifts in mind-sets and paradigms, which constitute the deepest leverage points, such as alternative human-nature relationships or degrowth. Ironically, where the *Limits to Growth* models (Meadows et al., 1972) showed that infinite population and economic growth on a finite planet would be impossible,[10] contemporary IAMs all assume continued economic growth. However, motivated by limited evidence of completely decoupling economic growth from material and energy use (Haberl et al., 2020), some scholars are arguing for the development of post- growth or degrowth[11] mitigation scenarios (Hickel et al., 2021; Keyßer & Lenzen, 2021). In contrast to what the term suggests, degrowth is not primarily concerned with reducing GDP but rather with strong reductions in material and energy use while achieving wellbeing as well as a redistribution of wealth (Hickel, 2021; Kallis et al., 2018). Strong energy and material demand reductions are also assumed in lifestyle scenarios explored with IAMs (e.g. Grubler et al., 2018; van Sluisveld et al., 2016; Van Vuuren et al., 2018). A prime example is the Low Energy Demand (LED) scenario (Grubler et al., 2018), which featured as one of the main mitigation scenarios in recent IPCC reports (IPCC, 2018; 2022). However, although the LED scenario is similar to degrowth scenarios in its demand reductions, it still assumes decoupling economic growth from energy use and relies strongly on technological efficiency measures (Keyßer & Lenzen, 2021 for a comparison). In other words, although the numbers may look similar, it matters what story they tell; a story of radical political and economic reorganisation towards socio- ecological justice driven by social mobilisation (e.g. Kallis et al., 2018) or a story of aggregated consumers whose individual responsibility is invoked to change their consumption patterns (cf. Barr et al., 2011; Van de Grift, 2022). Degrowth is obviously just one example of a transformative future. Other examples include futures that involve alternative human-nature relationships, such as calls for 'multispecies justice'

10 The Limits to Growth report did not literally suggest the need to reduce economic growth as it mostly described trends in population, industrialisation, food production and resource depletion. However, the authors assumed strong coupling between material and economic growth and argued that trends in the latter are 'inexorably widening the absolute gap between the rich and the poor', suggesting the need to prioritize health and education over economic growth in their conclusions.

11 Post-growth, degrowth and doughnut economics are closely related terms that are often used interchangeably. Post-growth is a broad set of visions that generally argue for prioritising wellbeing over economic growth in order to stay within the planetary boundaries. Degrowth is a post-growth vision that specifically foregrounds a redistribution of wealth between those with high – incomes that exceed planetary boundaries and those with lower incomes (see e.g. Hickel, 2021).

which views all beings as relational and extends climate justice to non-living entities (Tschakert et al., 2021). This could involve granting legal rights to nonhuman entities such rivers, which is starting to materialise (O'Donnell & Talbot-Jones, 2018). Such radical transformations are typically not part of the repertoire of IAMs.

Importantly however, it not just IAMs that are of concern here. Both scientists and policymakers tend to focus on 'shallow leverage points' such as financial incentives and monitoring schemes, failing to address the root causes of unsustainability (Abson et al., 2017). Most countries still prioritise economic growth, with GDP as the primary indicator for measuring progress.[12] More broadly, mainstream environmental policy reflects a predominantly technical and managerial approach, side-lining value discussions and alternative worldviews (Hammond, 2021). In other words, global modelling and climate policy seem to be reproducing dominant discourses of continued economic growth, technological solutions and market- based mechanisms (Stoddard et al., 2021). Some argue that transitioning to a low-carbon future therefore requires more 'radical imagination': new perspectives and forms of knowledge that unsettle this techno-scientific discourse and open-up imaginative visions of alternative futures (Hammond, 2021). Such demands for radical imagination call the prominence of IAMs in climate politics into question.

12 There are some exceptions to this. A prominent example is the Living Standards Framework (LSF) that was released in 2021 by the New Zealand government as a dashboard to assess wellbeing of policies.

1.2.3 From a centralised towards a polycentric climate governance architecture

The failed UN climate negotiations in Copenhagen in 2009 marked a shift from a global and top-down climate governance architecture towards one that is more polycentric (Bäckstrand & Lövbrand, 2019; Jordan et al., 2015). Legally binding agreements have made way for a bottom-up pledge and review system that has been institutionalised in the Paris Agreement, where countries submit their nationally determined contributions (NDCs) and long-term strategies.[13] Moreover, non-state actors from industry and civil society have become increasingly active in the negotiations (Bäckstrand et al., 2017). The rationality of green governmentality, that climate change is to be governed through global stewardship and carbon control, has certainly not fully disappeared (Bäckstrand & Lövbrand, 2019). Nevertheless, Copenhagen marked a turning point: non-state and sub-state actors increasingly take climate action into their own hands, as exemplified by the rise of transnational city networks, public-private partnerships and grassroots

13 The Paris Agreement (UNFCCC, 2015b) requests parties to submit Nationally Determined Contributions (NDCs). Article 4, paragraph 19, also states that all parties should strive to submit Long-Term Low Greenhouse Gas Emission Development Strategies (LT-LEDS).

mobilisation (Bäckstrand et al., 2017; Bulkeley et al., 2014a). Climate change has also become a primary issue of public debate. At the time of writing, the majority of the population worldwide is worried about climate change and believes it should be prioritised by their governments (Leiserowitz et al., 2022). Climate strikes and protests are organised all over the world, demanding more radical action and climate justice. This divergence of actors in climate politics brings at least two key challenges to the prominence of IAMs.

First, it is not self-evident that global IAMs can address the knowledge needs of national policymakers, city planners, NGOs, businesses or citizens (I discuss national IAMs and sectoral models in the next paragraph). Global IAMs provide some valuable insights into the gap between countries' pledges and required emission reduction to achieve climate targets (UNEP, 2022), the timing and magnitude of required emissions reductions (e.g. Van Soest et al., 2021) and mitigation pathways for some large emitting countries (e.g. Den Elzen et al., 2016). Global IAMs also influence lower governance levels in more implicit ways. For example, the 'net-zero by 2050', which emerged from global IAM pathways, is set or intended to be set as a climate target by more than 100 countries and 800 cities worldwide (Van Soest et al., 2021). Due to their global orientation however, global IAMs are generally less well-suited for the analysis of policy options on the national and local level because they overlook certain specific mitigation options and contextual consequences (Waisman et al., 2019). Some scholars have advocated that the IPCC should mirror the polycentric character of climate governance by including a broader set of actors in their reports, such as Indigenous peoples, practitioners, citizens and local communities (Beck et al., 2022). However, it is unclear if and how local knowledge could feature alongside – or perhaps even be prioritised over – global forms of knowledge such as IAMs in IPCC assessments. Given that IPCC's global orientation has crowded out local forms of knowledge in the past, some even seriously question its suitability to support local communities in exploring mitigation options (Miller, 2023).

Second, on the national level climate policymaking is still far removed from the demands, hopes and dreams of citizens. Climate policymaking strongly relies on expert analysis, not in the least model-based scenarios. This includes national IAMs or sectoral models such as energy models or land-use models, often used in combination.[14] Climate policymakers tend to focus on what Willis (2019) calls 'stealth strategies': the assumption that experts know best and can impose strategies on an unthinking public in the hope that no one will notice. However,

14 Examples of combined deployment of IAMs and sectoral models to develop mitigation scenarios on the national level include the Deep Decarbonisation Project (https://ddpinitiative.org/), the COMMIT project (https://www.pbl.nl/en/archive/commit), the ENGAGE project (https://www.engage-climate.org/), and the ELEVATE project (https://cordis.europa.eu/project/id/101056873)

conflicts over wind farm projects and the 'gilettes jaune' (yellow vests) movement in France point to the pitfalls of this technocratic approach. In recent years, these pitfalls seem to be increasingly recognised, as signified by the rise of citizen engagement practices in climate and energy policy across the world (Galende-Sánchez & Sorman, 2021).[15] A visible example of this trend are the national climate assemblies that are emerging all over Europe, including in Ireland, France, Germany, the UK and Denmark. These citizen engagement practices are often expected to 'open-up' policymaking, alluding to citizens' diversity in values and viewpoints and their capacity to identify policy options that experts and policymakers may overlook (e.g. Fiorino, 1990; Stirling, 2008). Indeed, citizens typically rely on a much wider set of economic, ecological, social, ethical and political considerations to assess the feasibility and desirability of climate mitigation strategies beyond cost- effectiveness and technical feasibility (Bellamy et al., 2014). As a result, model-based mitigation scenarios can be strongly misaligned with citizens' views on desirable futures (Xexakis et al., 2020). These developments imply that the reliance on models in climate policymaking is no longer tenable.

15 According to the review by Galende-Sanchez et al. (2021), participation initiatives in climate and energy policy and research are on the rise accross Europe, the Americas, Asia, Oceania and Africa. However, participation is much more mainstream in Europe as this region accounted for half of the initiatives and the large majority was from the Global North.

1.3 Perspectives on the future of IAMs in climate politics

IAMs have been subject to criticism over the past three decades (Pedersen et al., 2022; Skea et al., 2021). Prominent critiques concentrate on modellers' assumptions (e.g. being arbitrary or untransparent), the model structures (e.g. missing important social, institutional, economic or technological dimensions), the real-world feasibility of their scenarios (e.g. CDR), their lack of engagement with justice principles and their influence in the IPCC and climate politics (e.g. the networks of authorship) (Gambhir et al., 2019; Keppo et al., 2021). In their review, Gambhir et al. (2019) observed three prominent perspectives on the future of IAMs: 1) discard the models, 2) improve the models, and 3) complement models with other tools. In this section, I elaborate on the arguments and deficiencies of these perspectives (1.3.1) and argue for the need for a new perspective on IAMs in climate politics (1.3.2).

1.3.1 Three existing perspectives: discarding, improving or complementing

In line with the *discarding* perspective, Anderson (in Anderson & Jewell, 2019) argues that IAMs are simply the 'wrong tool for the job', because the suggestion of moderate change within the current economic system is not in line with the stringency of global climate targets. Others argue that deep uncertainties make projecting mitigation costs and benefits in the long term 'fundamentally impossible' (Rosen, 2015). I disagree with the *discarding* perspective, as I believe IAMs (both global and national ones) have capabilities that are valuable in the societal debate on low-carbon futures, most notably their simulation of the complex interaction and feedback between human activities and climate change, their sectoral scope and their long-term orientation (see also Geels et al., 2016). Their sectoral scope and long- term orientation also enable the understanding of the necessary speed and scope of low-carbon transformations. Both on the global and national level, IAMs can therefore provide valuable insights into the gap between countries' pledges and global temperature as well as tracking countries' progress on meeting their climate targets. Their representation of complex climate-society interactions and sectoral scope enables an understanding of the second and third order effects of various mitigation options as well as the complex interactions and trade-offs between those options, which 'cannot be handled by mental models alone' (Meadows et al., 1982, p. 13). Examples of such interactions and trade-offs are the influence of dietary change on land-use, which in turn affects the potential of bioenergy crops or afforestation (see e.g. Riahi et al., 2017).

In contrast, the *improving* perspective views the limitations of IAMs as 'gaps' that can be resolved by further model refinement (e.g. Keppo et al., 2021). This improvement includes improving the representation of actor heterogeneity (e.g. De Cian et al., 2020), representation of lifestyle changes (e.g. Van den Berg et al., 2019), interactions between technology and behaviour (Edelenbosch et al., 2018) or material flows in specific sectors (Stegmann et al., 2022). While some of these model improvements are certainly valuable, it is debatable whether only improving IAMs will sufficiently address the challenges brought by the three shifts. Due to their structural limitations, IAMs are limited in their capacity to represent many of the social, political and cultural transformations that would be required to achieve a low-carbon future. As stated in *Groping in the Dark* (Meadows et al., 1982), where global modellers reflect on the first decade of global modelling, 'the most important forces shaping the future are social and political, and these forces are the least well represented in the models.' (p. 280). Moreover, this perspective implicitly assumes that model improvement leads to higher accuracy, whereas the opposite is often true; greater complexity results in *more* uncertainty in projections (Dowlatabadi, 1995; Harremoës & Madsen, 1999; cf. Lee, 1973). Another implicit assumption seems to be that more accurate models lead to better decision-making. However, given that models can never represent reality in its full complexity, their primary value is heuristic (Oreskes et al., 1994); models can only offer policymakers a 'quasi-intuitive feel' or 'rule of thumb' for the trade-offs and policy choices (Edwards, 1996). Or, as stated by Meadows et al. (1982), 'the very best model is one that contains just what is needed for that purpose, and no more. It is elegant, which means, according to the dictionary, 'ingeniously simple' (p. 7).

The *complementing* perspective is somewhat in the middle (although not necessarily contrary to the improving perspective). It acknowledges that IAMs have both fundamental limitations and important strengths and should therefore be complemented or bridged with other tools. Geels et al. (2016), for instance, argue that IAMs should be complemented with socio-technical transition analysis and practice-based action research in order to offer more contextual analysis of dynamics of innovation and to account for the 'messiness' of local practices (see also Van Sluisveld et al., 2020). Likewise, Pereira et al. (2021) argue for an expansion of the 'toolkit' of futures approaches that are used in global environmental assessments such as the IPCC, such as agent-based modelling, simulation games and participatory scenarios. An implicit assumption in this perspective appears to be that these alternative methods could be taken out of their context and feature alongside IAMs in IPCC reports with a similar level of authority. Although I sympathise with this perspective, I question this assumption, as it disregards the multitude of ways in which global models have gained and exercise authority in global climate politics (Hulme, 2012). Moreover, although the IPCC has diversified the knowledge communities in their reports (see IPCC, 2018; 2023), the IAM community is still much better organised through shared data-bases, networks and modelling comparisons compared to other knowledge communities (Cointe et al., 2019).

1.3.2 The need for a new perspective: thinking beyond IAMs as a tool

The previous three perspectives all seem to view IAMs as a tool: a tool that needs improvement, a tool that should be complemented by other tools or the wrong tool altogether. I suggest, however, that the challenges that the three shifts bring imply the need to think beyond IAMs as a tool. Supporting a political debate on low-carbon futures (shift 1), might not only require different scenarios, but perhaps also entirely different ways in which models and scenarios are rendered authoritative. Authority is never pregiven, but resides in the interactions between modelling and climate policy (cf. Hulme, 2012; Jasanoff, 1990; Wynne, 1987). Furthermore, the focus on techno-economic futures (shift 2) is not merely the result of a bias in the models, but also reflects dominant discourses in climate politics (Ellenbeck & Lilliestam, 2019). Besides, the polycentric character of climate governance (shift 3) implies the need to rethink what and whose knowledge counts as relevant expertise (cf. Turnhout & Lahsen, 2022). In other words, none of the three perspectives seem to take into account how IAMs interact with climate politics. I therefore argue for the need for a broader perspective that takes these interactions into account; detailing how knowledge claims about the future are made, how such claims become authoritative and how, through those interactions certain ideas of possible futures arise and influence the political debate.

1.4 Understanding IAMs as a 'Technique of Futuring'

In this thesis, I therefore view IAMs as a 'Technique of Futuring' (ToF), defined as a 'practice bringing together actors around one or more imagined futures and through which actors come to share particular orientations for action' (Hajer & Pelzer, 2018, p. 225). In contrast to what the term 'technique' might suggest, the ToF concept does not refer to a specific tool, such as a computer model, scenario framework or cost-benefit analysis (CBA), but rather to the social interactions around these tools through which shared imaginations of possible futures emerge and are reproduced. Such shared imaginations are often referred to as 'imaginaries', defined by Jasanoff (2015) as 'collectively held, institutionally stabilised and publicly performed visions of desirable futures' (p. 2). Hajer and Pelzer (2018) introduced the concept of ToFs to explain how imaginaries around particular tools arise as well as to explore how by changing the physical setting, interactions between actors and representation of the future new imaginaries may emerge. The authors used the case study of *2050 An Energetic Odyssey* to exemplify how this analytical lens improved the understanding of how and why this multimedia installation shaped an imaginary of renewable energy. As argued by Hajer and Pelzer (2018), the success of this case could not just be explained from *what* future was imagined (i.e. off-shore wind on the North Sea), but crucially also from *how* it was presented (i.e. an immersive multimedia installation), *by whom* (i.e. a sequence of staged interactions between experts, business leaders, NGOs and Ministers) and *where* (i.e. in a new and unusual non-policy settings). In this thesis, I use the ToF concept as an analytical lens to study IAMs in climate policy. With 'analytical lens' I mean that my unit of analysis is not 'IAMs' themselves, such as the thousands of lines of computer code or the theories they represent, but to the particular way *storylines* are represented by IAMs, the *dramaturgy* of interactions between IAM and policy through which imaginaries get shaped and the organisational and discursive *structure* in which IAMs are situated (Oomen, Hoffman and Hajer, 2021). Using ToFs as an analytical lens also shifts the focus from the content of 'futures' to the act of 'futuring', or futures-in-the-making (Adam & Groves, 2007): the process through which futures are imagined, become collectively shared and shape actions in the present.

I use ToFs as an analytical lens to bring into view the interactions between IAMs and climate policy through which a particular 'possibility space' is shaped. The **'possibility space'**[16] is a frequently used but surprisingly ill-defined concept. The notion of the possibility space already appeared in early works by Bourdieu (1983), Nullmeier (1993) and Appadurai (1996). Nullmeier (1993), for instance, understands the possibility space – or *Möglichkeittsraum* – as the spectrum of policy options within which policy debates take place. More recent engagements with the concept in futures studies and sustainability literature focus more on possible futures, e.g. 'the range and analytical content of possible futures' (Miller, 2007, p. 350), or 'a realm of plausible alternatives for conceiving of socio-technical functions' (Smith et al., 2005, p. 1506). Haasnoot et al. (2020) introduced the concept of 'solution space' in the context of climate adaptation as 'the space within which opportunities and constraints determine why, how, when, and who adapts to climate risks' (p. 1). It describes how the realistically available adaptation solutions in the future are shaped by 'hard' limits such as biophysical changes or 'soft' limits such as laws and regulations (Du

16 See Oomen, Hoffman and Van Beek (forthcoming) for a more elaborate introduction to the possibility space concept (manuscript in preparation).

et al., 2022 for a refinement of the latter). While the 'solution space' concept assumes the existence of future possibilities, I view these possibilities as constructed and dependent upon current ideas and understandings of the world. I therefore adopt a more constructivist view on the possibility space, defined here as 'the range of future actions, solution-orientations or policy options that are discursively and imaginatively opened-up and closed-down'. Where the concept of possibility space describes *what* futures are imaginable, the ToF concept describes *how* this possibility space is shaped through interactions between actors – in the case of this thesis interactions between IAMs and global climate policy. I reflect on the value and limitations of the key concepts of possibility space and techniques of futuring in the final chapter (section 7.5.2).

I use the ToF lens not only to study IAMs, but also to explore encounters with alternative approaches to imagine low-carbon futures (Appendix a for examples of futures approaches). There is a wide range of tools, methods and approaches to imagine possible futures and various typologies have been made (e.g. Adam & Groves, 2007; Borjeson et al., 2006; Bradfield et al., 2005; Muiderman et al., 2020; Pelzer & Versteeg, 2019; Swart et al., 2004). Some of these approaches strongly rely on expert analysis, such as IAMs, energy models (e.g. Taylor et al., 2014; Zhang et al., 2016), cost-benefit analysis (e.g. Liu et al., 2018), agent-based models (e.g. Chen et al., 2018; Gerst et al., 2013) and socio-technical transition analysis (e.g. Geels et al., 2018). Others are more participatory in nature, such as participatory visioning and back-casting (e.g. Robinson et al., 2011; Wiek & Iwaniec, 2014), deliberative mapping (e.g. Bellamy et al., 2014), games (e.g. Mangnus et al., 2019; Vervoort, 2019) and citizens' assemblies (e.g. Willis, Curato, & Smith, 2022). Climate change has also become a prominent topic in the visual, narrative and performing arts (Galafassi et al., 2018a). Whereas earlier climate related art-works were predominantly focused on raising awareness of climate change, recent artistic projects are specifically concerned with imagining possible futures (Ibid.). Examples are climate fiction (e.g. Johns-Putra, 2016), participatory theatre (e.g. Heras & Tàbara, 2014) and speculative design (Pelzer & Versteeg, 2019; Stripple et al., 2021).

In this thesis, I explore encounters between the IAM practice and *artistic* practices, given their premise to creatively imagine radically different societies and thereby offer an alternative for the technical rationality that seems to dominate climate politics (Galafassi, Kagan, et al., 2018; Hammond, 2021; Yusoff & Gabrys, 2011). Artistic practices may also incite more inclusive conversations, raise questions about values by offering alternative forms of engagement beyond the cognitive and offer new possibilities for political engagement (Gabrys & Yusoff, 2012; Heras et al., 2021). In other words, encounters between IAMs and the arts offer opportunities to both *pluralise* and *democratise* the possibility space. I focus specifically on climate fiction, as it has grown in popularity to such an extent that it has given rise to a distinct literary genre; climate fiction or CliFi (Johns-Putra, 2016). While fiction writers arguably have more freedom to speculate on radically different worlds, both modelling and fiction writing involve storytelling. The ToF lens guides the analysis of encounters between IAMs and climate fiction by specifically attending to the *storylines*. I also study *participatory* practices informing climate policymaking on the national level, which could be viewed as attempts to *democratise* the possibility space. This level of governance is particularly noteworthy: modelling seems to take centre stage in policymaking, but at the same time the emerging citizen engagement approaches such as climate assemblies seem to challenge this prominence. I focus on two approaches: an online participation method that shares remarkable characteristics with the IAM approach and a climate assembly, an approach that is contrasting to the online tool and growing in popularity across Europe at the time of writing. Both cases could be viewed as attempts to democratise the possibility space of climate mitigation on the national level that has so far been dominated by policymakers and experts. The ToF lens guides the analysis of these practices, by not just focusing on the characteristics of the methods themselves, but attending to the *dramaturgy* of interactions through which the possibility space is constructed.

1.5 Research aim, questions and structure

This thesis addresses the following overarching research question: **How do IAMs shape the possibility space of low-carbon futures in climate politics, and how could this possibility space be pluralised and democratised?**

As illustrated in Figure 2, this thesis is structured in two parts: in **Part I,** I aim to better understand the interactions between IAMs and climate policy and how these interactions shape the particular possibility space of low-carbon futures **(chapters 2 and 3)**. In **Part II**, I build on the insights of the previous chapters; most notably the challenges that the prominence of IAMs brings with regard to the three shifts. Here

I explore how this possibility space might be pluralised and democratised in light of the three shifts **(chapters 4, 5 and 6)**. Both part I and II answer two sub questions.

Research question 1: how and why have IAMs become prominent in global climate politics?

Chapter 2 aims at better understanding how and why IAMs could evolve into the most prominent way of exploring low-carbon futures. Together with my co-authors, I reconstruct the co-evolution of IAMs and climate policy between 1972 (the *Limits to Growth*) and 2015 (the Paris Agreement). The analysis starts with the 'World 3' model underlying the *Limits to Growth* report, which was in effect not an IAM but lay its foundations. The chapter involves not just a descriptive reconstruction of *how* this co-evolution unfolded, but seeks to find factors that explain *why* IAMs could co-evolve with climate policy despite changing knowledge demands and discourses. Although not used explicitly, the ToF lens guided the analysis by attending not just to model qualities, but their particular representation of futures, the organisational and material capacities of the modelling community and the more structural epistemic authority in the global climate science-policy interface. This historical analysis provides a crucial first step to further explore how this coupling between modelling and policy shapes particular understandings of possible low-carbon futures.

Research question 2: how do modellers and policymakers mutually construct the possibility space of low- carbon futures?

Chapter 3 takes a closer look at the micro-level interactions between IAM modelling and climate policy through which particular imagined futures become persuasive. It reconstructs the IAM-policy interactions around the Special Report on 1.5°C (IPCC SR1.5, 2018). The reconstruction involves the period following chapter 2, starting with the Paris Agreement in 2015, when the IPCC was invited to develop this report. The reason to focus on the IPCC SR1.5 is that it serves as a prime example of how the possibility space is shaped, as the 1.5°C goal was first seen by the scientific community as an unrealistic target, but shifted to the new guardrail for climate action and through this process legitimised particular mitigation strategies. Starting from that observation, we aim at reconstructing *how* that imagined future became persuasive. The ToF concept is used more explicitly in this chapter to understand how this imagined future became persuasive by focusing on the particular

Figure 2. Structure of this thesis and research questions

way in which IAMs represent possible futures, the negotiation process between the modelling and policy community, the more structural epistemic authority in global climate politics and the material and organisational capacities of the IAM community.

1.5.2 Part II: experimenting with pluralising and democratising the possibility space

Research question 3: how might an interaction between IAMs and artistic practices pluralise and democratise the possibility space?

Chapters 4 and 5 both involve engagements between the IAM community and artistic practices. The central hypothesis is that artist communities have complementary strengths to IAMs, most notably their ability to imagine more radically different societies (shift 2), but also their ability to bring in questions of values (shift 1) and to engage wider sets of actors (shift 3). Both chapters bring modellers into conversation with artists to explore if and how an interaction between IAMs and artistic practices might pluralise and democratise the possibility space.

In **chapter 4** I collaborate with Wytske Versteeg, an academic scholar who is a celebrated novelist at the same time, to bring modellers into conversation with climate fiction writers and compare how both practices tell stories of possible future worlds. Climate fiction is a prominent artistic practice that has the potential to emotionally engage publics in radically different worlds. Arguably, IAM modelling and climate fiction are contrasting 'techniques of futuring', with different types of storylines, actors and audiences. Climate fiction is also far removed from the global science-policy interface and operates within a different organisational and discursive structure. However, in both modelling and fiction writing, storytelling is central. We therefore hypothesise that viewing both as storytelling practices could offer potentially fruitful interactions. With regard to the ToF concept, we specifically zoom in on the *storylines*: both the content of these storylines as well as the process through which they are constructed. Based on the comparison, we sketch potentially fruitful ways forward in which both practices could interact.

Whereas chapter 4 is more exploratory and comparative in nature, in **chapter 5** I seek to intervene more directly into the IAM practice through an artistic intervention; the Future Models Manual. This speculative manual – in the form of an interactive website – asks what an IAM would look like if it was developed by artists. It takes modellers on a journey to through different steps, inviting them to reflect upon their assumptions and political influence and suggesting alternative ways to imagine transformative futures and interact with society. The manual is the result of an eight-months collaboration with two artists-in- residence, involving group discussions, workshops and interviews with the IMAGE modelling group at the Dutch Environment Agency and Utrecht University (one of the major global IAM teams). By analysing the conversations between the artist duo and the IMAGE team, I aim to understand the mechanisms through which the artists stimulated reflection among IAM modellers. The chapter builds on insights from chapters 2 and 3 by inviting reflections on the political nature of global scenarios and from chapter 4 by proposing different ways of telling stories.

Research question 4: how do alternative dramaturgies of mobilising expertise open-up or close-down the possibility space?

Chapter 6 responds most directly to the move towards a polycentric climate governance (shift 3) by comparing how expertise is mobilised across two contrasting cases of citizen engagement practices in national climate policymaking. At first glance, this focus may seem out of place in a thesis on IAMs in climate politics, because of its geographical focus on the national level. However, this chapter takes this step to explore the national context, as this is where a tension arises between modelling as the primary approach informing climate policymaking on the one hand, and citizen engagement practices on the other. One of the cases, the Participatory Value Evaluation (PVE) method (Mouter et al., 2019) is a relatively new online method that bears strong similarities with IAMs: citizens select an optimal policy mix towards a quantified emissions target based on cost-effectiveness and other policy effects. Together with my co-authors, I compare this case with a case that is contrasting in how expertise is mobilised: the Irish Citizens' Assembly (ICA), in which citizens engage with expertise through live expert presentations and Q&A. Besides illuminating the tension between the traditional prominence of modelling and upcoming citizen engagement practices, this comparison also illuminates how a different way of mobilising expertise (including modelling) might lead to different dynamics of opening-up and closing-down possible low-carbon futures. The ToF lens guides the analysis by looking specifically at the *dramaturgy* of how expertise is mobilised: the scripting, staging and setting of expertise (cf. Hajer, 2009).

1.6 Research approach and methods

The object of study in this thesis is the practice of IAM modelling in climate politics. With 'practice' I mean the contextualised set of routinised social interactions around IAMs through which imagined futures become collectively shared. Hence, my focus is on how IAMs function as a Technique of Futuring (Hajer & Pelzer, 2018; Oomen et al., 2021). My analysis is embedded in a constructivist epistemology. While I acknowledge an observable reality, I view meaning-making processes and interpretation as dependent on the observer and recognise the central role of ideas in shaping reality. Accordingly, my analysis is framed by a co-productionist approach as defined by Jasanoff (2004). Rather than viewing knowledge as neutral, this epistemological stance regards knowledge-making as a performative practice that both shapes and is shaped by ideas about social order. This constructivist epistemological stance immediately implies that I recognise that my findings are influenced by my own worldviews, socio-political context and position towards the research subject (cf. Rose, 1997). I therefore reflect on my position as a researcher before turning to the methods applied in this thesis. Importantly, I move from a retrospective and analytical approach in **Part I** towards a prospective and interventionist approach in **Part II**. The reason for this move is my observation that despite ample suggestions in the scholarly debate on IAMs in climate politics,[17] it is often unclear what these suggestions could mean in practice, which I had the opportunity to explore given my access to the IAM community. Besides, the opportunity to work with artists and initiators of a participation tool also allowed me to explore new future directions that are potentially fruitful. The move towards an interventionist approach suggest a more active involvement in the research, which has implications for the research design and outcomes. I therefore discuss the different roles I take as a researcher across this thesis and its implications in the next paragraph.

Wittmayer and Schäpke (2014) distinguish the following ideal-type roles of researchers in sustainability research: reflective scientist, process facilitator, knowledge broker, change agent and self-reflexive scientist. This typology is relevant for this thesis because the authors make a distinction between 'descriptive-analytical' and 'process-oriented' research which is similar to the move I make between Part I and II. Besides, similar to this thesis their focus is on sustainability research and the authors provide useful considerations in evaluating the potential implications for the research design, responsibilities and outcomes. The analysis of IAMs in climate politics

17 Key examples include improving the transparency of IAMs and their scenarios (e.g. King et al., 2022; Schneider, 1997; Skea et al., 2021; Van der Sluijs, 2002), more reflection on assumptions and discourses (e.g. Ellenbeck & Lilliestam, 2019; Rubiano Rivadeneira & Carton, 2022), seeking interactions between the IAM practice and other disciplines (e.g. Geels et al., 2016; Trutnevyte et al., 2019; van Sluisveld et al., 2020), expanding knowledge communities underlying the IPCC (Castree et al., 2014; Beck et al., 2022), including broader sets of stakeholders (Low & Schäfer, 2020) and changing research priorities of environmental science more generally (Turnhout & Lahsen, 2022).

in **Part I** is situated in the constructivist and interpretative research traditions of STS. In both **chapter 2 and 3**, I take the role of a 'reflective scientist' that systematically collects, analyses and interprets data to reconstruct the interactions between IAM modelling and climate policy (cf. Wittmayer & Schäpke, 2014). While the choice to focus on climate mitigation is motivated by my deep concern about the climate crisis, I aim at understanding how the IAM practice works without trying to take a normative position towards IAMs. **Part II** is situated in a transdisciplinary tradition that is characterised by mutual learning among academics from diverse disciplines and non-academics in developing solution-oriented knowledge (cf. Lang et al., 2012). Here, I take a deliberate normative stance towards the IAM practice; the argument of pluralising and democratising the possibility space. This argument reflects my belief that the prominence of IAMs may foreclose certain pathways and viewpoints from the climate debate, which is driven by a deep concern about the slow progress on climate targets and my conviction of the need for a democratic debate on low-carbon futures. While this normative position is reflected throughout Part II, my role varies between chapters. In both **chapters 4 and 6,** my role is best described as 'process facilitator' (cf. Wittmayer & Schäpke, 2014). In **chapter 4**, this involves initiating and convening conversations between modellers and fiction writers, inviting participants and facilitating the process. While this role enables direct insights into how modellers and fiction writers interact, it also implies that my chosen framing and selection of the participants influences the research design and outcomes. For example, the framing of the workshop aims may attract only participants that are interested in finding common ground. In **chapter 6**, the facilitator role applies to only one of the two cases; involving the co-design of the PVE including the suggestion of policy options, organising workshop meetings, drafting information for citizens and contributing to the reporting to policymakers. This implies more direct insights into expert mobilisation, but also risks an unequal comparison and a potential underestimation of my own influence as an expert. In the analysis, I therefore switch to a 'reflective scientist' role where I rely on a diverse set of methods beyond personal observation to compare both cases (see Table 1) and take a deliberate critical stance towards the PVE (see chapter). Nevertheless, the paper reflects my conviction of the need for democratisation and the selection of cases in the Netherlands and Ireland also implies a partial understanding of what democratisation might look like. In **chapter 5**, I act as a 'knowledge broker' in mediating between modellers and the artist duo by providing spaces for conversation, facilitating mutual understanding and joint knowledge generation as well as a 'change agent' by participating in the conversations and supporting the artists in intervening in the modelling team (cf. Wittmayer & Schäpke, 2014). While the mediating role facilitates the art-science collaboration, the role of the change agent implies that the outcomes strongly reflect my view on the IAM practice. Rather than imposing my views on either the artists or modellers however, I empower the artists to better understand the IAM practice themselves, give them full agency over the process and motivate modellers to engage in reflective conversations with the artists (see chapter for more details).

The differences in research approach between chapters are also reflected in the diverse set of research methods (see Table 1 for an overview). **Chapters 2 and 3** take an interpretative approach to reconstruct science-policy dynamics, mainly through a literature review and semi-structured interviews (18 in chapter 2 and 22 in chapter 3). Both chapters also involve a quantitative analysis of the number of IAM publications and their prominence in IPCC reports, which mostly functions as a starting point for a qualitative analysis of *how* and *why* IAMs became prominent and shape the possibility space. **Chapter 4** draws on a unique transdisciplinary workshop that brought together IAM modellers and climate fiction writers as well as relevant literature on both practices. Rather than a systematic comparison of modelling and fiction writing, the chapter is exploratory in seeking to understand what an interaction between the practices might bring. In the art-science collaboration in **chapter 5**, the artist duo and I engage with the IMAGE modelling group by means of group discussions, interviews and workshops at various academic and public events, which informed the development of an artistic intervention. I draw on personal observations and semi-structured follow-up interviews with six modellers and the artist duo to analyse the interactions between modellers and artists. In **chapter 6** we compare the PVE application to Dutch climate policymaking with the Irish citizens' assembly on climate change. Given my personal involvement in developing the PVE case, the analysis of this case draws mostly on personal observations and the survey responses of 2000 participants of the PVE (involving both quantitative and qualitative data) and three semi-structured interviews with involved actors, whereas the analysis of the citizens' assembly more strongly relies on semi-structured interviews (12) and academic and grey literature. I discuss the methodological challenges in the final chapter of this thesis (section 7.5.3).

Methods	Chapter				
	2	3	4	5	6
Semi-structured interviews	x	x		x	x
Quantitative document analysis	x	x			
Transdisciplinary workshops			x	x	
Literature review	x	x	x		x
Survey					x
Personal observations				x	x

Table 1. Overview of methods used in this thesis

1.7 Contributions to academic literature

This thesis contributes to the scholarship on the politics of (climate) expertise by bringing new empirical insights to the co-production of climate science and politics and by bringing theoretical insights into studying how science is negotiated in political settings (1.7.1). This thesis also brings empirical and theoretical insights to the scholarship on the sociology of the future by investigating how particular visions of the future become performative (1.7.2). Lastly, this research contributes to the anticipatory governance literature by bringing new empirical insights into the particular forms of anticipation in climate governance; most notably modelling and to a lesser extent citizen engagement (1.7.3). This thesis ties these bodies of literature together by focusing on how modelling as a future-oriented form of expertise becomes mobilised and shapes climate governance.

1.7.1 The politics of expertise: co-producing climate science and policy

This thesis aligns with and hopes to contribute to existing work on the politics of expertise, which focuses on the dynamic and complex ways in which expertise is constructed and negotiated in political settings

(Fischer, 1990; Wynne, 1987). I place myself in the co-productionist tradition in STS as defined by Jasanoff, who holds that ways of knowing are inherently interlinked with social order (Jasanoff, 2004). In the area of climate change, scholars have investigated how climate science and in particular climate models have shaped climate policy (Demeritt, 2001; Edwards, 1996; Lövbrand, 2011; Lövbrand & Stripple, 2006, 2011; Miller, 2004; Shackley & Wynne, 1995; Turnhout et al., 2016); by representing the climate as a singular global entity, global climate models set the stage for a top-down, centralised and globally orchestrated response to climate change at the expense of local and situated ways of knowing (Hulme, 2010; Miller, 2004; Shackley & Wynne, 1995). Compared to climate modelling, there are relatively few accounts of IAMs and climate policy (Beck & Krueger, 2016; Beck & Mahony, 2017; Cointe et al., 2019; Edwards, 1996; Hughes & Paterson, 2017 for notable exceptions). This thesis addresses this knowledge gap through new empirical insights and hopes to shed new light on the politics of expertise more broadly by studying IAMs as a Technique of Futuring (Hajer & Pelzer, 2018; Oomen et al., 2021). Some have studied how the IAM community emerged as an 'epistemic community', with a shared set of norms, beliefs and procedures to produce policy-relevant research (Cointe et al., 2019; Edwards, 1996; Hughes & Paterson, 2017; cf. Haas, 1992). While the ToF concept is also practice-oriented, it shifts the focus from how knowledge is produced towards how this knowledge shapes and is shaped by the types of futures that are imaginable. Others have focused on how 'boundary objects', relatively stable and flexibly interpretable artefacts (Star & Griesemer, 1989), facilitate communication between global modelling and politics, such as the 1.5°C and 2°C temperature goals (Livingston & Rummukainen, 2020; Randalls, 2010). While both the concepts boundary objects and ToFs are concerned with how actors mutually construct a discursive space, the latter brings into view the complex and dynamic interactions through which these objects – in particular shared images of the future – come into being and collectively shared.

1.7.2 Sociology of the future: how imagined low-carbon futures become performative

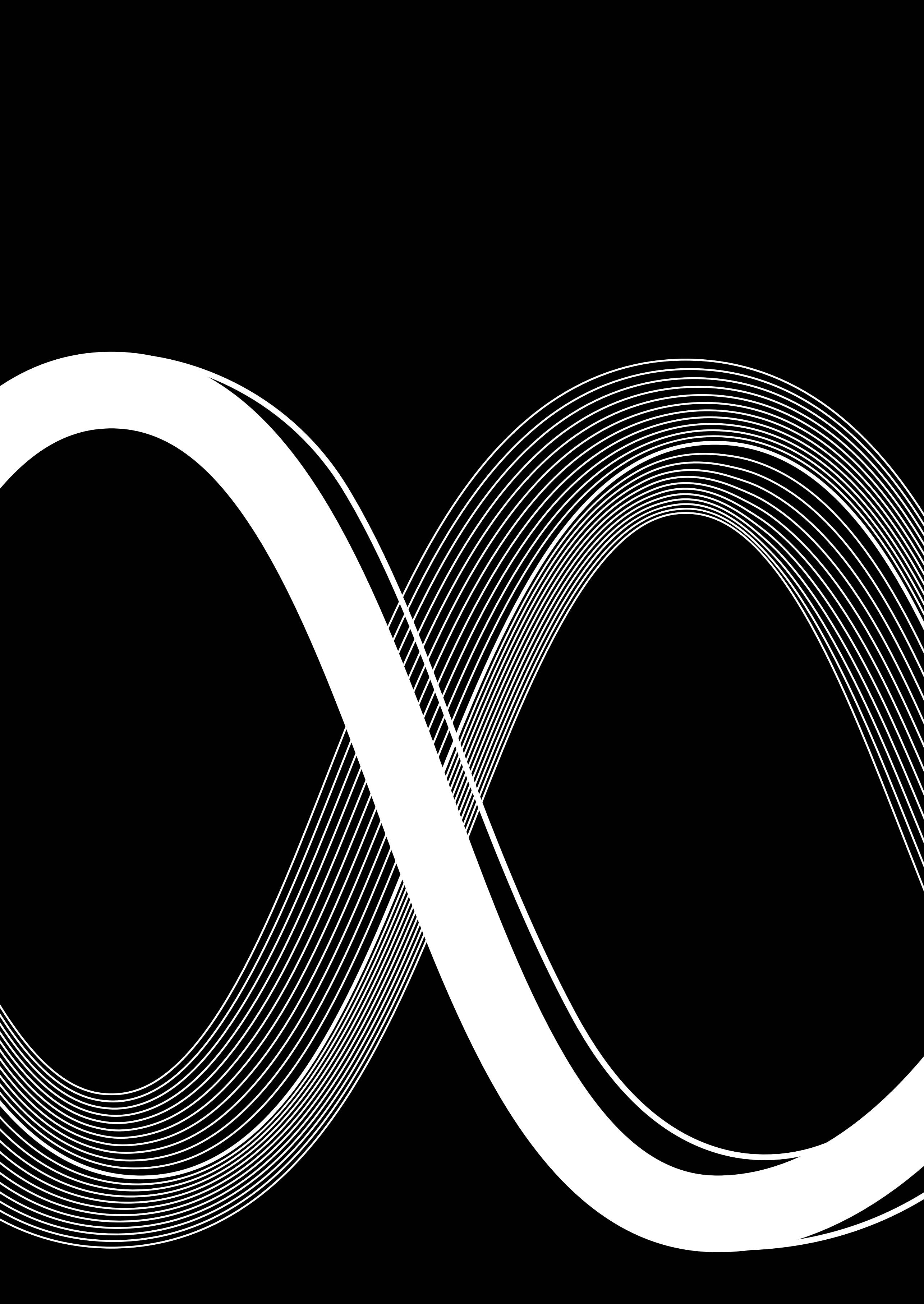
Scholars in STS and other fields are becoming increasingly concerned with 'the future' as an object of analysis. This includes historians reconstructing the emergence of strategic and systematic engagement with the future in the post-war period (Andersson, 2018). Sociologists also seek to understand how the future shapes the present, for instance by critically scrutinising the increasingly uneven relationship between knowing, acting and taking responsibility towards the future in the face of the ecological crisis (Adam & Groves, 2007), analysing how expectations guide scientific and technological progress (Borup et al., 2006) or economic decision-making (Beckert, 2013) and by scrutinising the multitude of ways in which the future is anticipated by states, universities and corporations (Urry, 2016). The future has also occupied anthropologists in their pursuit to understand the cultural frameworks through which aspirations towards the future come about (Appadurai, 2013). While this scholarship is somewhat scattered, a shared premise is that futures are *performative*: they shape social interactions and decisions in the present. Performativity is central to literature on imaginaries, which seeks to understand how certain visions of the future become collectively held and institutionalised while others remain unnaturalised (Ezrahi, 2012; Jasanoff & Kim, 2015). Some of the literature on imaginaries has focused specifically on climate and energy. Scholars have, for example, distilled and compared dominant imaginaries of climate and energy futures among societal actors such as NGOs, businesses and policymakers (e.g. Delina, 2018; Levidow & Raman, 2020; Levy & Spicer, 2013; Marquardt & Nasiritousi, 2022). Others have focused on the *politics of anticipation*, the unevenly distributed capacities to bring futures into the present and make them effective (Granjou, Walker, & Salazar, 2017; Groves, 2017). Research on the politics of anticipation has focused specifically on how IAMs render low-carbon futures imaginable and shape political debates (Beck & Oomen, 2021; Beck & Mahony, 2017; 2018a; 2018b). While these studies illuminate the political effects of IAM pathways, it is still largely unknown *how* and *why* they become persuasive, to which this thesis brings new insights by analysing IAMs as a ToF.

1.7.3 The anticipatory governance of low-carbon transformations

Governance refers to the co-ordination between societal actors through structures, rules and processes that shapes how these actors make decisions and share power and responsibility in the pursuit of collective action (Kooiman, 1992; Pierre, 2000; Folke et al., 2005). Environmental governance, which specifically aims at reducing and/or mitigating environmental impacts, comes in many forms including centralised governance, public-private governance and self-governance (Driessen et al., 2012). Driven by the accelerating climate crisis, environmental researchers and practitioners are increasingly seeking ways to imagine and govern climate futures, which is referred to as *anticipatory governance* (Vervoort & Gupta, 2018). While the notion of anticipatory governance is used in various contexts, in the environmental domain it usually concerns sustainability transformations (Muiderman, 2022). Although the governance of sustainability transformations is inherently future-oriented, anticipatory governance scholarship focuses explicitly on how futures are anticipated in and shape these governance processes (Ibid.). In the domain of climate governance, different 'anticipatory approaches' exist which differ in how the future is conceptualised as well as how they aim to steer actions in the present (Muiderman et al., 2020). These approaches represent a wide range of methods, ranging from more traditional expert-based methods such as CBA (e.g. Liu et al., 2018) to formal deliberative methods such as citizens' assemblies (Willis et al., 2022) or deliberative mapping (Bellamy et al., 2014), to more creative methods such as interactive art installations (Bendor et al., 2015), participatory theatre performances (Galafassi et al., 2018b) or games (Vervoort et al., 2022). As Muiderman et al. (2022) observe, climate governance has been dominated by relatively rigid methods to anticipate futures, at the expense of more creative and participatory methods. IAMs are arguably the most prominent form of anticipation in the governance of low-carbon transformations, at least on the global level. This thesis brings new empirical insights to the anticipatory governance literature by illuminating how and why this prominent form of anticipation in climate governance came into being and by investigating alternative anticipatory approaches.

Part I

How the possibility space is shaped through IAM-policy interactions



2.

The historic co-evolution of IAMs and climate policy

Abstract

IAMs have gained a prominent role in the climate science-policy interface. The chapter reconstructs the evolution of IAMs and their changing role in the science-policy interface, investigating how and why IAMs have become so prominent. Based on literature analysis, quantitative document analysis and semi-structured interviews, we describe the historic evolution of the interactions between IAMs and policy-making between 1970 and 2015. We identify five historic phases in which IAMs played distinct mediating roles between science and policy, succeeding to adjust their scenario efforts to the continuously evolving demands for knowledge from the policy community. In explaining the prominent role of IAMs we differentiate between background conditions (material and sociological) and more contextual factors, most notably the flexible, hybrid and broad nature of IAMs as well as the pro-active character of the IAM community to enhance their policy relevance. We draw on the notion of institutional work to explain this success. We suggest that the IAM community may consider engaging a wider range of publics and societal stakeholders beyond the science-policy interface.

Published as:

Van Beek, L., Hajer, M., Pelzer, P., van Vuuren, D., & Cassen, C. (2020). Anticipating futures through models: the rise of Integrated Assessment Modelling in the climate science-policy interface since 1970. *Global Environmental Change, 65*, 102191.

https://doi.org/10.1016/j.gloenvcha.2020.102191

2.1 Introduction

Human-induced climate change presents a major challenge for future human development. As of 2020, the impacts are becoming more and more visible and the need for rapid low-carbon transformations of our current social, economic and technological systems seems increasingly evident. In 2015 this urgency was recognised in the political realm as countries under the United Nations Framework Convention on Climate Change (UNFCCC) agreed to keep global temperature to well below 2°C and pursue efforts to limit warming to 1.5°C in the Paris Agreement (UNFCCC, 2015b). Accordingly, policy-makers face the challenge of developing mitigation strategies. The Paris Agreement has stressed the need for tools and approaches to anticipate possible futures in global climate governance (Vervoort & Gupta, 2018). The multitude of possible climate strategies and the uncertainties regarding their challenges, effectiveness and interlinkages, inevitably involves an exploration of possible socio-economic transformation pathways that are consistent with the temperature goals. This culminated in 2015 when the UN IPCC announced its new direction from the attribution of causes towards response strategies (Goldenberg, 2015). This implied a prominent role for IAMs which form the basis of the defined response strategies of the IPCC since the Fifth Assessment Report (AR5; IPCC, 2014 cf. Cointe et al., 2019).

IAMs are in essence computer simulations that represent complex interactions and feedbacks on a long time scale between the socio-economic system (including climate policies) and the natural system, which are explicitly designed to inform climate policy-making (Parson & Fisher-Vanden, 1997; Van Vuuren et al., 2011). The models vary largely in their structure, detail and type of policy questions they are designed to address (Kelly & Kolstad, 1998; Weyant et al., 1995). An important distinction is made between (1) detailed process-based IAMs, which form the basis of IPCC's assessments of transformation pathways towards temperature targets, and (2) highly aggregated cost-benefit IAMs that estimate optimal mitigation levels relative to economic costs of climate impacts, which play a less prominent role in the IPCC, but are particularly influential in US climate policy (Weyant, 2017; Wilson et al., 2017). One of the first contributions of process-based IAM scenarios was to show how existing socio-economic trends resulted in high emission levels and as the political ambition grew, IAMs were increasingly used to construct mitigation pathways (Weyant, 2017). An analytical strength of IAMs is their ability to integrate information from various scientific disciplines into a single framework, enabling the coherent analysis of social, technological and physical processes relevant to low-carbon transformations (Geels et al., 2016). However, the use of IAMs for developing mitigation strategies is also criticised. The epistemic, political and ethical implications of the various dimensions of uncertainty and how modellers deal with those are often brought up for discussion (see Beck & Krueger, 2016; Van der Sluijs, 1996; Van Asselt & Rotmans, 2002 for overviews). With regard to their use to inform climate mitigation policy specifically, IAM scenarios are often criticised for favouring large-scale supply-side solutions like negative emissions technologies (NETs)[18] (Fuss et al., 2014; Anderson & Peters, 2016; Vaughan & Gough, 2016) and more generally their limited ability to conceive of radical transformation pathways beyond economic and technological measures (Anderson & Jewell, 2019; Gambhir et al., 2019; Van Vuuren et al., 2018).

18 In the introduction and conclusion I use the term CDR, given that it is the more commonly used term in academic literature at the time of writing (2023).

IAMs are the backbone of scenario analysis of WGIII of the IPCC – which focuses on response strategies – since the IPCC AR5. Consequently, the IAM community plays a leading role in climate policy research and assessment (Cointe et al., 2019). Figure 3 illustrates this trend, showing a growing prominence of IAM analyses in subsequent IPCC reports, as well as an increasing number of IAM publications on climate change, signalling the growing modelling community around this topic. Another observable trend in Figure 3 is the sharp increases in IAM publications towards each IPCC report, which indicates a strong ambition to provide policy-relevant information. The relative high share in IPCC reports compared to academic climate research further underline this aspiration. The underlying science-policy dynamics that explain these trends however, remain unclear. The first studies on the application of climate models in the science policy interface focused on General Circulation Models (GCMs), the first generation of climate modelling that constitute the backbone of IPCC WG I (e.g. Edwards, 1996, 1999; 2010; Hulme & Dessai, 2008; Mahony & Hulme, 2016; Miller, 2004; Shackley & Wynne, 1995; 1996; Shackley et al., 1999; 2001). At the time of writing, only a handful of studies on organisation and application of IAM research in climate policy exist (i.e. Beck & Krueger, 2016; Beck, 2018; Beck & Mahony, 2017, 2018; Cointe et al., 2019; Corbera et al., 2016; Edwards, 1996; Hughes & Paterson, 2017; Lövbrand, 2011; Low & Schäfer, 2020; McLaren & Markusson, 2020). These studies repeatedly found that although IAMs aim to function as ‘heuristic guides’ to explore strategies (Edwards, 1996), they are in fact *performative*: they shape the possibility space in which future options for climate action are discussed and thus the content of policy deliberation in international climate politics (Beck & Mahony 2017; 2018; Lövbrand 2011;

McLaren & Markussen, 2020). As Beck and Mahony (2018b, p.1) put it: IAMs exercise a '[...] 'world-making' power by providing new, politically powerful visions of actionable futures'. While the prominence and performative effect of IAMs in the climate science policy interface is evident, we still lack an understanding of how and why IAMs gained this position. This is only more relevant given the fact that any modelling effort will necessarily render certain possible futures more actionable and legible at the expense of other possible futures thus guiding the transformation towards a post-fossil society. To further our understanding of the emergence of IAMs, this chapter is driven by the following research question: *how and why have IAMs become prominent in the climate science-policy interface?*

In order to answer this question we applied an analytical strategy with a historical focus for which we used different sources: academic work on the history of IAM (e.g. Parson & Fisher-Vanden 1997; Weyant et al., 1995) and the history of international climate politics (e.g. Bodansky, 2001; Gupta, 2010; 2014), 18 semi-structured interviews and document analysis (see Appendix B for an elaboration on the methodology). We describe historic developments in modelling and policy and identify the changing 'role' of IAMs over time (referring to how the alignment of science and policy was negotiated, such as agenda- setting, target formulation or evaluation of response strategies). The focus of this role was on both the characteristics of IAMs as well as on the emerging community of experts around IAMs: both the *model* and the *modeller* are relevant to understand the role of IAM in the science-policy interface. With regard to the model, since model results are typically represented in the form of scenarios, we attend to the type of *future representation* (referring to how possible futures were represented using scenarios, with varying numbers of alternatives, distinct framing and action orientations). With regard to the modeller, we analyse the *strategies to obtain policy relevance* (referring to efforts of the modelling community in pursuing policy relevance).

The chapter is structured as follows. In section 2.2, we introduce five distinct phases and discuss their dynamics. In section 2.3, we interpret these historical developments and discuss the key factors that explain the prominent role of IAMs in the climate science-policy interface at the time of writing (2020) and provide a set of reflections on the development and future role of IAMs in the climate-science policy interface.

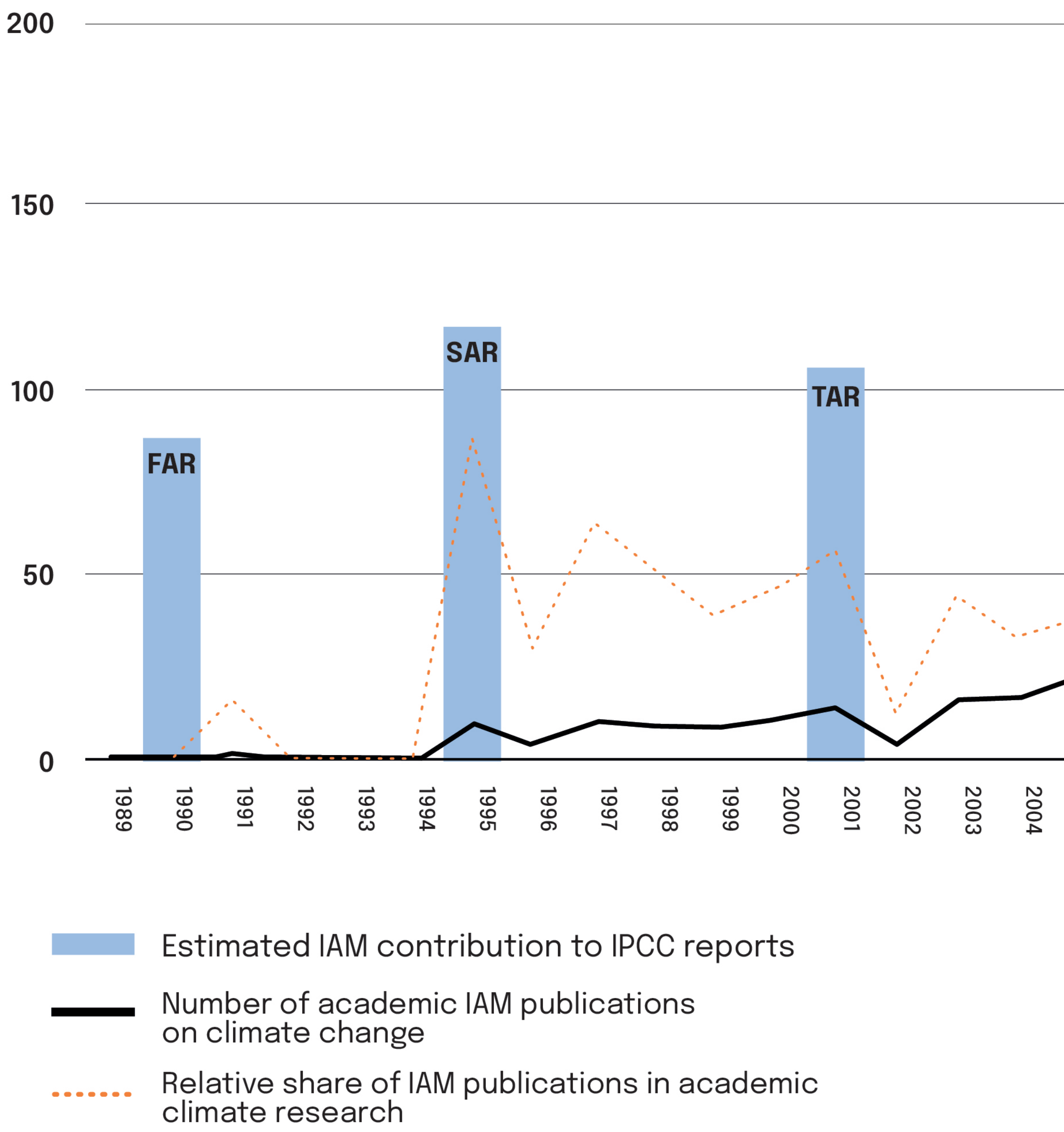
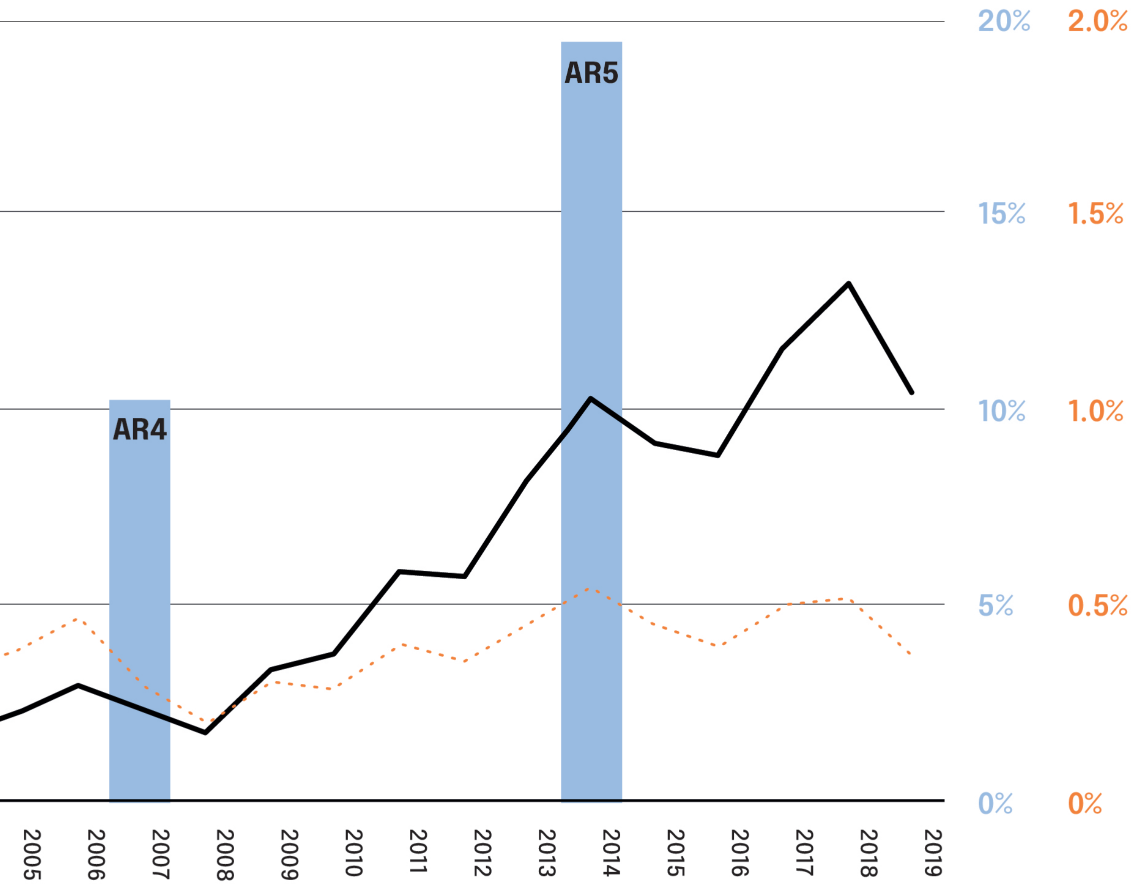


Figure 3. Number of publications involving IAM in academic literature between 1989 and 2019



FAR	First Assessment Report
SAR	Second Assessment Report
TAR	Third Assessment Report
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report

The black line represents the number of publications, the blue bars represent the estimated percentage of IAM results in IPCC Synthesis Reports and the red dotted line the relative share of academic IAM publications within the total body of academic climate research (see Appendix B2 for methodology).

2.2 The historic evolution of the role of IAMs in the climate science-policy interface

Most climate IAMs appeared in the early 1990s and their development largely co-evolved with the UN climate negotiations. Yet, their origins can be traced back to the early 1970s, to the first global models such as used for the *Limits to Growth* study (Meadows et al., 1972), the energy-economic modelling that appeared after the 1973-74 oil crisis and early efforts in climate-economics (Weyant et al., 1995; Edwards, 1996; Parson & Fisher-Vanden, 1997). We identify five historic phases from 1970s up until 2015 that are each characterised by a shift in IAM-policy interactions (see Figure 4).

2.2.1 PHASE 1: The emergence of global modelling (1970–1985)

The first global models urging concern of finite resources

In the vein of early warning of environmental degradation starting in the 60's, the publication of the *Limits to Growth* (Meadows et al., 1972), initiated by the Club of Rome, truly marked a shift from local pollution to awareness of the global environment. Forrester and his MIT research team convinced the Club of the capability of their system dynamic modelling technique, developed in the late 1950s for analysis of industries and cities (e.g. Forrester, 1970), to offer an understanding of the complexity of the 'world problématique' (Elichirigoity, 1999). The final model, 'World 3', included population, agricultural production, natural resource depletion, industrial output and pollution (which included CO2). Aurelio Peccei (chair of the Club of Rome) deliberately used the World 3 model runs '[…] to move men on the planet out of their ingrained habits' (Ashley, 1983, p. 497). The report was first sent to selected policy-makers and later published in more popular language, becoming an international bestseller. Its powerful neo-Malthusian message – of an exponentially growing population and economy ending in societal collapse – was quickly adopted by the public and

Figure 4. Overview of phases representing shifts in the position of IAMs in the climate science-policy interface (1970 – 2015).

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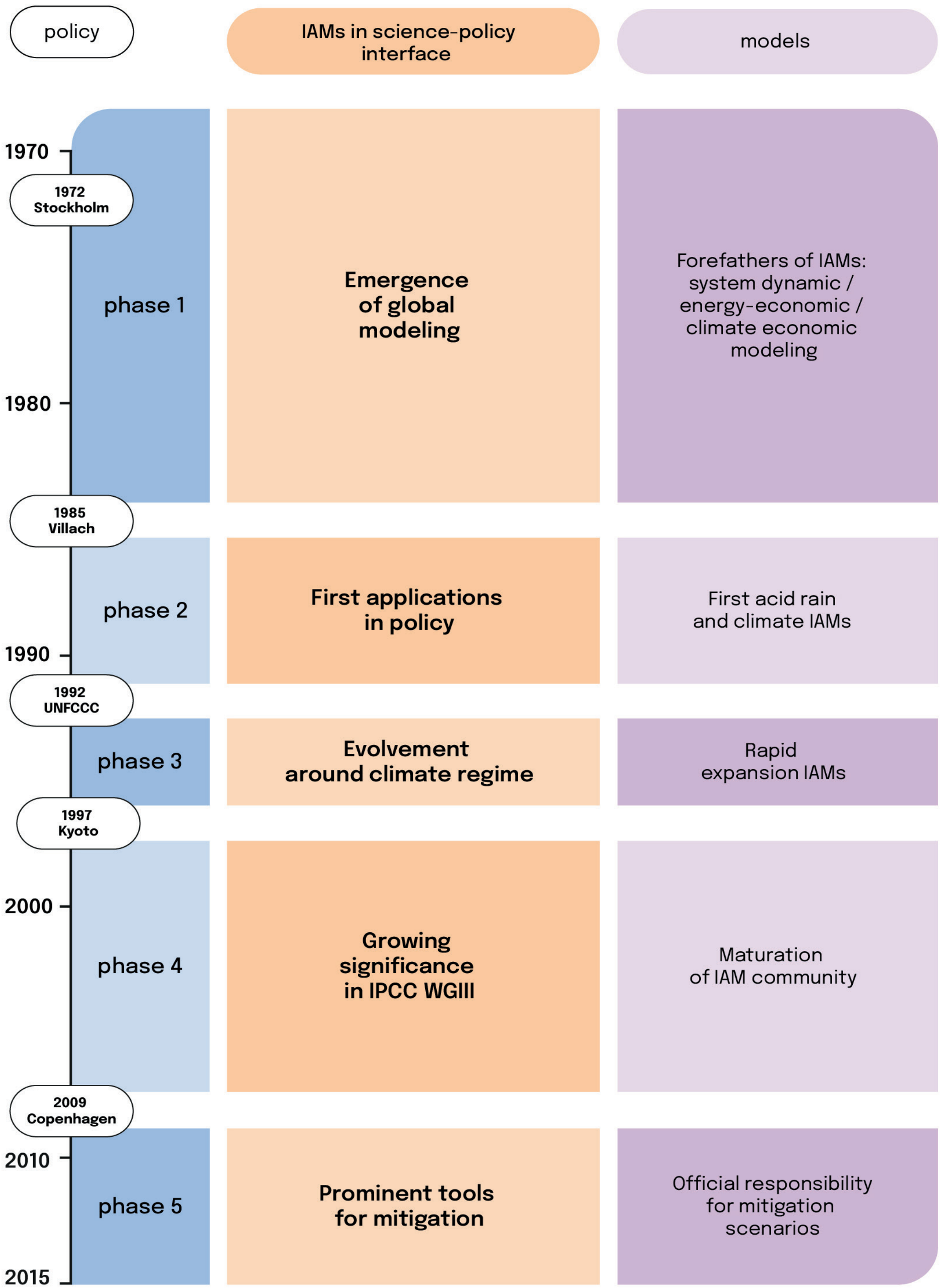

policy
IAMs in science-policy interface
models
1970
1972 Stockholm
phase 1
Emergence of global modeling
Forefathers of IAMs: system dynamic / energy-economic / climate economic modeling
1980
1985 Villach
phase 2
First applications in policy
First acid rain and climate IAMs
1990
1992 UNFCCC
phase 3
Evolvement around climate regime
Rapid expansion IAMs
1997 Kyoto
2000
phase 4
Growing significance in IPCC WGIII
Maturation of IAM community
2009 Copenhagen
2010
phase 5
Prominent tools for mitigation
Official responsibility for mitigation scenarios
2015

the global policy community (Edwards, 1996). The World 3 model runs were thus powerful in shifting the environmental discourse from local pollution to appreciating processes of global environmental change. It marked the advent of using computer models capable of forecasting long-term futures into the imagination of governments and scientists worldwide (Ashley, 1983). Although the World 3 model was criticised for its simplicity and lack of data and although the *Limits to Growth* was regarded with suspicion because of the elite character of the Club of Rome (Edwards, 1996), the World 3 model was a true paradigm change (interview 4,6,7,10,13,17): 'It wasn't called an IAM but in effect it pioneered this notion of computational science to look at the deep future of the planet by simulating different dimensions of human development and environmental impact' (interview 10). Supported by advances in computer technology and data availability, six other global models rapidly appeared across the USA, Latin America, Europe and Japan (e.g. Mesarovic & Pestel, 1974; Herrera et al., 1976). The modelling groups often strongly criticised the political-economic assumptions of the World 3 model, such as assuming continuation of North-South inequalities (Blanchard, 2010). Despite the critiques and methodological differences however, the global modelling teams generally agreed that population growth and capital could not grow indefinitely (Meadows et al., 1982). The launch of 'Limits to Growth' coincided with the first UN Conference on the Human Environment in Stockholm in 1972. Moreover, the International Institute for Applied Systems Analysis (IIASA) was established in Austria in the same year, which marked an exceptional scientific cooperation between East and West (Schrickel, 2017). It was by no means self-evident that global modelling should play a strong role at IIASA. While strongly advocated by Peccei, opponents feared that the controversy around *Limits to Growth* would harm its reputation (Rindzevičiūtė, 2016). As a compromise, rather than building a global model, IIASA played a key role in coordinating global modelling efforts by organising symposia where modellers shared insights, enabling them to evolve into a community of scholars (Meadows et al., 1982). IIASA has continued to operate as a central node in the IAM field ever since (Hughes & Paterson, 2017; Schrickel, 2017).

Emergence of energy-economic modelling in the aftermath of the oil crisis

The 1973-74 oil crisis brought worldwide fear of finite fossil energy supplies. This mobilised a vast amount of energy forecasting projects

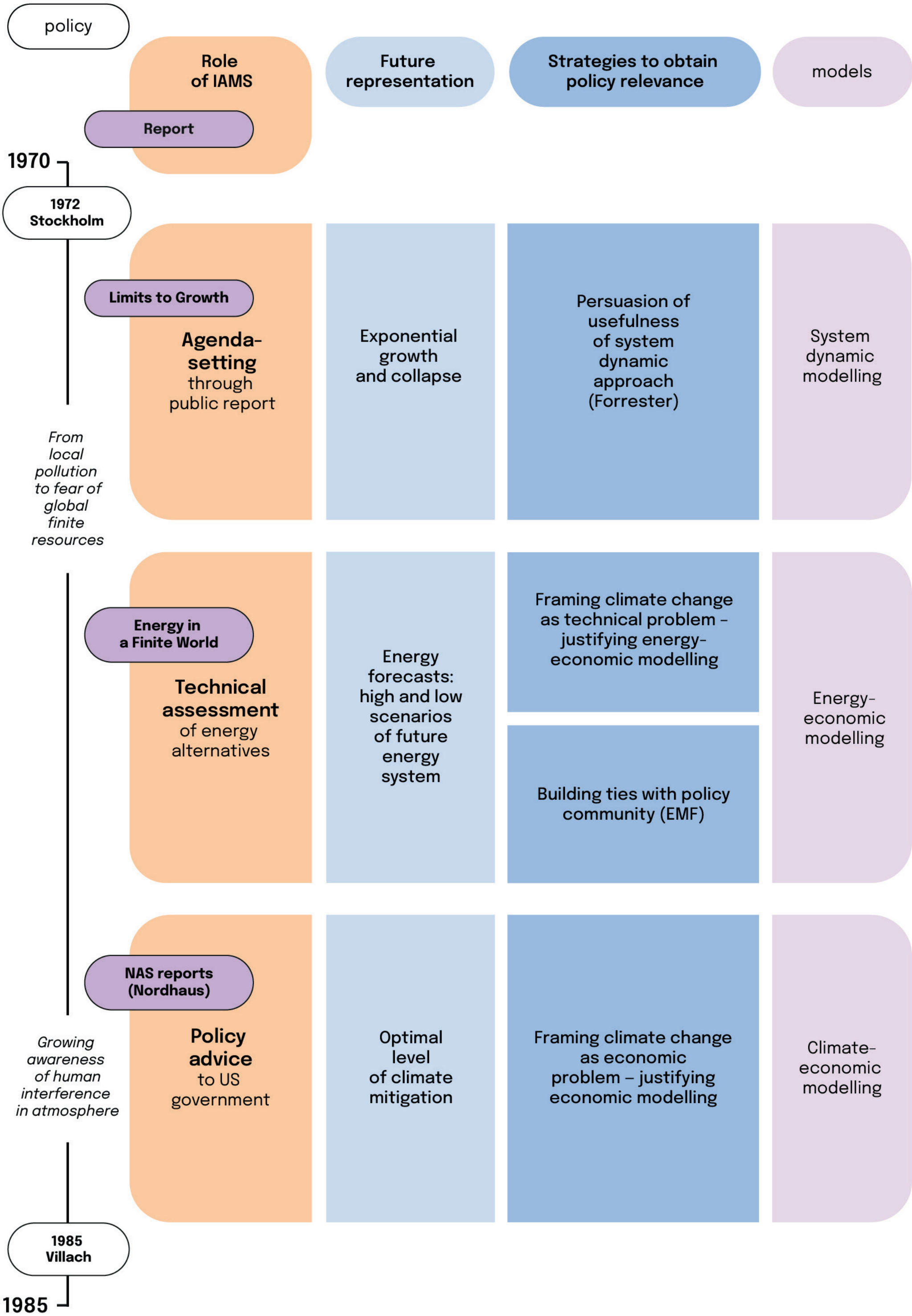


Figure 5. Overview of the IAM-policy interface in phase 1 (1970-1985).

and institutes around the world, such as the US Energy Information Administration (EIA). The usefulness of computer models to do projections as well as the dependency of economic development on energy was soon realised, which gave birth to a new discipline: energy-economic modelling such as the famous MARKAL energy model (Taylor et al., 2014). Although this field was rapidly expanding, the actual use of models in policy had '[…] fallen short of expectations' (Greenberger et al., 1976, p. 26). In the US, the Energy Modelling Forum (EMF) was established in 1976, which was a deliberate attempt to bring together energy modellers and policy-makers in order for the models to gain policy relevance. The EMF functioned as crucial platform for energy-economic modellers and later IAM modellers to come together, compare modelling practices and enabled the first steps towards a scientific practice: 'The EMF […] was really powerful because it brought together the community every year. It was really important in building the social capital, the community of practice of IAMs' (interview 1). One of the most elaborate global energy assessments following the oil crisis was IIASA's Energy Project, which lasted for 9 years and involved more than 250 scientists (Thompson, 1997). Three models were used to construct a low and high scenario of future global energy demand, which formed the most visible elements of the publication *Energy in a Finite World* (Häfele et al., 1981). The authors explicitly aimed at a 'hard science' approach, following the rationale that modelling would lead to more credible and analysable scenarios (Wynne, 1984). Thereby, their 'hard' techno-centric and top-down energy path based on fossil fuels and nuclear power to meet energy demand was made more conceivable at the expense of micro-level 'soft' energy paths (Thompson, 1984). Despite significant critiques, particularly regarding the models would play only a minor role in scenario construction (Keepin, 1984), the report's conclusions were influential in shaping policy discussions on future energy. Namely, the scenarios were adopted by the European Commission as well as national governments to formulate energy policy (Wynne, 1984). Moreover, the authors framed the energy problem deliberately as a 'technical' problem, which justified the use of energy-economic modelling.

Climate-economic modelling

One of the economists involved in the Energy Project was Nordhaus, professor of Economics at Yale University. In several IIASA papers, he laid out the principles of a linear programming model of energy supply constrained by peak concentrations of CO2 (Nordhaus, 1975; 1977).

These early papers introduced a new heuristic in thinking about climate policy as part of an economic assessment of costs and benefits of reducing emissions (Randalls, 2011; Schrickel, 2017). Nordhaus' conceptualisation justified the use of economic analysis to the climate problem and was in sharp contrast with the *Limits to Growth*, which he and other economists critiqued for lacking data and underestimating the role of technology (Nordhaus, 1973). His early efforts grew out into the most widely used CBA-type IAM: the Dynamic Integrated Climate and Economy (DICE) model (Nordhaus, 1993). Nordhaus is recognised as a key figure in the history of IAMs. He pioneered the climate-economics field – for which he received a Nobel prize in 2018 – and many followed on his tradition (interview 1, 4, 5, 7, 8, 17). During the early 1980s, Nordhaus served in several committees of the National Academy of Science (NAS) such as the Carbon Dioxide Assessment Committee (Randalls, 2011). As the use of CBA has a long-standing tradition in US policy (Porter, 1996), Nordhaus' analyses rapidly moved from general claims about climate action to direct policy advice (Randalls, 2011; interview 9). For instance, one of the NAS Committee reports concluded that considering the costs of mitigation and unclear benefits, advising adaptation and further research. The DICE work has also been important for the political stance of the US in the climate debate, i.e. too radical early policies can be costly (Bodansky, 1993). Co-evolving with US climate science-policy interface, the work with DICE still remains important in 2020 in the international climate debate.

2.2.2 PHASE 2: First applications in policy (1985–1992)

The 1970s and 1980s saw an increased awareness of human impacts on the global atmosphere: first acid rain and ozone depletion dominated the debate and later climate change (Kowalok, 1993). The Vienna Convention (1985) and the Montreal Protocol (1987) on Ozone raised optimism that other atmospheric issues could be addressed by international conventions as well (Agrawala, 1998). The first World Climate Conference was convened by the World Meteorological Organisation in 1979 in Geneva and was followed by several international workshops in the 1980s in Villach to better understand the climate problem (Agrawala, 1998). The last 'Villach workshop' in 1985 marks the 'arrival' of climate change on the global political agenda, as scientists reached consensus that global temperature would exceed all historical records (Hajer & Versteeg, 2011). In 1988, the IPCC was established at the World Conference on the Changing Atmosphere in Toronto. The Second

Climate Conference in Geneva (1990) attracted numerous ministers and government leaders and the IPCC's First Assessment Report (FAR) in 1990 clearly concluded that trends in human activities were causing substantial increases in GHG emissions in the atmosphere. Together with a context of optimism for political cooperation on global environmental issues triggered by the fall of the Berlin Wall this led to the adoption of the UNFCCC in 1992.

IAMs to support acid rain negotiations

One of the first applications of IAMs were to model acid rain. Acid rain was first raised as a problem by the Swedish government at the Stockholm conference in 1972, as research demonstrated relationships between sulphur emissions in Europe and acidification of Scandinavian lakes (Tuinstra et al., 2006). An international research program followed and this led to the Long-Range Transboundary Air Pollution (LRTAP) treaty signed by 30 countries in 1979 under the auspices of the UN Economic Commission for Europe (UN-ECE) (Hordijk, 1991; Levy, 1995). The first protocol was the Cooperative Program for Monitoring and Evaluation of the LRTAP in Europe (EMEP). It was soon discovered that acid rain threatened not just Scandinavian lakes, but terrestrial ecosystems over the entire continent and this forged the need for strong science-based emission reductions targets (Tuinstra et al., 1999; Hordijk, 1991). Meanwhile, IIASA initiated a project to integrate ecology, meteorology and technology with an ambition to aid the negotiations and started building the Regional Acidification Information and Simulation (RAINS) model (interview 5). Although the RAINS modellers were not officially allowed at the negotiations and their added value compared to EMEP was not self-evident, they managed to present their model runs during coffee breaks and convinced some UN-ECE members of the usefulness of their method (Tuinstra et al., 2006; interview 5). A few years later, the RAINS modellers organised a number of review meetings with negotiators and scientific experts to simultaneously maintain policy relevance and scientific credibility (Hordijk, 1991; interview 5). The emission reduction targets that later followed were largely based on model runs from RAINS and the model became officially adopted in the following protocols (Hordijk, 1995). It was a major success story: 'Very few models can show a direct impact on policy. RAINS was actually used to formulate policy.' (interview 1). There are various reasons for this success (Hordijk, 1991 for overview): the fact that RAINS was developed at IIASA, which was considered a politically neutral institute and therefore trusted by negotiators, the expert

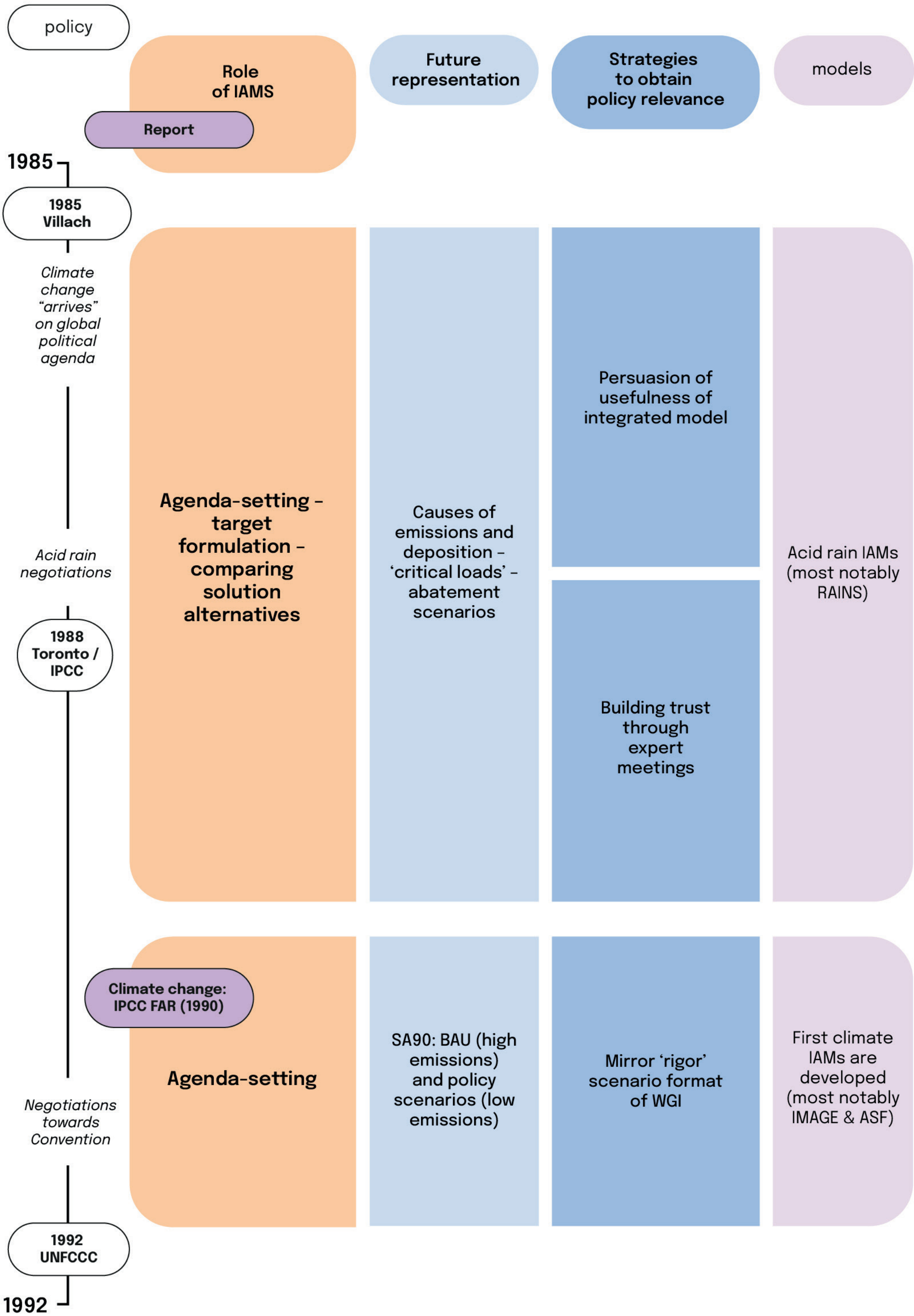


Figure 6. Overview of the IAM-policy interface in phase 2 (1985-1992).

review meetings that safeguarded credibility and relevance, the use of data from the already established EMEP and its broad coverage of acid rain aspects as well as geographical dispersion. This flexibility and breadth enabled RAINS to adjust to new scientific insights as well as emerging knowledge demands and thus functioned as communicative bridge between scientific experts, modellers and negotiators from different nationalities (Sundqvist et al., 2002). This way, RAINS served various roles: agenda-setting, target-setting and evaluation of abatement strategies. Regarding target-setting, the concept of 'critical loads' used in RAINS – a maximum allowable range of deposition that ecosystems could endure – was particularly successful in helping to break the deadlock of the negotiations as it served as science-based policy objective (interview 5). The success of RAINS was a true inspiration for the pioneering climate IAMs.

The first climate IAMs during the emerging climate regime

As climate change was emerging on the global political agenda, several scholars started working on building IAMs in Europe and the US in the mid-80s, with an ambition to support climate policy-making. As outlined by Weyant et al. (1995), significant efforts were (1) the Model of Warming Commitment (MWC) (Mintzer, 1987), (2) the Atmospheric Stabilisation Framework (ASF) (Lashof & Tirpak, 1989) and 3) the Integrated Model to Assess the Global Environment (IMAGE) (Rotmans et al., 1990). Two of these models, ASF and IMAGE were used to construct the first set of emissions scenarios for the IPCC: 'When the IPCC was established, it appeared they needed scenarios […] and it quickly became apparent only two models existed that could produce scenarios with all greenhouse emissions' (interview 3). In the early days of the IPCC the emphasis was still on WGI, with a strong quantitative focus: 'The core of the IPCC was WGI. Everything else that happened had the primary goal to support WGI. And they wanted numbers.' (interview 3). IAMs could provide scenarios with a similar look-and-feel as WGI, which could arguably explain their use in this report despite the fact that this practice was still in its infancy. The IMAGE model, initiated by Rotmans in the Netherlands as an intern at the National Institute for Public Health and the Environment (RIVM), was a pioneer in climate IAMs (Dowlatabadi & Morgan, 1993; Weyant et al., 1995; interview 2,3,4,7,10): 'It was to my knowledge the first of what we now call an Integrated Assessment Model of climate change' (interview 10). IMAGE and ASF were both also influential in respectively Dutch and US policy discourses. The IMAGE model runs became adopted in ‘Zorgen voor Morgen’ (‘Concern for Tomorrow’; RIVM, 1988; interview 3,17), a highly influential in Dutch political discourse as it dramatically pictured an environmental crisis, ranging from local pollution to global threats (Hajer, 1995, p.175 ff.). The ASF model was developed at the consultancy company ICF and used by the US Environmental Protection Agency (EPA) to develop a report to the US Congress on policy options to climate change (Lashof & Tirpak, 1989). The EPA involved influential actors in the climate debate and was highly involved in the establishment of the IPCC. Due to its close connections with the EPA, the ASF model instead of Mintzer’s model was chosen to construct the WGIII scenarios (interview 3,4,8,17). Despite large differences between modelling frameworks and sometimes contrasting results, the US and Dutch modellers succeeded in developing a coherent set of emissions scenarios for the FAR (IPCC, 1990). The so-called SA90 scenarios represent possible futures similar to those in the EPA report: a business-as-usual scenario resulting in high levels of emissions with several policy scenarios associated with lower emission levels (Lashof & Tirpak, 1989; IPCC, 1990). The SA90 scenarios were strongly criticised by the political community, arguing policy scenarios would not be allowed because it would assume international conventions that were not yet existent (interview 3). As a result, a second set of emissions scenarios was developed, the IS92, which only presented reference scenarios in the absence of policy (Girod et al., 2009; interview 3,8). Nevertheless, the scenarios were crucial in agenda-setting as they drew an upsetting picture of where the world was headed without policy intervention (interview 8).

2.2.3 PHASE 3: From agendas to targets in emerging climate regime (1992-1997)

The Brundtland Report (WCED, 1987) as well as the establishment of the UNFCCC at Rio (1992) caused a ‘new wave’ in global scenario development, especially global modelling efforts (Swart et al., 2004). The UNFCCC was the first cornerstone of the international climate regime (the international climate negotiations under the convention), followed by the adoption of the Kyoto Protocol in 1997. While countries at Rio agreed to keep warming below dangerous interference, however with ambiguous formulations of stabilisation levels (Bodansky, 2001), the Kyoto Protocol imposed legally binding commitments to Annex I countries (mainly OECD countries). In the meantime, the conclusions of the Second Assessment Report (SAR; IPCC, 1995) confirmed that human-caused greenhouse gas emissions contributed, which set the stage for the Kyoto Protocol. IAMs became more formally adopted in the IPCC and were used to inform emission targets setting under Kyoto.

How the newly born discipline became quickly adopted in IPCC WGIII

The emergence of the climate regime forged a rapid expansion of climate IAMs; from three models in 1990 to 40 in 1997 (Van der Sluijs, 1996). Despite the fact that the IAM field was relatively underdeveloped, it was nonetheless quickly adopted in IPCC WGIII, for several reasons. First, the establishment of the UNFCCC raised new policy questions, from understanding the problem, to impacts, strategies and costs. It appeared that the complex GCMs of WGI were unable to answer these questions (interview 10): 'That provided the entry point for IAMs and other forms of simple calculative devices because it could bring together questions around economics, impacts, and policy' (interview 10). Secondly, the IPCC recognised the need to assess social and economic aspects with a similar scientific rigor compared to WGI that is rooted in physical science (interview 3,8). Several IPCC workshops organised at IIASA evaluating existing scenario approaches, concluded that assessments of impacts and costs should be integrated in a single modelling framework. The IPCC thus adopted the IAM approach to the core of its WGIII assessments (Kaya et al., 1993; Nakicenovic et al., 1995). The SAR (IPCC, 1995) devoted an entire chapter to IAM, where the authors emphasised the many benefits of IAM compared to other IA approaches (see Weyant et al., 1995).[19] A third important reason was that IAM analysis mirrored the look-and-feel of WGI scenarios while being calibrated on the much more compressive GCMs, which are rooted in the 'non-negotiable laws of physics', thereby holding an 'epistemic power to make prognostications' (interview 10). IAMs could thus perform similar – albeit much more simplified – analyses much faster and for a fraction of the costs while leaning on this epistemic power. This not only resulted in an increasing prominence of IAM in IPCC's assessments, the IPCC also proved crucial for the advancement of the IAM field; '[…] the IPCC lead author meetings were very powerful and intense processes which were multiple times a year for each assessment report. That provided an environment in which they could grow and be applied' (interview 1).

19 At the time of SAR (IPCC, 1995), IAM analysis are however only part of the landscape of the reviewed evaluations. Chapter 8 and 9 in the SAR are dedicated to the costs of climate policies, primarily concerning the divide between bottom-up (sectoral modelling) and top-down (macro-economic modelling) including national, regional and global (IAM) analysis

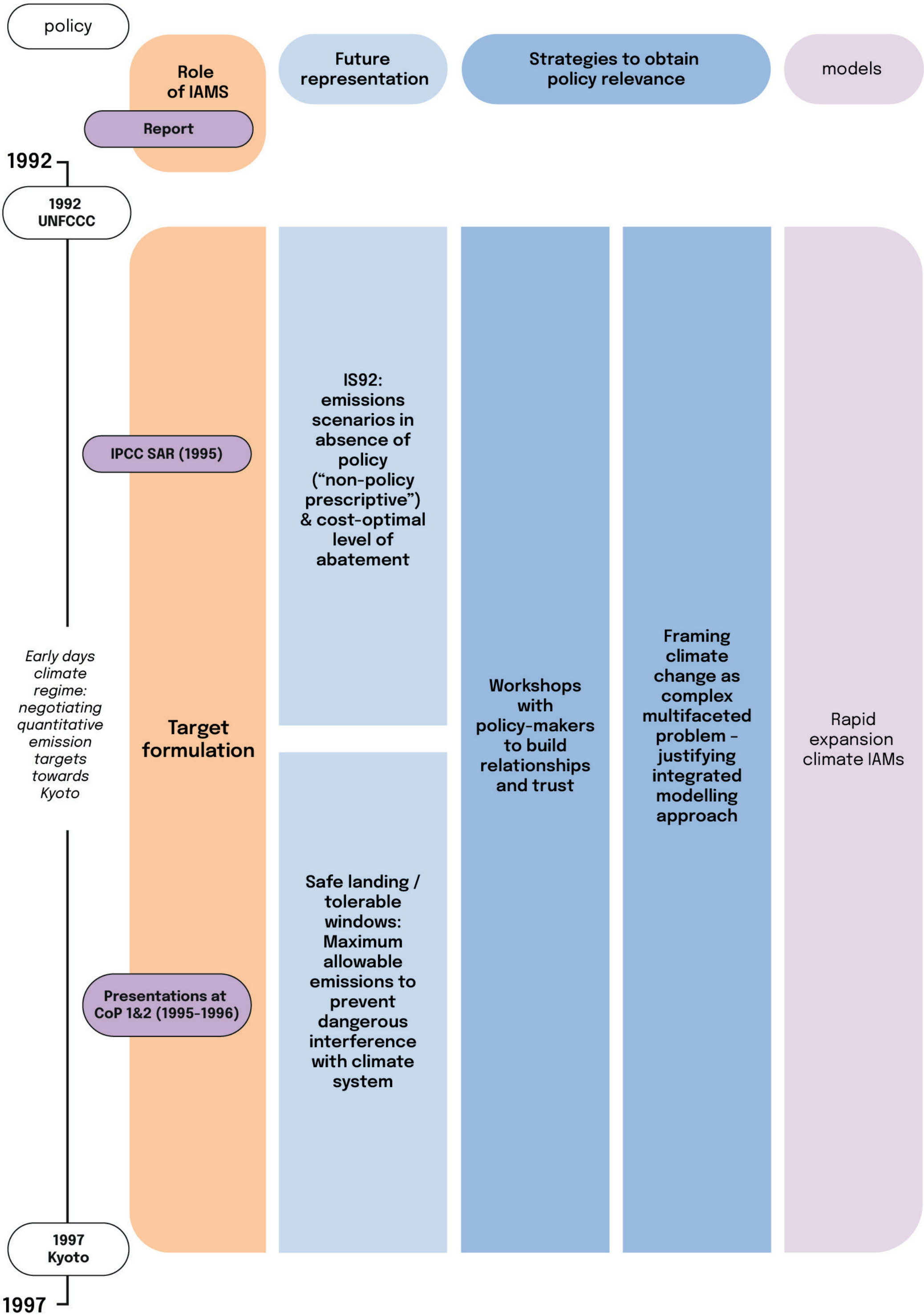


Figure 7. Overview of the IAM-policy interface in phase 3 (1992-1997)

Facilitating quantitative target-setting towards Kyoto

As the international convention was being negotiated and the need for scenarios emerged, several modelling projects were funded in the US, Europe and Japan (Weyant et al., 1995). These and earlier climate IAMs provided crucial inputs to the negotiations towards Kyoto. One of the key applications of IAMs were the 'tolerable windows' or 'safe landing' concepts, which represented lower and higher bounds of emissions that would prevent dangerous climate change and were inspired by the success of 'critical loads' in the acid rain negotiations (interview 2,4,5,7,10). The tolerable windows approach was used in an integrated assessment project at the Potsdam Institute for Climate Impact and Research (PIK) and the safe landing concept resulted from a number of workshops in the Netherlands (the 'Delft workshops') using the IMAGE model in which modellers and policy-makers interacted (Bruckner et al., 1999; Alcamo and Kreileman, 1996). The latter was directly inspired by the expert review meetings of RAINS, a success they hoped to repeat with IMAGE (Alcamo & Kreileman, 1996; interview 4). The concepts presented at the first two Conferences of the Parties (COPs) in 1995 and 1996 helped to formulate the quantified emission targets under the Kyoto Protocol (Van der Sluijs, 2002). Various approaches were also proposed to determine the allocation of emission reduction ('burden sharing') between UNFCCC parties. The 'triptych' approach that allocated emissions based on three categories of emissions developed by Phylipsen et al. (1998) was particularly influential in formulating an EU-wide abatement target during the years preceding Kyoto (Groenenberg et al., 2001). The tolerable windows / safe landing concepts and the IS92 emissions scenarios played a considerable role in the emergence of the 2°C target. The history of the target can actually be traced to Nordhaus (1975; 1977), albeit merely as heuristic, and began to emerge as a concrete target due to a confluence of political events during 1980s to early 1990s (Randalls, 2010; Morseletto et al., 2017). It was first officially raised as a political target at the first COP in 1995 by the German Advisory Council on Global Change (WBGU, 1995), basing their argument largely on the tolerable windows principle (Morseletto et al., 2017). Moreover, the rationale of the adoption by the European Union of the 2°C target in 1996 was partly based on the IS92 emissions scenarios constructed with IAMs (Randalls, 2010). The 2°C goal was certainly not *only* the result of IAM analyses, but the model outputs arguably played a significant role in target formulation.

2.2.4 PHASE 4: Growing significance in IPCC WGIII (1997–2009)

The decade that followed the Kyoto protocol were the 'mature years of the IPCC and the UNFCCC' (Hajer & Versteeg 2011, p. 83). The ratification of the protocol by at least 55 countries appeared quite challenging, especially after the failed negotiations at COP6 and the US withdrawal. With the EU taking the lead, political attention was on ratification of Kyoto which finally entered into force in 2005 (Gupta, 2014). The 'alarmist repertoire' (Hulme, 2009) triggered by the period following 9/11 was further augmented by mounting evidence of anthropogenic climate change in the Third Assessment Report (TAR) (IPCC, 2001) and emerging metaphors of 'tipping points' and 'abrupt climate change' (Gardiner, 2009). The Fourth Assessment Report in (AR4; IPCC, 2007) further highlighted the need for action, accompanied by Al Gore's *An Inconvenient Truth* in 2006 that largely raised public awareness. Slowly but surely, the political ambition for mitigation began to stabilise throughout this phase. Climate change was predominantly framed as an economic challenge to be solved by market-based mechanisms, as exemplified by the EU Emissions Trading System launched in 2005. This phase also saw a 'frame diversification' of climate change, which was reflected in the IPCC, such as climate change as ethical and development issue (Hulme et al., 2018).

The emergence of alternative perspectives on the climate problem

As the IPCC matured, it began to be criticised from various angles, most notably on the limited social science perspectives and the lack of representation of developing countries in their assessment (Hulme & Mahony, 2010). This debate in fact remained unresolved even after the Fifth Assessment Report (Victor, 2015). Together with the underestimation of sources of socio-economic uncertainty in IS92, this critique led to the development of a new set of emissions scenarios (interview 3), which were published in a WGIII Special Report on Emissions Scenarios (SRES) (Nakicenovic et al., 2000). In contrast to previous scenario sets, the SRES started with qualitative storylines, which were then used as input for six (process-based) IAMs to derive quantified emissions pathways. Responding to the critiques, the SRES authors organised an 'open process', allowing for involvement of a wide range of disciplines and ensuring a considerable proportion of representatives from developing countries in the author team (Nakicenovic et al. 2000; Girod et al., 2009; interview 3). The use of (process-based) IAMs seemed inevitable: 'The SRES covered everything from driving forces of the future development all the way to consequences. For that you needed integrated models, there was no other way of doing it' (interview 7). The ability of process-based IAMs to produce such socio-economic scenarios that involve a wide range of perspectives is arguably one of the reasons for the emerging predominance of process-based as opposed to CBA-IAMs in IPCC's assessments. A second reason was presumably the controversy raised by developing countries around the valuation of human life in the damage calculation in CBA-IAMs in the preparation of the Summary for Policymakers (SPM) of the SAR (O'Riordan, 1997). A third development considering the role of CBA-IAMs and the legitimacy of the CBA approach more generally was the Stern Review of Economics of Climate Change (Stern, 2006), which proposed a social discount rate of almost zero based on ethical considerations, concluding that climate action now would be more cost-effective than later. It was the literal opposite of what Nordhaus had been reiterating for decades and economically legitimised early climate action (Nordhaus, 2007; Ackerman et al., 2009). The political effect of the Stern Review remains debated: on the one hand it forged improvements of CBA-IAMs and preserved its use in decision-making, yet its legitimacy was no longer given (Randalls, 2011).

IAMs as an anchor to connect the Working Groups

Starting with the preparation of the SRES (Nakicenovic et al., 2000), IAMs began to serve an important 'anchoring' function within the IPCC. The SRES became one of the most often cited IPCC WGIII reports ever produced and was used as input for the TAR (IPCC, 2001) and AR4 (IPCC, 2007). The SRES was used by all three WGs and particularly forged more formal collaboration between the GCM and IAM communities (interview 1,2,8,16). This proved vital for the IPCC to bring the complex and dispersed information into a coherent report (interview 1,2,7). As several limitations of the SRES became apparent, the IPCC created a Task Group on New Emissions Scenarios (TGNES) in 2005 in which IAM teams were heavily involved (Cointe et al., 2019). The TGNES proposed the Representative Concentration Pathways (RCPs): four pathways spanning a range of radiative forcing values in the year 2100 from low to high (2.6 – 8.5 W/m2). As a solution to the 'tedious' sequential scenario process, the RCPs could be used in parallel by the IAM and GCM communities (Moss et al., 2010). IAMs were used to construct the RCPs as well as the socio-economic emissions scenarios and thus

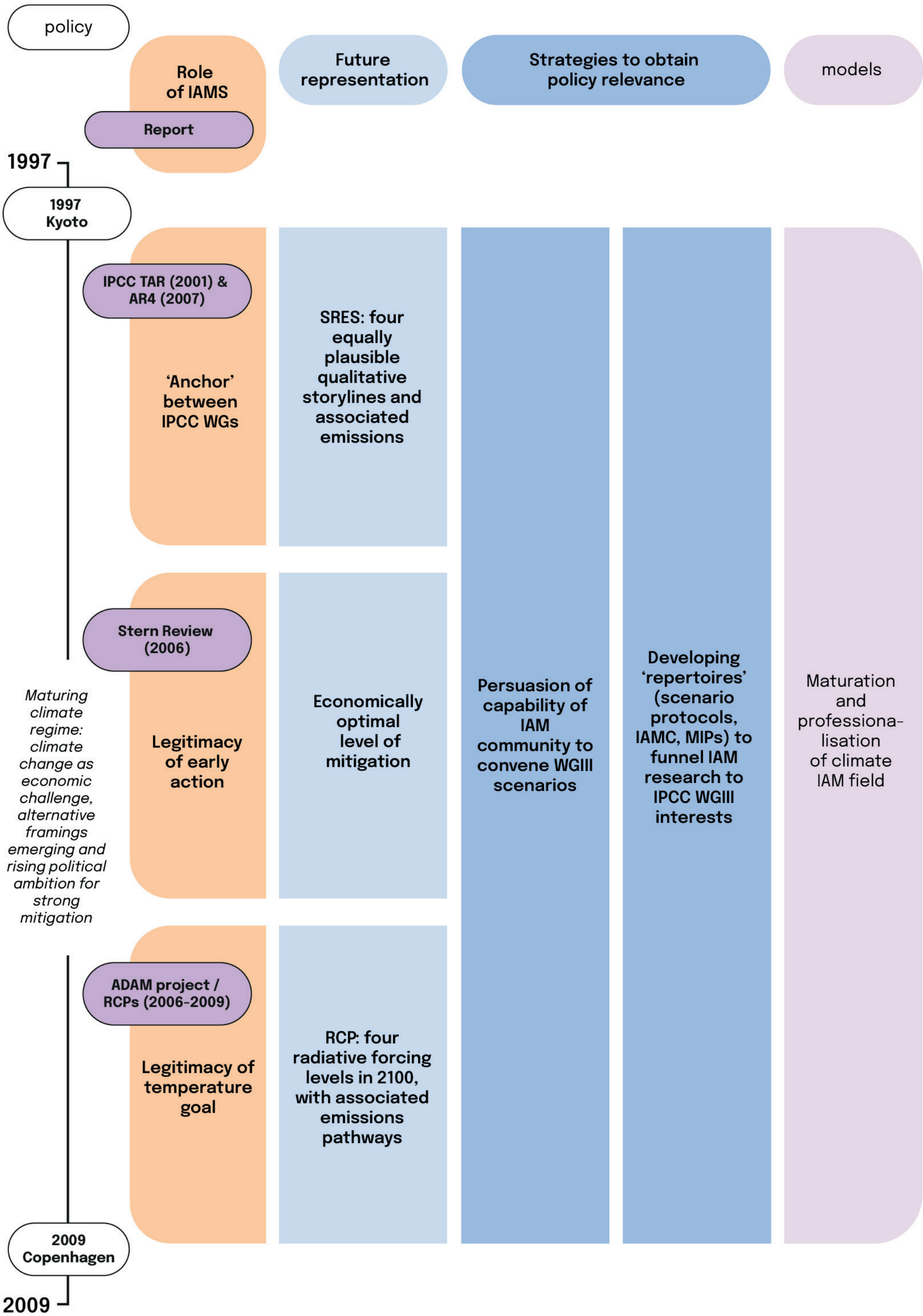


Figure 8. Overview of the IAM-policy interface in phase 4 (1997-2009)

played a more important role in the IPCC scenario practice. Moreover, the mandate of the IPCC in scenario making began to be disputed: an assessment bureau should evaluate rather than produce scenarios (Cointe et al., 2019, interview 3,14). IAM teams convinced the bureau that they were capable of organising the scenario process (Cointe et al., 2019, interview 11). The modellers established the IAM Consortium in 2007 (IAMC), which indeed became responsible for the coordination of IPCC's emissions scenarios.

The role of IAMs in the feasibility of the 2°C goal

While no 'additional climate policy initiatives' were requested in the terms of references of the SRES (IPCC, 1996), the adoption of the Kyoto Protocol and discussions around a future global agreement by 2005 increased the political interest for mitigation scenarios in this historic phase, as reflected in the titles of the WGIII reports where 'mitigation' began to emerge.[20] The IPCC expert meeting in Noordwijkerhout in the Netherlands in 2007 – where the RCP framework was discussed – marked a critical moment in the evolution of the role of IAMs in the evaluation of mitigation scenarios. UNFCCC negotiators at the meeting showed explicit interest in mitigation targets and policy responses, discussing the feasibility of RCP2.6 – a low mitigation scenario (Lövbrand, 2011; Moss et al., 2010). That scenario had been developed some years before by the IMAGE research team in response to an emerging increase in the 2°C target, for the first time identifying what would be needed to reach such a target using an IAM model (Van Vuuren et al., 2006). The IAM work and the selection of RCP2.6 induced a range of subsequent research activities into the feasibility of the 2°C target. This includes, for instance, the Adaptation and Mitigation Strategies (ADAM) project (Lövbrand, 2011) and other Modelling Intercomparison Projects (MIPs) including EU funding projects and EMF sessions (Cointe et al., 2019). These MIPs and the RCP process introduced a far more regular contact among modelling teams, but also scenario protocols, standardised reporting and documentation, common databases gathering model results. These 'repertoires' appeared crucial to hold the heterogenous IAM field together and organise their research towards providing policy-relevant knowledge (Cointe et al., 2019). The IAM research into the feasibility of RCP2.6 was also used strategically by the EU to explore different pathways towards 2°C, that could be used internally (to legitimise its 2008 Climate and Energy Package) and to legitimise the temperature goal in the UN climate negotiations (Lövbrand, 2011).

20 Titles of subsequent IPCC reports: FAR (1990) "Response Strategies", SAR (1995): "Social and Economic Analysis of Climate Change", TAR (2001) "Mitigation", AR4 (2007) & AR5 (2014) "Mitigation of Climate Change"

2.2.5 PHASE 5: Prominent tools for mitigation analysis (2009–2015)

Despite the disappointment following the Copenhagen conference, this phase represents a breakthrough in international climate negotiations, characterised by political ambition for strong mitigation targets, with the official inclusion of the 2°C target at Bali. First emission targets ('the carbon budget') and later temperature goals were debated in this phase (McLaren & Markusson, 2020). It also marks a shift from a top-down and legally binding (Kyoto and Copenhagen attempt) to a more fragmented and decentralised governance architecture (Bodansky, 2010; Bäckstrand & Lövbrand 2019). The Paris Agreement in 2015 went a step further in this paradigm shift as countries agreed to keep global temperature increase 'well below 2 degrees' and 'pursue efforts' to limit warming even further to 1.5°C (UNFCCC, 2015b), which was hailed by many as a major political breakthrough. IAMs gained an increasingly important position in the climate science-policy interface by becoming the backbone of IPCC's Fifth Assessment Report (AR5; IPCC, 2014), where they adopted an important function regarding the legitimacy of the temperature targets as well as monitoring progress of the UNFCCC in their political ambition. The realisation that climate change is closely connected with other environmental and social issues forged the rise of co-benefit analysis (e.g. Ürge-Vorsatz et al., 2014) and a broader agenda of 'sustainability', ultimately culminating in the Rio+20 conference held in 2012.

IAMs to explore the feasibility of stringent temperature targets

As shown in Figure 3, the number of IAM publications in scientific journals exploded in the period 2008-2014 and the prominence of IAM analyses in AR5 was substantial compared to previous reports. Likewise, Cointe et al. (2019) observed that with the AR5, for the first time IAMs truly functioned as backbone of the assessment where it was described as 'invaluable' to guide policy decisions (IPCC, 2014, p. 51). As emissions continued to rise, resolving for the cumulative carbon budget would require later withdrawals and this forged the idea of negative emissions in IAM scenarios (McLaren & Markusson, 2020). The use of NETs became prominent in the AR5 pathways – most notably Bioenergy with Carbon Capture and Storage (BECCS) – as it would make the 2°C more attainable (Guillemot, 2017). The RCP scenario framework functioning as 'red thread' throughout the report and the explicitly inclusion of mitigation pathways towards the 2°C target in turn forged the development of simulation consistent with 2°C in a wider range of scientific communities (Guivarch & Hallegatte, 2013). The IAM scenarios in the AR5 were thus crucial in showing economic and technological feasibility of achieving the 2°C and were arguably pivotal in the run up to the Paris Agreement in 2015. IAM modellers were also involved in the Structured Expert Dialogues (SEDs) held between 2013 and 2015, which can be viewed as a 'live' version of the AR5 in which UNFCCC delegates and authors across all three WGs as well as experts outside the IPCC engaged in a face-to-face interaction. The difference between 1.5°C versus 2°C was a central topic in these discussions and the adoption of the 1.5°C target in the Paris Agreement can to a considerable extent be attributed to these dialogues (Guillemot, 2017; Livingston & Rummukainen, 2020; Tschakert, 2015; interview 6). IAM modellers have been argued as being 'central actors' in these debates, as they provided the so-called 'deep carbonisation pathways', which were widely used by protagonists of the 1.5°C (Guillemot, 2017, p. 47).

UNEP gap reports: monitoring the level of ambition

Although arguably less authoritative compared to the IPCC SPMs, which are negotiated and approved line-by-line by government representatives, the Emissions Gap Reports published by UNEP have also provided significant input into the negotiations. Rather than an elaborate assessment of available science, the UNEP 'gap reports' answer the simple question: are the pledges made by UNFCCC countries sufficient meet the 1.5°C and 2°C? These calculations of the 'gap' between expected emissions resulting from pledges and those compatible with the temperature goals are primarily performed based on IAM scenarios, thereby IAMs function as a monitoring progress on policy targets. The first 'gap report' was published in 2010 as a response to the pledges made by 85 countries under the Copenhagen Accord in 2009 (UNEP, 2010). Since then, the UNEP Gap Reports have been published annually and since the Paris Agreement evaluate the Nationally Determined Contributions (NDCs). With several IAM authors, the UNEP gap reports thus ensured a policy-relevant outlet of IAM work along the decentralisation of the international climate regime.

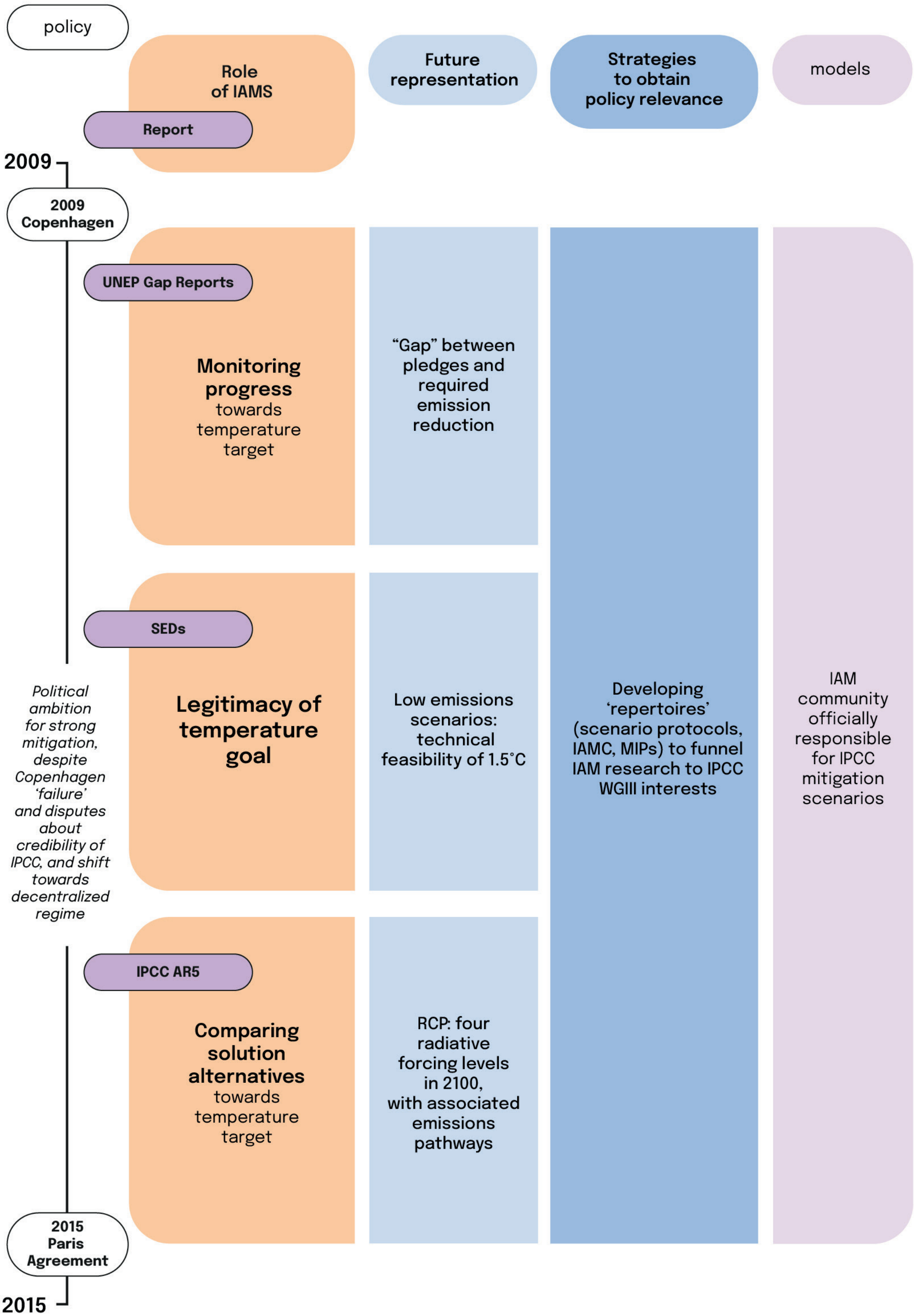


Figure 9. Overview of the IAM-policy interface in phase 5 (2009-2015)

2.3 Discussion

The historic IAM-policy interactions between 1970 and 2015, reveal the increased prominence of IAMs in the climate science-policy interface. Their policy relevance came out in the capability to represent a range of possible futures and meet emerging knowledge demands on behalf of the policy community. Over the years IAMs adopted various roles between science and policy from agenda-setting in early phases to target-setting and monitoring political ambition for mitigation in later phases. To explain the ‘career’ of IAMs we refer to several material and sociological background conditions as well as to particular features of both the IAMs as model and the IAM as community.

2.3.1 Material conditions enabling model building

Two obvious conditions that have enabled model building are advances in computer technology and data availability. An essential driving force behind global environmental modelling in general is the exponential growth in computing power (Heymann et al., 2017). As computer technology was becoming increasingly available, computer scientists became interested in applying models to policy-making across a wide range of issues already since the 1970s (Greenberger et al., 1976). This diversity in models allowed IAM modellers to combine multiple models into coherent frameworks. The development of internet technology and software development further facilitated the sharing of practices, computer code and online data sets, enabling to look into a couple thousand scenarios from a large set of models, thus facilitating the connections among individual modelling groups. A second and related material condition underlying the development of IAMs is the growing data availability since the first models. Especially the availability of socio-economic data was an important condition enabling the rapid growth of climate IAMs in the early 1990s (Weyant et al., 1995).

2.3.2. Sociological trends in the authority of global and quantitative forms of knowing climate change

The prominence of IAMs cannot be fully understood without appreciating how the practice of ‘modelling’ could tap into the established position of statistics and quantified indicators in modern policymaking. First of all, the general ‘trust in numbers’. Theodore Porter has shown how trust in quantified knowledge is deeply embedded in Western cultures. Indeed, it proved vital for decision-makers to construct policy legitimation from the nineteenth century onwards (Porter, 1996). As the trust in traditional elites declined, quantitative forms of knowledge became increasingly important according to the logic that 'A decision made by the numbers […] has at least the appearance of being fair and impersonal.' (Porter, 1996, p. 8). This trust in numbers is persistent: statistics still tend to take the centre stage in the environmental science-policy interfaces (Wesselink et al., 2013). Clearly, this sociological fact, that legitimate decision making depends on a solid quantitative basis, helps understand how IAMs could gain such a prominent role in climate policymaking.

Secondly, IAMs should be understood against the background of the emergence of predictive practices that gained significant scientific and political authority from the second half of the 20th century onwards (Heymann et al., 2017). The first climate models that were built soon after WWII that are rooted in meteorology became the single possible way of conceiving of global climate change (Edwards, 2010). GCMs have grown out into an authoritative scientific discipline with a vast infrastructure of data collection and distribution and set the stage for the 'cultures of prediction' to become to increasingly dominant in our understanding of global environmental change (Heymann et al., 2017). The system dynamic and energy-economic modelling efforts in the 1970s and 1980s, which are the roots of IAMs, helped to further establish and reinforce these cultures of prediction (Ibid.). It is against this background that IAMs added the possibility of 'what-if' queries: their analytical strengths lie in comprehensive insights in human-nature interlinkages and the exploration of climate policy alternatives under various conditions (Geels et al., 2016). Paradoxically, the desire for numbers and predictions of policy communities certainly helps explain the influence of IAMs, yet is incongruent with the goals and conclusions of IAM analyses.

A third and intricately related factor is that climate models have consistently represented climate change as a global phenomenon, rather than a local or national issue, and thus a problem to be governed on a global scale (Miller, 2004). From a macro-level perspective, this tight coupling between knowledge-making and social order essentially amounts to a form of 'co-production' (Jasanoff, 2004). Since GCMs were the primary epistemic entry point to understand future climate change, it became the backbone of IPCC WGI right at its establishment, which implied a global governance approach (the UNFCCC). This global governance architecture in turn legitimises the use of global models, such as GCMs and IAMs. This co-production has several implications for policy deliberation on climate strategies. In particular, the top-down technocentric approach to climate action has legitimised the use of international carbon markets and technologies such as BECCS (Lövbrand, 2011; Hourcade et al., 2015).

2.3.3. Adopting various roles in the evolving science-policy interface

Where the material conditions explain the capacity of building models in the first place and the sociological trends of trust in quantification and legitimacy of global models helps to explain the authority of modelling in general, our historical reconstruction also suggests additional, more contextual, explanatory factors relating to both the particular features of the IAMs as models as well as to the role of the communities that shaped up around the IAMs. Overall, we observed that the role of IAMs in the science-policy interface shifted from agenda-setting (Forrester, phase 1) towards monitoring progress of climate mitigation policy (UNEP gap reports, phase 5). Moreover, IAMs have applied to various environmental issues that emerged over the past 50 years: from population growth and energy (phase 1) to acid rain (phase 2) and finally to climate change (phase 3-5). IAMs seem to have succeeded to anticipate and respond to emerging developments in the science-policy interface through adjusting their analysis to emerging knowledge demands from the policy community. Rather than being responsive to policy developments however, IAMs were active in helping to shape policy change as well. For instance, the World 3 model runs in the *Limits to Growth* were a key paradigm change that raised environmental awareness globally. In later stages, the low-emissions scenario played a key role in the legitimacy of the global temperature goals. IAMs were thus able to co-evolve with the continuously changing climate science-policy interface and adopt different roles. Informed by the descriptions of the *future representation* and *strategies to obtain policy relevance*, we believe this capacity to adopt different roles results from specific model characteristics of IAMs as well as the pro-active role of the modelling community.

Flexibility, breadth and hybridity of IAMs

The ability of IAMs to play various distinct roles between science and policy in various environmental policy domains (energy, acid rain, climate) throughout the historic phases can partly be explained from the structure of the modelling frameworks. A first key characteristic of IAMs is their *flexibility*, allowing for multiple sub-models to be coupled or decoupled. This flexibility is conducive to their wide application (Weyant, 2017). Secondly, IAMs are typically broad in scope, enabling the integration of information from a wide range of disciplines and covering environmental problems from causes to response strategies. Their breadth and flexibility allow IAMs to remain up-to-date, incorporating new scientific insights as well as providing knowledge inputs relating to newly emerging societal interests and political concerns. Third, the 'hybrid' nature of IAMs, bringing together scientific and policy elements, provide the modellers to move backwards and forwards between experts, modellers and policy makers. For instance, the RAINS modellers started out with showing emission maps (the problem) and, responding to knowledge needs from acid rain negotiators, then started developing abatement scenarios. This hybridity is also apparent in their *representation of futures*, such as the critical loads, safe landing and 2°C target, which cater both for expertise as well as to the evolving policy-makers' needs. With regard to the IPCC specifically, the capacity of IAMs to connect the scientific communities underlying the three different WG's appeared crucial to achieve coherence of its assessment reports. This capacity explains why the IPCC and IAM community became progressively mutually interdependent in the last three phases and their growing prominence in assessment reports (see Figure 3). Considering the dense network of a relatively small group of authors and institutions underlying WGIII, this prominent position may be problematic as it risks 'narrowing' the construction of climate mitigation within the IPCC (Hughes & Paterson, 2017).

The pro-active modelling community in anticipation of policy relevance

A final element of our explanation for the evolution of IAMs in the science-policy interface in the pro-active nature of the modelling community in their search for policy relevance. Our analysis indicates that modellers were not only reactive to the developments in science and policy; at crucial moments they were able to *anticipate* (and sometimes even helped to generate) policy makers' future demands. We think this agency of modellers, listening to policy conversations and assessing possible responses, can be understood as part of their 'institutional work', which is defined as 'the purposive action of individuals and organisations aimed at creating, maintaining and disrupting institutions' (Lawrence & Suddaby 2006, p. 215). In our historical analysis, we recognised multiple forms of institutional work as distinguished by Lawrence and Suddaby (2006, p. 221).

One form of institutional work that we observed is 'advocacy': the mobilisation of support through deliberate social persuasion (Lawrence & Suddaby, 2006). For instance, Jay Forrester deliberately persuaded the Club of Rome of the applicability of his system dynamic modelling approach to the 'world problématique' in phase 1. In a similar vein, the RAINS modellers convinced acid rain negotiators of the usefulness of their model and more recently the IAM community assured the IPCC bureau of their ability to convene the WGIII scenario process (phase 4). A second form of institutional work distinguished by Lawrence and Suddaby (2006) is 'theorising': developing abstract categories or understandings of cause-effect relationships. This more indirect and discursive form of institutional work occurred through primarily through the particular *representation of possible futures* that legitimised the use of models for policy purposes. In phase 1 for instance, the energy-economic and climate-economic modellers framed the energy problem as technical and economic problem, legitimising energy and climate economic models. Later on, the RAINS modellers formulated cause-impact-strategy relationships, legitimising an IAM approach to acid rain (phase 2). Similarly, when climate change emerged on the political agenda in phase 3, modellers framed climate change as a complex multifaceted problem in need for integrative modelling approaches (e.g. Weyant et al., 1995). A third form of institutional work is 'mimicry': associating new practices with former practices or technologies in order to facilitate their adoption (Lawrence & Suddaby, 2006). A key example is the replication of the success of the RAINS model to the issue of climate change: not only was this success an inspiration, but specific lessons such as the set-up of expert workshops were explicitly repeated. Another form of mimicry was observable in phase 3, when the IAM community mimicked the scientifically rigorous, trusted and well-established GCM practice, by adopting visual language of comprehensive graphs with quantitative long-term scenarios. The fourth form of institutional work that we recognised is 'defining': the development of rule systems that define boundaries of a field, such as the creation of standards (Lawrence and Suddaby, 2006). This primarily occurred in the last two historic phases when the IAM community established a number of 'repertoires' that organises their research (Cointe et al., 2019). For instance, the IAM community formulated a number of criteria that scenario developers need to meet in order to be included in the scenario database that was used for the IPCC AR5 (Ibid.). These criteria, such as a minimum set of variables and a full energy system representation, thus strongly defined the scenario practice within the IPCC WGIII and excluded scenario approaches such as sectoral modelling.

The institutional work concept is commonly used in organisational studies and not so much in understanding science-policy interactions (Arpin et al., 2016 for a notable exception). However, the concept begins to emerge in environmental governance literature to better understand the diverse forms of agency in transformations of governance systems (Beunen & Patterson, 2019). Institutional work as a lens helps to grasp the micro-dynamics through which actors support, maintain or disrupt institutions (Ibid.). We believe that the concept may hold strong analytical strength explaining the role of models in policy-making on top of the more commonly used concept of 'epistemic communities' (Haas, 1992). Whereas the concept of epistemic communities has been valuable to explain the capacity of the IAM field to organise itself and reach consensus among peers – such as through a dense network of IPCC WGIII authors and institutions (Corbera et al., 2016; Hughes & Paterson, 2017) – it ignores the pro-active 'work' of a scientific community to show the relevance of its findings for policymaking. We believe the notion of institutional work is a helpful addition to existing conceptual understandings of science-policy interactions, illuminating the actual micro-practices through which actors (either deliberately or not[21]) support, maintain and disrupt institutions.

21 Apart from intentional strategies, recent studies in institutional work suggests unintentional strategies might be at play as well (for a discussion on intentionality, see Beunen and Patterson, 2019, p. 5). The unintentional strategies of the IAM community are beyond the scope of this chapter.

2.3.4 Implications for the future role of IAMs

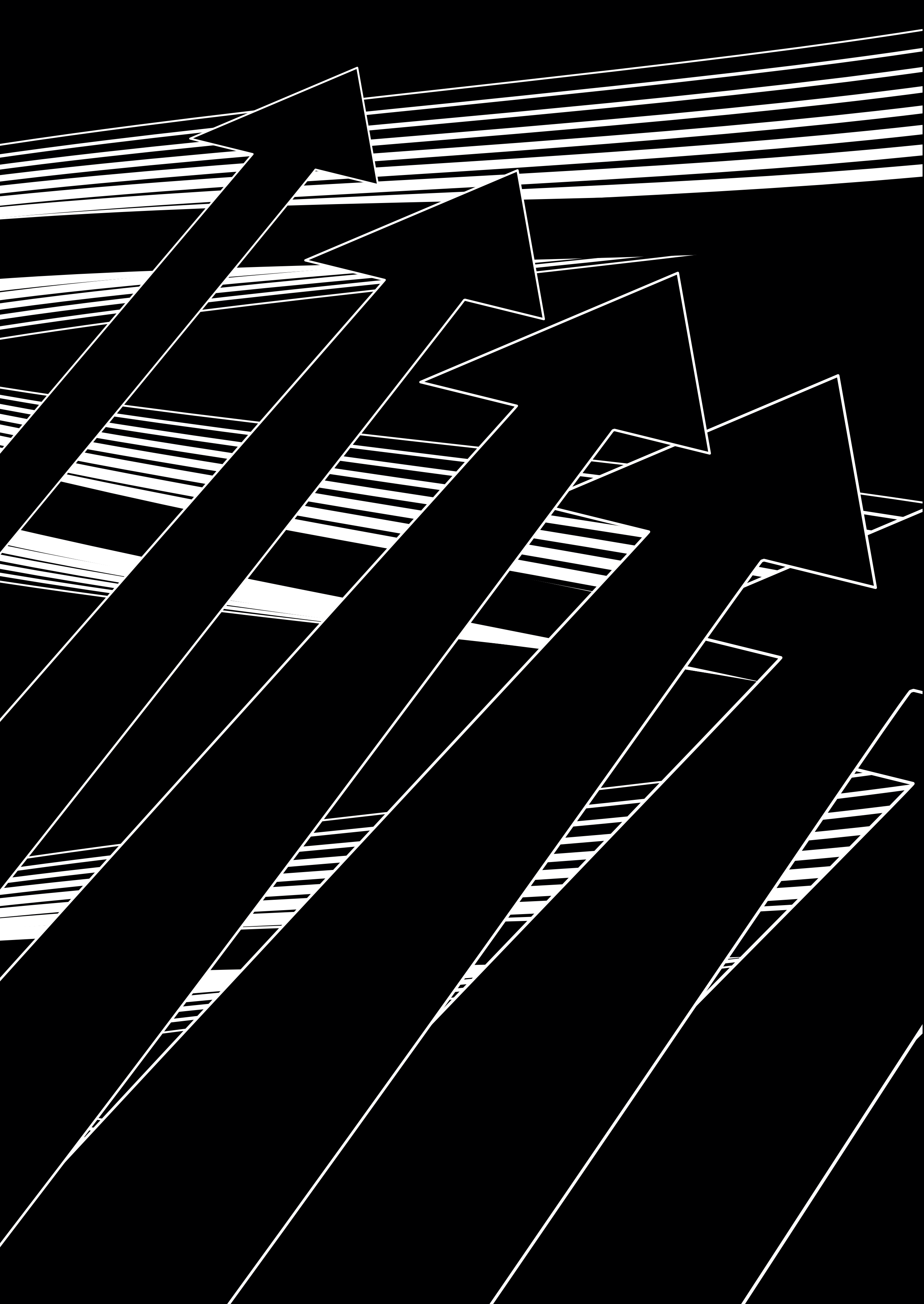
Our research indicates that between 1970 and 2015, IAMs became more prominent and adopted various roles in the evolving science-policy interface. Their strong embeddedness in IPCC's scenario practice implies that IAMs will most likely continue to play an important role. However, since IAMs have historically adopted various mediating functions between science and policy, this role is not at all fixed. The need for radical and rapid low-carbon transformations implies that their role should be continuously re-evaluated, especially since IAMs are powerful in making certain pathways more legible and actionable at the expense of other strategies that may be crucial in responding to the climate crisis (Beck & Mahony, 2017; 2018a). Modellers themselves are active in this debate by expanding their typical scenario set to alternative pathways (e.g. Van Vuuren et al., 2018) and propose ways to complement IAM with alternative analytical approaches to explore low-carbon futures (Geels et al., 2016). Yet, the fundamental technological, economic and socio-cultural transformations necessary to evolve to a decarbonised society points raises a debate on the ability of IAMs to conceive of more radical societal reorganisation. These fundamental socio-cultural transformations points to the need for IAM community to seek new engagement with a broader range of disciplines that are rooted in social sciences and humanities. An example of such an engagement is a broader conception of human agency beyond rational choice, which implies an integration of heterogeneous agent profiles within IAMs (Otto et al., 2020). Future research could further explore if, how and under what conditions such links could be fruitful. Moreover, the climate debate is transpiring far beyond the realm of the climate negotiations. Climate action that is happening on the ground ('seeds') could be insightful for IAM modellers to identify new processes, patterns or social relations relevant to their scenario practice (Raudsepp-Hearne et al., 2020). Another implication of the widening debate is that the IAM community may need to expand their role to engage a wider range of publics and societal stakeholders in order to involve a wider range of perspectives on possible and desirable futures.

2.4 Conclusion

In this chapter we investigated how and why have IAMs became prominent in the climate science-policy interface. We identified five phases between 1970 and 2015 in which IAMs adopted various roles towards science and policy, from agenda-setting in early phases to target formulation and monitoring political ambition for mitigation in later phases. While IAMs found ways to provide policy makers with relevant knowledge in each phase, we found that the interaction between IAMs and the policy world had distinct characteristics in each of the five phases. The fact that IAMs adopted multiple distinct mediating roles between science and policy helps explain how they maintained and indeed could enhance their relevance. We found that the number of articles in academic journals drawing on IAMs per year rose from incidental in 1990 to over 140 in 2015, indicating the growing relevance of and recognition for IAM findings. We suggest there are several factors that help explain the growing prominence of IAMs in the climate-science policy interface. We differentiate between material and sociological background conditions and particular features of the IAM as model as well as the role of the communities that shaped up around the IAMs.

In terms of the background conditions we first signal the advances in computer technology and data availability that provided the material conditions for model-building in the first place. Secondly, the IAM-policy interactions played out against more persistent trends in growing authority of global and quantitative forms of knowledge. Yet we cannot fully explain the rise to prominence of IAMs without taking the specifics of the interaction around IAMs into account. On the one hand the particular features of IAMs, their breadth, flexibility and hybrid nature explains their diversity in their applications and their 'anchoring' function between IPCC's WGs. On the other hand our research reveals that the IAM field acted as pro-active scientific community deploying several purposive strategies to gain policy relevance over time.

We conclude that the current prominence of IAM to explore low-carbon futures is a result of complex historic science-policy dynamics. The urgency of the societal response to the climate crisis and the broadening of the issue to the wider public debate points to the need to continuously and actively re-evaluate the role of IAMs and reflect on their use in combination with alternative approaches to explore possible futures.



3.

An analysis of modelling and climate policy around the 1.5°C goal

Abstract

Some of the most influential explorations of low-carbon transformations are conducted with 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 policymaking 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.

Published as:

Van Beek, L., Oomen, J., Hajer, M., Pelzer, P., & Van Vuuren, D. (2022). Navigating the political: An analysis of political calibration of integrated assessment modelling in light of the 1.5 C goal. *Environmental Science & Policy, 133*, 193-202.

https://doi.org/10.1016/j.envsci.2022.03.024

3.1 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 et al., 2016). Model-based scenarios form an important tool to explore these low-carbon transformations. Such scenarios are typically made using 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[22] have become increasingly prominent in the climate science-policy interface, co-evolving with global climate politics (McLaren & Markusson, 2020; Bosetti, 2021; chapter 2). While scattered over different institutions, together the IAM modellers constitute a globally organised epistemic community with a leading role in scenarios underlying WG III of the 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.

22 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).

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 & Mahony, 2017; Guillemot, 2017). As such, the capacity of IAMs to explore mitigation options has become increasingly central to inform climate policy (chapter 2). IAM scenarios quantify a range of alternative climate policy pathways (Edenhofer & 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 & Mahony, 2018a). For instance, alternatives that are not part of the IAM repertoire are 100% renewable energy scenarios (Hansen, Breyer & Lund, 2019), degrowth scenarios (Keyßer & 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 & 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 & Mahony, 2017, 2018a; 2018b; McLaren & Markusson, 2020). More recently, the 1.5˚C goal has become the new symbol for climate action – despite serious doubts about its feasibility (Livingston & 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 NETs,[23] 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.

23 In the introduction and conclusion I use the term CDR as it is the more commonly used term in academic literature at the time of writing (2023).

The current study aims to address this gap. We study integrated assessment modelling using the concept of 'Techniques of Futuring' (ToF; Hajer & 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 C1 and C2), a quantitative literature analysis and reviewed IPCC and UNFCCC documentation (Appendix C3 and C4). 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 C1 and C2). The selection of IPCC SR1.5 authors was based on their role in chapters relevant to climate mitigation (chapter 2, 4 and 5 of the report) 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 3.2), which guides our reconstruction. We then provide background information on the emergence of the 1.5˚C target (section 3.3). Section 3.4 presents our analysis on how and why the 1.5˚C gained traction. In section 3.5, we reflect upon this analysis and discuss implications for the use of IAMs to explore low-carbon transformations.

3.2 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 (Jasanoff, 2004; cf. Latour, 1993). 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, 2015, p. 4) and how 'fictional expectations' enable actors to make decisions under uncertainty based on the shared assumption 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 & Mahony, 2017; Beck & 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 & 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 C1 and C2).

3.3 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 1980s (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 & 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[24] and 22, government representatives at COP21).

24 The interviewees were numbered anew in this chapter and therefore do not match the numbers attached to interviewees in chapter 2

3.4 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 Figure 12):

→ **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.

3.4.1 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 emphasised. 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 & 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 & 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-organised (cf. Cointe et al., 2019; chapter 2), the IAM community could rapidly develop 1.5°C pathways (see Figure 10). 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.

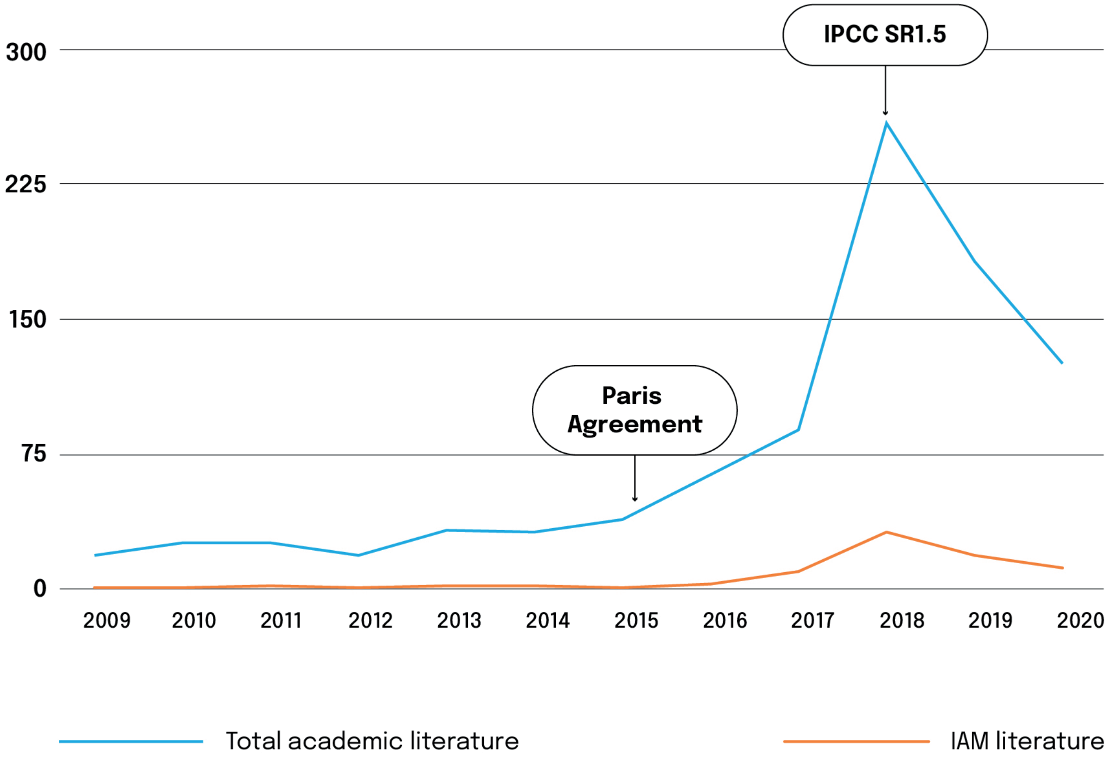


Figure 10. Number of academic peer-reviewed literature on 1.5˚C published over time between 2009 and 2020. Data derived from Scopus (Appendix C4 for methodology).

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 & Gough, 2016; Forster et al., 2020). Others argue that counting on NETs in the future risks undermining near-term climate action (Markusson, McLaren and Tyfield, 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 organisation 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.

Organisation

First, modellers often work closely together in large-scale modelling 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 organisational 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 & 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).

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 much longer history of 'trust in numbers' among policymakers (Porter, 1996; cf. chapter 2) 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).

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 national approaches. As our interviews revealed, modellers as well as non-modellers struggle to identify viable alternative to IAMs:

'If we didn't 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)

3.4.2 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 & 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.

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, 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, 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 policy: 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.

Harmonising 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 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, 2017c;d, 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 harmonise 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).

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.

3.4.3 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 & 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 & 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 characterised by a tightened interdependence between modelling and climate policy and through which pathways towards the 1.5°C became solidified (Figure 11).

2015

Paris Agreement December 2015
request to draft SR1.5, specific request for emissions pathways to 1.5C

Scoping Meeting August 2016
outline SR1.5 developed

LAM 1 March 2017
drafting content based on outline

LAM 2 June 2017
preparing First Order Draft

First Order Draft July 2017
only overshoot scenarios presented

Expert review July-Sept 2017
back of non-overshoot scenarios

Expert review July-Sept 2017
back of non-overshoot scenarios

LAM 3 Oct 2017
preparing Second Order Draft (& SPM)

Second Order Draft Dec 2017
non-overshoot scenarios included

LAM 4 April 2018
preparing Final Government Draft

Final Government Draft June 2018
LED scenario appears as archetype

Government reviews Sept 2018

IPCC 48: SPM approval Oct 2018
little comments on illustrative pathways

Report published & press release Oct 2018
Need for 'net zero' in 2050 and necessity of NETs elevated

Media resonance Oct 2018
'12 years left' and 'recipes of the future'

'Net-zero' adopted by various countries & NETs included in long-term strategies 2019-2020

2020

Climate policy

UNFCCC needs to show feasibility of the 1.5˚C

Governments, experts and civil society criticise the level of overshoot of the 1.5˚C

Illustrative 1.5˚C pathways survive SPM approval

'Net zero' and NETs implemented as policy commitments towards the 1.5˚C

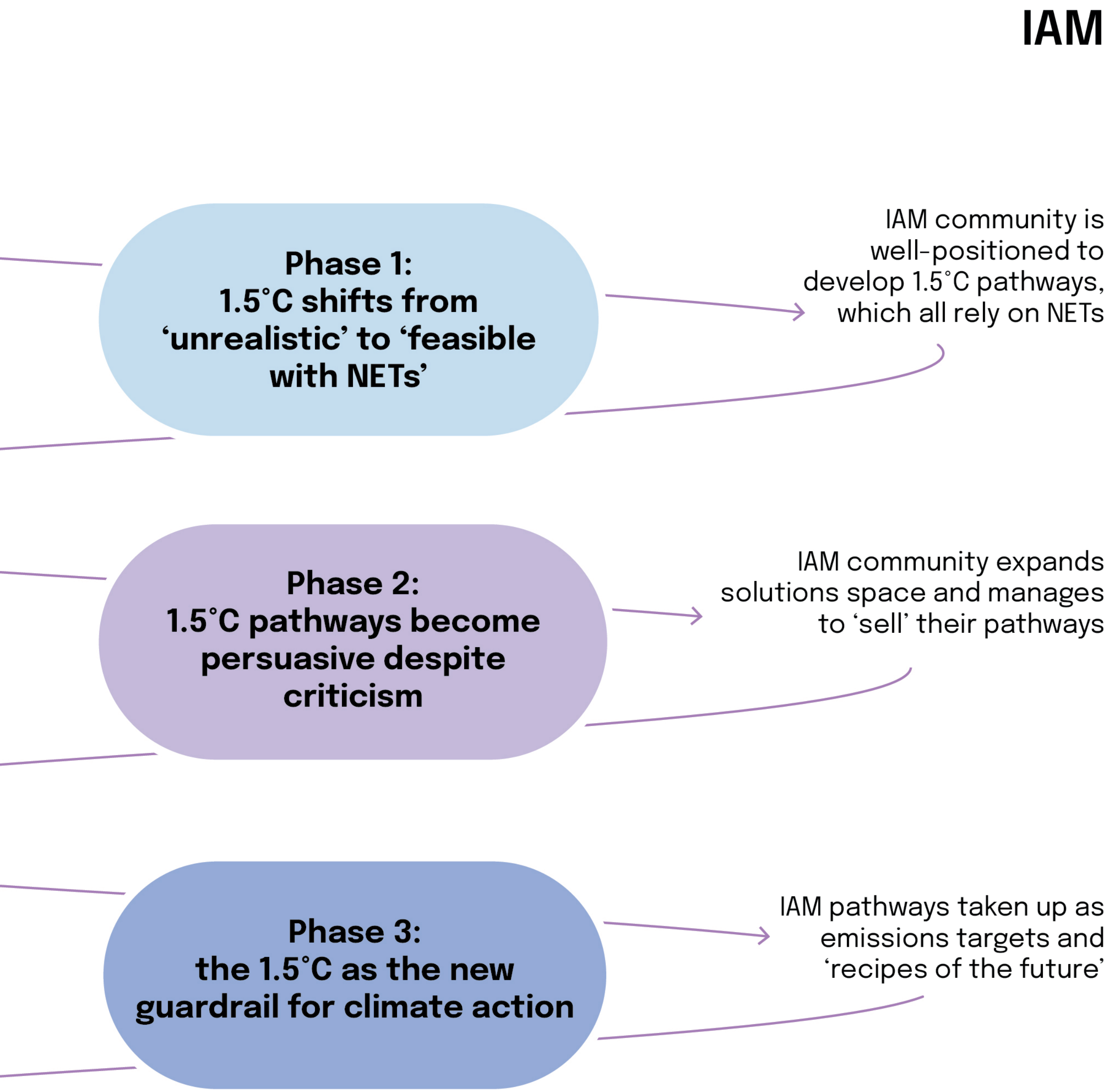


Figure 11. Overview of the sequence of science-policy interactions around the IPCC SR1.5 between 2015 through which the 1.5°C goal increasingly gained traction.

3.4.4 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, Shrader-Frechette & Belitz, 1994). The extent to which model behaviour reproduces historic or 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 modellers.

3.5. 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 shifted 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 & Pelzer, 2018; Oomen et al., 2021), we explained the role of IAMs 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; chapter 2);

→ 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; chapter 2); 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 on policymaking 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 policy 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.

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.

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 & Kowarsch, 2015; Beck & 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 in the context of the IPCC SR1.5, modellers explored more demand-side mitigation options to reduce the use of NETs. However, more radical 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 & 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 radical transformative pathways that contain politically challenging but potentially crucial low-carbon strategies.

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. chapter 2; Porter, 1996). 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.

3.6 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 & Mahony, 2017; Beck & 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 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 & Mahony, 2018b; Beck & 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 & 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 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.

Part II

How the possibility space might be pluralised and democratised

4.

Opening-up plausible futures through an interaction with climate fiction

Abstract

IAMs are critical tools to explore possible pathways to a low-carbon future. By simulating complex interactions between social and climatic processes, they help policymakers to systematically compare mitigation policies. However, their authoritative projections of cost-effective and technically feasible pathways restrict more transformative low-carbon imaginaries, especially because IAM pathways are often understood in terms of probability rather than plausibility. We suggest an interaction with climate fiction could be helpful to address this situation. Despite fundamental differences, we argue that both IAMs and climate fiction can be seen as practices of storytelling about plausible future worlds. For this exploratory chapter, we staged conversations between modellers and climate fiction writers to compare their respective processes of storytelling and the content of both their stories and story-worlds, focusing specifically on how they build plausibility. Whereas modellers rely on historical observations, expert judgment, transparency and rationality to build plausibility, fiction writers build plausibility by engaging with readers' life worlds and experience, concreteness and emotionally meaningful details. Key similarities were that both modellers and fiction writers work with what-if questions, a causally connected story and build their stories through an iterative process. Based on this comparison, we suggest that an interaction between IAMs and climate fiction could be useful for improving the democratic and epistemic qualities of the IAM practice by 1) enabling a more equal dialogue between modellers and societal actors on plausible futures, and 2) critically reflecting upon and broadening the spectrum of plausible futures provided by IAMs.

Published as:

Van Beek, L., & Versteeg, W. (2023). Plausibility in models and fiction: What Integrated Assessment Modellers can learn from an interaction with climate fiction. *Futures*, 103195.

https://doi.org/10.1016/j.futures.2023.103195

4.1 Introduction

The catastrophic impacts of climate change lend an urgency to the need for a rapid and radical transformation towards a low-carbon future. Countries have responded to this urgency by setting ambitious climate targets. In the context of global climate science and policy, low-carbon transformations are typically explored with model-based scenarios. More specifically, in assessment reports of the IPCC, global pathways towards the global climate goals are explored with IAMs. IAMs are computer simulation models that represent complex interactions and feedbacks between human developments and the climate system, which are explicitly designed to inform policymaking. Their representation of both the drivers and the consequences of environmental change provides policymakers an 'intuitive feel' of global change on long timescales and enables the systematic comparison of response strategies (Edwards, 1996; Weyant, 2017). Since early global modelling efforts in the *Limits to Growth* in 1972, IAMs have played a significant role in policymaking and are currently the primary approach to developing mitigation scenarios in IPCC assessments (chapter 2; Weyant et al., 1995, 2017).

With this growing prominence, IAMs have also been subject to increased scrutiny in recent years (Skea et al., 2021). A substantial share of the criticism is directed at their techno-economic bias and emphasis on CDR (Gambhir et al., 2019 for an overview). Recognising the uncertainties in their models, modellers typically describe their scenarios as 'plausible stories' (Van Vuuren et al., 2011, p. 9). However, these quantitative scenarios in authoritative IPCC reports tend to become more powerful than intended, resulting in a bias towards technologically feasible and cost-effective pathways in climate politics (Beck & Oomen, 2021). This bias is not solely the result of model capabilities, but is also, importantly, informed by the discursive context in which IAM modellers are situated (Ellenbeck & Lilliestam, 2019). In chapter 3, we coined the term 'political calibration' to describe how the imagined space of mitigation alternatives is continuously negotiated between modelling and policy communities. The IAM community currently responds to this situation by identifying gaps in their model structure and further model development, improving transparency, engaging with stakeholders and interacting with other scientific disciplines (see Keppo et al. 2021 for overview of critique and responses). For example, modellers increasingly explore lifestyle-oriented scenarios (Grubler et al., 2018; Van den Berg et al., 2019; Van Vuuren et al., 2018) and interact with transition scholars (Geels et al., 2016; Van Sluisveld et al., 2020).

We suggest an interaction with climate fiction as an additional future direction for the IAM practice to a) improve the *democratic* qualities of the IAM practice by opening the imagination to more diverse publics and b) to improve their *epistemic* qualities by stimulating reflection upon and expanding the spectrum of possible futures that modellers explore. Previous research has indicated that climate fiction could complement or inform IAM scenarios (Nikoleris et al., 2017). Various authors have pointed to the potential of narratives and storytelling to create, engage with and make sense of climate and energy futures (Galafassi et al., 2018; Milkoreit, 2016; Miller et al., 2015; Moezzi et al., 2017; Raven, 2017). Literary scholars use the term CliFi[25] to describe fiction that addresses possible consequences and strategies to mitigate or adapt to climate change (Johns-Putra, 2016 for an overview). While IAMs and climate fiction may seem contradictory in their aims and publics, we argue that both involve storytelling of plausible future worlds. The IAM community has been using storylines to combine qualitative and quantitative scenario components for decades, an approach formally introduced in the early 2000s as the story-and-simulation approach (Alcamo, 2001; Nakicenovic et al., 2000). The current key scenario framework underlying IAM analysis is the Shared Socio-economic Pathways (SSPs), which comprises global storylines describing plausible trajectories of human and environmental change (O'Neill et al., 2017). Storytelling is thus inherent to contemporary modelling. Modellers need a set of assumptions to run their models, which typically involves narrative characteristics (a sequential ordering of events from causes to outcome). These assumptions are then used by modellers to understand and 'tell stories' of how phenomena have arisen (Morgan, 2001, 2012). Models thus encompass some characteristics of storytelling, whereas fictional stories can be seen as models to the extent that they, too, are distilled representations of the world. Climate fiction could complement or inform the SSPs through the consideration of different human motivations in relation to climate change, the impact of taken-for-granted structural conditions, and the possibility of radically different futures (Nikoleris et al., 2017).

25 For the purposes of this chapter, we view climate fiction as a subgenre of speculative fiction, focusing on aspects or consequences of anthropogenic global warming (see John-Putra 2016 for a similar definition). Considering that we are interested in literary fiction as a practice and that our research involved fiction writers representing various literary genres, this broad definition spans multiple literary genres, including but not limited to science fiction.

To explore potential interactions between modelling and climate fiction, we staged a conversation between IAM modellers and climate fiction writers from the Netherlands and Sweden. Conversations were aimed at obtaining an emic understanding of the similarities and differences between their respective modes of storytelling and thereby exploring the possibilities for further interaction between IAMs and climate fiction. Building on the results of this workshop, here we compare the respective characteristics of IAMs and climate fiction in terms of both the process of storytelling and the content of stories and story-worlds. We compare how IAM modellers and climate fiction writers build future scenarios to better understand what the IAM practice could learn from climate fiction writing. First and foremost, with this comparison we aim to contribute to the scholarly debate on the biases of IAMs and their authority in climate politics (e.g. Beck & Oomen, 2021; Beck & Mahony, 2018a; chapter 3) by exploring new ways in which these problems might be addressed. Moreover, we bring insights into how storytelling might be deployed in climate research more generally (e.g. Moezzi et al., 2017; Nikoleris et al., 2017). We also aim to contribute to futures studies, most notably to a better understanding of how diverse futures practices engage with plausibility (e.g. Ramírez & Selin, 2014), and how imagined futures become persuasive (e.g. Oomen et al., 2021).

In the following sections, we first reflect on IAMs and climate fiction as representations of two 'cultures' of scenario building (cf. Ramírez & Selin, 2014). These cultures have epistemological and ontological differences and relate to their publics in different ways (section 4.2). We describe the conversation that we staged between modellers and climate fiction writers (section 4.3), before zooming in to compare first their respective processes of storytelling and then the content of their story-worlds (section 4.4 and 4.5). We end by proposing that an interaction between the practices can help to critically reflect on and expand the possible futures explored with IAMs as well as to build relationships between modellers and relevant publics.

4.2 Plausible and probable futures in a time of 'post-truth'

When considering possible futures, it is common practice to question whether they are probable or plausible, two terms that are used interchangeably in everyday language. However, whereas probable describes something that is likely to be the case or to happen, 'plausibility is defined as the quality of seeming reasonable or probable' (Ramírez & Selin, 2014, p. 65). Plausible, in other words, can be used to describe something that merely appears to be probable, without this necessarily being the case. As a term based on statistics, the notion of probability corresponds to its associated epistemology, using mathematical calculus to determine whether an expected occurrence is normal or exceptional, likely or unlikely (Ramírez & Selin, 2014). In contrast, describing something as plausible – which has etymological roots in the Latin verb *plaudere*, to applaud, immediately raises the question of the intended audience. Plausibility is not only determined by physical laws but, importantly, also assessed by publics who will judge whether something seems reasonable or credible based on their knowledge, experience, and values.

It could be argued that, whereas climate fiction typically aims for plausibility, IAM modelling belongs to a tradition of probability, even though modellers themselves avoid casting their scenarios in probabilistic terms. Modellers base expectations of future occurrences on systematic observation of socioeconomic, technological, and environmental trends (Moss et al., 2010). For example, observed links between economic growth and emissions are used to project possible future emissions trajectories. Modellers are well aware of the multiple forms of uncertainty connected with their models (Meadows et al., 1982; Rotmans & van Asselt, 1999). The IAM community defines a scenario as a 'plausible, comprehensive, integrated and consistent description of how the future might unfold [...] while refraining from a concrete statement on probability' (Van Vuuren et al., 2014, p. 377). In other words, modellers typically view their own work as dealing with plausibility rather than probability.

However, the authority of IAMs is rooted in the formal expertise of a positivist quantitative tradition (Edwards, 2010; chapter 2). As a result, even groups who feel at home with quantified scenarios such as climate researchers and policymakers seem to blindly 'trust the numbers' (cf. Porter, 1996). This arguably applies even stronger to other societal actors such as the media and citizens who are less familiar with scenarios but are increasingly engaged in the climate debate. The IAM pathways in the IPCC Special Report on 1.5°C (2018) for example, were interpreted by journalists as 'recipes for the future' rather than 'illustrative' futures (chapter 3). Moreover, climate researchers disproportionally use the middle-of-the-road scenarios as opposed to more extreme ones (O'Neill et al., 2020). Although the comparison of baseline projections to climate policy scenarios makes perfect sense from a modelling perspective, given that their function is to provide insights into the effects of climate policies, the prominent use of baselines implicitly suggests a higher probability. All this results in a somewhat paradoxical situation: modellers typically view their own work as dealing with plausibility, but relevant publics tend to view IAMs through the lens of probability.

In contrast to modellers, fiction writers are seldom asked about the likelihood that their story will come true. But it is crucial to most types of climate fiction that readers find the story – however improbable – at least plausible enough to keep on reading. The eighteenth-century invention of the novel allowed writers to let go of the pretence that their stories were merely a retelling of real events, while at the same time confining them to a tightly circumscribed realm of credibility. Most contemporary (climate) fiction relies on the so-called suspension of disbelief, which describes the willingness of an audience to temporarily treat what it knows to be fiction as a bracketed truth. This fictional truth is bracketed, because even when the audience is transported by the story, it can still distinguish between the surrounding reality and the fiction of the story – few people will be tempted to call the police when encountering a murder in a detective novel. This has not always been the case. Prior to the eighteenth century, a nominally believable story would have been far more likely to be treated as an account of actual events, with the consequence that its author might be accused of slander or fraud. 'Plausible stories are [...] the real test for the progress of fictional sophistication' (Gallagher, 2006, p. 339). Such fictional or imaginative sophistication became crucial for modern society, not in the least for the consideration of possible futures for the individual subject: 'almost all of the developments we associate with modernity – from greater religious toleration to scientific discovery – required the kind of cognitive provisionality one practices in reading fiction, a competence in investing contingent and temporary credit' (Ibid., p. 347). Contemporary fiction has thus always been a means to engage with uncertainty; it is 'at ease with what if-scenarios' (Caracciolo, 2022, p. 26). This applies perhaps even more to climate fiction, which explicitly focuses on near or distant possible futures.

Cognitive provisionality might seem to be the last thing needed for an appropriate response to the mounting problems caused by climate disruption. Trying to mix science and fiction can easily be seen as playing into the hands of those with a vested interest in the denial of climate disruption, which seems especially risky now that the authority of facts is frequently considered to be under threat (Groves, 2019). There are also practical problems. Fictional approaches to possible climate futures differ in important respects in their conceptualisation of climate change from those taken by modellers. IAM modellers approach the climate change problem as a 'CO2 emissions gap': a difference between projected emissions levels based on current policies and desired levels consistent with the Paris Agreement (UNEP, 2022). Writers of climate fiction, on the other hand, tend to treat climate change as a cultural phenomenon that reshapes how we think about ourselves and our place on Earth (Armitstead, 2021; cf. Hulme, 2009). Such ontological differences pose challenges to the combined deployment of IAMs and fiction: the mathematical structures in IAMs leave little room for the ambiguity associated with climate change in fiction. But, as Hulme (2012) has pointed out, it is only through making explicit the typically unquestioned ontological assumptions about climate change that it becomes possible to see which epistemologies are appropriate to reveal it. If it is true that 'the meaning of climate change remains ineffable, incapable of being predicted through numbers or reduced to words' (Hulme, 2012, p. 19), it might be precisely the difference in worldviews and epistemologies that makes the effort to draw words and numbers together so worthwhile (Nikoleris et al., 2017).

Moreover, recent publications suggest that a rapprochement between words and numbers, between plausibility and probability, is already underway in the relevant disciplines. A wealth of research has already been conducted into the possible uses of narrative when thinking about, or trying to intervene in, processes of climate change (see, for instance, the Special Issue of Energy Research and Social Science (2017) devoted to this topic). Within the field of climate change research, there have been calls to represent uncertainties regarding the physical aspects of climate change through an approach that is more plausibility-oriented than the current probabilistic approaches (Shepherd et al., 2018). On the other end of the spectrum, cognitive narratologists have started to suggest the relevance of probabilistic thinking in readers' understanding of fiction. When engaging with a narrative, readers start out with beliefs about the fictional world in question, which they will revise as the narrative develops through a process of Bayesian inference (Kukkonen, 2014). Building on this work, Janasik (2021) suggests that when a scenario is perceived as plausible, the construction of feedback loops between the mind-body of the reader/listener and the fictional story proceeds with relative ease.

All of this suggests that the boundaries between storytelling through words and modelling through numbers might be more porous than they appear at first sight, which provides a basis for further exploration. How do practitioners themselves describe the storytelling that they are engaged in?

In the next part of the chapter, we first describe the characteristics of the workshop that we conducted with modellers and fiction writers to learn more about their respective practices (section 4.3). We then compare the respective storytelling practices of modelling and fiction writing in terms of the process of storytelling (section 4.4) and the content of the resulting story-worlds (section 4.5).

4.3 Methodology: staging a conversation between modellers and fiction writers

4.3.1 Data collection and analysis

To stage a conversation between modellers and climate fiction writers and enable them to reflect on their differences and similarities in terms of storytelling, a workshop was organised on March 4, 2020 in Utrecht. This workshop was held in the context of the international research project CLIMAGINARIES and attended by approximately forty participants from Sweden and the Netherlands.[26] We invited modellers from the Netherlands Environmental Assessment Agency (PBL) that are currently or were formerly affiliated with IMAGE modelling team as well as fiction writers with experience in writing climate fiction. Furthermore, we created an open invitation on social media for participants to attend. As part of this workshop, we conducted live interviews for which participants split into four groups. Each group included one modeller, one writer, an interviewer and a note-taker, along with additional workshop participants. The participants included interested individuals, such as academics, students, artists and business representatives, who contributed to the conversation through questions and observations. The interviewers conducted a thirty-minute interview with both the writer and the modeller in their group, following a pre-structured interview guide. The interview guide included the following aspects of the *process* of storytelling – how a story/scenario is built (starting point, collaboration, guiding principles) and the process of story/scenario development (daily practice, moments of frustration/inspiration) – as well as the *content* of the story-worlds – qualities of a good story/scenario (e.g. contingency, outside influences) and typical characteristics of storylines (e.g. temporality, actors). After the interviews, we allowed space for an unstructured interaction between participants (modellers and writers). The interviews and conversations were recorded and transcribed, then analysed to identify the main differences and similarities between modelling and fiction writing. We then interpreted these main findings to understand how these characteristics shape the way plausibility is built and constrained, using

26 CLIMAGINARIES was a three-year research project initiated in September 2018 and financed through the Swedish research council FORMAS. It aimed to advance the understanding of imaginaries as means through which to catalyse the forms of political, economic and social responses required for transitioning to a post-fossil fuel society.

relevant literature on modelling and fiction writing to arrive at a final comparison of process (Table 2) and content (Table 3).

4.3.2 Biases and methodological limitations

Our interest in developing a comparison between modelling and fiction writing was sparked by a single workshop involving a limited number of IAM modellers and (climate) fiction writers. Their statements offer rich material about their practices but are not necessarily representative for climate fiction and the IAM practice. The invitation policy for the workshop probably resulted in a selection of participants that already had an interest in possible overlaps between the respective fields, and modellers and fiction writers may have been inclined to seek similarities rather than differences. We address these limitations by placing their statements in the context of relevant literature on modelling and literary fiction, building as well on our own respective backgrounds in IAM research and fiction writing to better understand how plausibility is built. Our findings should thus be perceived as exploratory rather than a definitive systematic comparison.

4.4 Storytelling in IAMs and climate fiction: a comparison of process

The conversations with modellers and climate fiction writers involved questions regarding their world-building process, how their story develops over time and how they collaborate with others. Table 2 presents a summary of our findings.

4.4.1 World-building

World-building is the process of building a detailed and plausible imaginary world. This is crucial for all fiction, but especially for less naturalistic literary genres such as science fiction and fantasy. The relevance of world-building for IAM modelling might be less obvious. After all, models take the existing world as their starting point:

‘World-building is a given, I don’t have to start with it.’ (modeller 3)

‘Through increasing amounts of data, more and more complex models become possible. These models attempt to tell a true story about the world.’ (modeller 4)

The latter quote illustrates that IAMs represent reality as a system of interactions between climate and society, constructed through historical observations of global trends. Moreover, IAMs are rooted in mainstream economics, with a strong emphasis on cost-effectiveness and technological change. This has implications for the ‘policy stories’ that can be told with IAMs (Beck, 2018). The modeller must work within the parameters of the model, although these boundaries are not set in stone:

‘Some things are not possible in IMAGE and those are then crossed from the list. [...] it’s the balance between what is possible within the model but also challenging the model.’ (modeller 1)

At first glance, the seemingly unfettered freedom of the climate fiction writer seems very different from the given worlds with which modellers work:

‘Writers are artists, they just go their own way. You can’t really know where they will be going.’ (writer 3)

However, writers noted that their freedom is not unlimited: fictional world-building happens within constraints. Plausibility in mimetic or realistic fiction requires narratives to relate to their readers’ lifeworld, including the specific perspectives and knowledge that publics bring to a story. Suspension of disbelief could be abruptly discontinued when, for instance, a character living in the 1970s suddenly starts typing on a small laptop. Plausibility thus depends not just on what is written, but on the interaction between text and reader. As Welsh (1953) puts this, although he objected to using the term plausibility in relation to fiction: ‘[w]hat we accept at any time, what a literary generation will accept, is always a complex of the beliefs and opinions of the day, the loose conventions of the particular kind of literature, and our needs and attitudes.’ (p. 107). In our example, many young readers might not notice the anachronism, simply assuming that small consumer computers were already around in that decade. Readers also rely on genre conventions to determine the plausibility of the story, though fictional norms for plausibility typically exclude some aspects of reality. Amitav Ghosh (2016) has pointed out that much ‘realist’ fiction in modern mimetic storytelling is ill-suited to deal with large-scale climatic events, because it adheres to its own conventions: typically focusing on the psychology of urban characters (ignoring the interaction between humans and the non-human environment), and backgrounding events that are deemed to be unlikely or exceptional. Ghosh's criticism is less applicable to most speculative fiction, a genre in which a more explicit focus on worldbuilding contributes to questioning the seemingly self-evident, socio-economically sanctioned parameters of what constitutes a plausible world (see also Oziewicz, 2017). Climate fiction can therefore be seen as resulting from near-future speculative fiction's 'fidelity to the real' (Robinson, 2016, p. 17). In this context, disruptions to plausibility can be deployed intentionally, for instance to achieve an effect of defamiliarisation (Shklovsky, 1917), cognitive estrangement or social criticism (Suvin, 1979; see also Pelzer & Versteeg, 2019 in the context of futuring). As noted by writer 1:

'A story is kind of a way of testing what will happen or what this relationship can say about the real world.'

The suggestion of a laboratory echoes the previously mentioned work by Gallagher (2006) and Kukkonen (2014). The experimental writer Donald Barthelme (1997) famously described writing as a 'process of dealing with not-knowing, a forcing of what and how […] The not-knowing is not simple, because it's hedged with prohibitions, roads that may not be taken.' (p. 12). Interestingly, modellers also describe their models as 'virtual laboratories' (Keppo et al., 2021). In other words, both modellers and writers seem to work with a modelled situation of uncertain future realities. Whereas models aim to simulate futures that are unknown or unexplored, they start from existing parameters and constraints that influence the spectrum of futures that can be considered.

4.4.2 Story development

A key difference in terms of story development was that modellers typically start broad and narrow down, whereas writers indicated that they start small and broaden out. Writers indicated:

'I often start with a specific situation' (writer 1)

'It can be something random on the street, someone doing something unusual […] but also media articles. For example something an academic said about California flooding and the setting up of barriers for people. […] it got me thinking about a story for a better way to adapt altogether' (writer 3)

'I start from a very narrow perspective […] It starts from an image: what if something happens? Example of a refugee frozen falling into a garden, which became a story about the garden guy having PTSD, seeing fallen angels, and building wings for people.'. (writer 2)

In contrast, modeller 1 indicated they start with a large range of possibilities and then narrow it down: 'with each step you start something new I have that same approach. Starting broad and then filter down'.

Another modeller made a distinction between explorative scenarios and target-based scenarios: 'explorative scenarios are often the ones, such as the SSPs, we don't know exactly where they will end up. […] We contrast that strongly with more target-based scenarios where we start with the question: what needs to happen to meet those targets?' (modeller 3).

Despite these differences, the quotes exemplify that both modellers and fiction writers ask 'what-if' questions to start their stories. As the quote by modeller 3 indicates, typical what-if questions explored by IAMs are: How might emissions trends develop if no climate action is taken? Which changes in the global energy system are necessary to achieve the Paris goals? As suggested by writer 3, such factual questions can be a starting point for fiction writers too. What-if questions asked in the context of climate fiction often describe the effects of systemic changes on the psychology and everyday life of individuals, but sometimes also involve a critique on the seemingly self-evident absurdities of the present (Pelzer & Versteeg, 2019).

Both modellers and fiction writers indicated that plausibility is built through an iterative process of responding to emergent questions:

'Knowledge develops gradually over time. There is always an emergent follow-up set of questions.' (modeller 3)

'Storytelling is gradual, with different prompts.' (writer 2)

Although the world of IAMs seems given, models still contain surprises even for the modellers. Contrary to what might be expected, modellers are not necessarily in full control of their story:

'Models are built from assumptions about variations, and ranges. You are never sure what story you are really telling.' (modeller 2)

'The model is huge and global, so there are areas unseen and unexplored and we can draw from that aspect […]. Models are interesting because they give a different result than you initially expected.' (modeller 3)

Thus, for both the modellers and fiction writers in our workshop, the relevant questions – including their narrative characteristics – emerged only through engaging with the model or the fictional story over time and through getting to know the areas that have not yet been explored. Both modelling and storytelling require processes of iteration in which plausibility is continuously evaluated.

4.4.3 Collaboration

During the workshop, we also asked both modellers and writers whether and how they collaborate. Fiction writers all noted they typically work alone. In contrast, contemporary IAM modellers often work in multidisciplinary teams, collaborating with many stakeholders from different backgrounds. This can complicate their work:

'[…] we are working in a multidisciplinary environment, you are actually always in conflict with someone to a certain extent. Because people want to do it their way.' (modeller 1)

On the other hand, their close collaboration in large modelling intercomparison projects, shared databases and consortia also hold the IAM community together (Cointe et al.,2019). Modellers work with a set of shared assumptions to enable model intercomparison: the SSP framework. Each of the five global storylines in this scenario framework is characterised by a set of assumptions in global quantitative parameters, such as population growth, food demand and energy demand. In the IAM practice, plausibility means that a scenario is 'judged as a plausible story of the future by experts' (Van Vuuren et al., 2011, p. 9). The SSPs were developed by a group of experts who judged the plausibility of how these global parameters may evolve as well as the capacity of different models to represent scenario characteristics (Riahi et al., 2017). Expert judgment is thus a key mechanism through which plausibility is built. Given that IAMs are situated in the science-policy interface, modellers are held accountable to both scientists and policymakers through a process of transparency. Apart from shared assumptions, transparency was another key mechanism of building plausibility:

'[It] needs to be transparent. You can't write an article and say: this just happened to be my inspiration.' (modeller 3).

Although writers typically work alone, it is important to note here that the difference between modelling and fiction writing in terms of collaboration is gradual rather than absolute. Like models, novels do not stand on their own, but draw upon a corpus of previously published texts and other depictions of fictional worlds and published novels are the result of networked, rather than individual efforts.[27] This means that, even when a professional author primarily follows her artistic integrity to build a plausible story, she cannot fully disregard the ways in which others, such as readers and editors, will read the work and judge its plausibility.

27 To such an extent that Swiss writer Martine Clavadetscher was hard pressed when asked at Next Frontiers 2021 to distinguish between the creativity of human writers and the regurgitation of materials by AI writers.

4.4.4 Comparison of process

Having explored the processes through which climate fiction authors and IAM modellers develop narratives of possible future worlds, we can note some obvious differences: writers typically work alone, modellers in a team; IAMs aim to provide policy advice, fiction does not; fiction engages with the lifeworld of its readers, IAMs depend on historic observations and expert judgment. But many of these differences are not as absolute as they seem at first sight. Writers of (climate) fiction may have more narrative freedom than modellers, but both groups build on the reservoir of previously issued stories and models and their success depends to an important extent on whether their stories are deemed plausible by their readers. Interestingly, we also found similarities between the two endeavours. Both writers and modellers engage in world-building and explore what-if questions; neither the writer nor the modeller is fully in control of the stories (s)he tells, and the plausibility of their stories develops gradually over time.

		IAMs	Climate fiction
Characteristics	World-building	World-building is given	World-building is more open, but not unlimited
		Engage with modelled situation of future uncertainties	Engage with modelled situation of future uncertainties
	Story development	Start broad and narrow down (explorative scenarios) or start narrow (target-based scenarios)	Often start narrow (e.g., from a situation, character, location) and broaden out
		Explore what-if questions	Explore what-if questions
		Iteration is crucial to development of story	Iteration is crucial to development of story
	Collaboration	Scenarios are typically developed through a process of cooperation	Fictional stories are typically developed by a single author, situated in a network
Plausibility	is built through	an iterative process of world-building and story development	an iterative process of world-building and story development
		historical observations, transparency and expert judgment	resonance or contrast with reader’s life world and experience

Table 2. Summary of the comparison of the process of storytelling

4.5. Storytelling in IAMs and fiction: a comparison of content

As discussed in section 4.3, we also asked modellers and fiction writers about the content of their stories, including what they view as qualities of a good storyline and characteristics of a storyline including the characters, plot and setting. This comparison is summarised in Table 3.

4.5.1 Storyline

Modellers often refer to themselves as 'mapmakers' who neutrally map out a wide range of different pathways towards a policy target with associated policy effects, which policymakers ('navigators') can navigate to make decisions (Edenhofer & Kowarsch, 2015; Edenhofer & Minx, 2014). Regarding the qualities of a good storyline, a modeller in our workshop responded that:

'The biggest thing for me is capturing a wide range of different possibilities' (modeller 1).

Given that modellers explicitly aim to inform policymaking, the boundaries of this 'wide range' are shaped by their interactions with climate policy (chapter 3; Lövbrand, 2011). The SSP framework for instance, consists of a 2 by 2 scenario matrix, with 'challenges to mitigation' on the x-axis and 'challenges to adaptation' on the y axis, which were deliberately chosen as being policy relevant (see O'Neill et al., 2017). As noted by modeller 3:

'Our work needs to be useful to make policy decisions upon. There needs to be a logic that explains to a policy-maker whether he needs to invest a certain amount of money.'

The latter suggests that plausibility is derived through 'logical' causal connections between parameters such as population growth, urbanisation, and technology development, such as the relationship between high carbon-intensive lifestyles and technological development (Riahi et al., 2017). Using narratives as explanatory logics is a key strategy for modellers to ensure this internal consistency of their scenarios.

Like modellers, fiction writers do not merely summarise series of events but order them to bring about the desired final effect of the story (LaPlante, 2007, p. 377). In that respect, fiction writers have more – albeit, as indicated above, not unlimited (Ghosh, 2016) – possibilities than modellers to describe change that is not a logical extrapolation of already existing developments. What is more, fictional narratives have the freedom in structure and form to engage with non-linear time (Davoudi & Machen, 2021) and indeed depend on this for plotting. A story can devote pages to a single moment, while skipping over years, thus running the gamut of ways in which humans experience time, including the past. Because of this different approach to time, the world that is sketched through fiction is less stable than the one portrayed through the causal mechanisms on which models are built. This is not without limitations. In our workshop, writer 2 noted that she can become dissatisfied with her story if it is 'no longer logical': the internal coherence of the storyline is crucial for it plausibility. What is more, because the provision of meaningful sensory details is crucial to help readers empathise with fictional characters, zooming out to incorporate a large timescale can diminish the resonance of the narrative.

4.5.2 Physical setting

Storylines developed by IAM modellers, such as the SSPs, are set in the 'generic world'. IAMs focus on understanding the order of magnitude of environmental change, as well as the interactions between societal and climatic developments on an aggregate level:

'A tension between modeller [and] the real world is that the model is always an abstraction–and usually something that tries to describe the whole world.' (modeller 4).

Although modellers are seeking increasing levels of detail and granularity in their models, they tend not to focus on specific localities. Indeed, one could argue that modellers build plausibility precisely through abstraction. For example, a majority of IAM-based mitigation scenarios presented in IPCC reports strongly rely on BECCS (see e.g. IPCC, 2018). Due to a lack of detail on specific localities, IAMs assume that various forest and savannah areas are 'empty lands' that can be used for bioenergy crops, whereas when looking more closely these scenarios are actually home to people and constitute of habitats (Creutzig et al., 2021, p. 513). In other words, while these scenarios seem plausible as viewed from a global level, the potential for bioenergy might be limited when looking at specific locations.

In contrast, fictional stories are typically set in a specific physical setting. As the American writer Eudora Welty put this (1997, p. 786-787), ‘place in fiction is the named, identified, concrete, exact and exacting, and therefore credible, gathering spot of all that has been felt, is about to be experienced, in the novel’s progress. Location pertains to feeling; feeling profoundly pertains to place; place in history partakes of feeling, as feeling about history partakes of place’. Precisely for this reason, concerns have been voiced regarding the sloppy rendering of ecological facts (e.g., placing a particular species in a place or habitat where it does not occur) (Fischer, 2011). It should be noted here that the relations between place-based literature and anthropogenic climate change are complex, as planetary warming challenges ideas about local versus global: it changes but can also reinforce bioregional characteristics and identities (Rosenthal, 2020: 273-274). Caracciolo (2022, p. 66) therefore points to the importance of asking readers to engage with ontologically unstable spatial story-worlds, to bring world concepts into alignment with the uncertainties of climate change.

4.5.3 Protagonists

To the extent that individual protagonists or characters are of importance in IAMs, they tend to be ‘average Joes’, as one of the modellers at our workshop put it. Traditionally, this average Joe is projected as a rational actor who makes decisions in isolation from others, equipped with faultless information and driven solely by utility. Having recognised this limited view on the complexity and heterogeneity of social change, modellers are currently expanding this range to include multiple ‘consumer groups’ and exploring how attitudes and beliefs underlying human behaviour could be better represented in IAMs (De Cian et al., 2020; van den Berg et al., 2019; van Sluisveld et al., 2020):

‘My work on lifestyles it is very much focused on the individual or collective group of individuals. I want to look at it from different types of groups and from that point of view you can tell a story that differs between individuals.’ (modeller 1)

In fiction, protagonists can act as first-person narrators of the story, but they are crucial for the focalisation (cf. Genette, 1980) of the story even when the writer chooses a different style of narration. Protagonists quite literally provide readers with eyes through which to experience an alternative world, allowing for a necessarily limited and therefore highly particular perspective on the narrated events.

In contrast to the modellers' 'average Joe's', characters in mimetic (climate) fiction are seldom wholly rational. Instead, they are driven by emotions and typically find themselves in conflict with either themselves, other characters, or the environment in which they find themselves. Especially in more complex forms of storytelling, characters tend to be complicated and morally ambivalent, overstepping 'readers' comfort zone, confronting them with perspectives and worldviews radically different from their own' (Lissa et al., 2016, p. 45). And yet they are transparent to the reader, because, as E.M. Forster (1974) argued, a character becomes 'real when the novelist knows everything about it. He may not choose to tell us all he knows […] but he will give us the feeling that though the character has not been explained it is explicable, and we get from this a reality of a kind we can never get in daily life.' (p. 69).

4.5.4 Comparison of content

Having explored the content of storytelling in IAMs and fictional stories respectively, we can see that they have different strategies for attaining plausibility (see Table 3 for a summary). In IAM scenarios, the abstract and generic future worlds as well as the rational actor are key mechanisms through which plausibility is built. In contrast, fictional narratives build plausibility through the perspective of the individual and the emotionally coloured description of tangible places. IAMs focus on global systems, but most (climate) fiction stories use the lens of focalising characters, with their specific experiences, as an entry point to understand large-scale societal developments. concreteness and emotionally meaningful details

4.6. Telling plausible stories of low-carbon futures: bridging IAMs and climate fiction

In the preceding paragraphs, we have identified several differences and similarities between IAMs and climate fiction in terms of both the process and content of storytelling. Whereas modellers' spectrum of imagined futures is constrained by the model structure, shared assumptions and policy relevance, writers have more – but certainly not unlimited – freedom to explore radically different futures. But

		IAMs	Climate fiction
Characteristics	Storyline	Capturing a wide range of equally plausible, policy-relevant scenarios	Ordering of events that achieves the story's desired final effect
	Physical setting	Generic world	Specific locations
	Protagonist	'Average Joe': rational actor driven by utility	Emotionally driven, complex but knowable characters
Plausibility	is built through	abstraction and rationality	concreteness and emotionally meaningful details
		causal relationships between parameters (e.g. GDP, energy use, etc.)	causal relationships between events conveying moral order

Table 3. A comparison of the content of storylines

both practices engage in world-building, building plausibility through an iterative process of asking what-if questions, and many of the differences between the practices seem gradual rather than absolute. This is perhaps not surprising, because storytelling is used not only to make sense of everyday life, but also in more systematic attempts to understand the world.

Our research is exploratory: a full comparison of the similarities and differences between the two storytelling modes requires a larger study. Such a study seems even more worthwhile because the complementary strengths of both practices seem to offer opportunities for interaction, that might help counteract the biases of IAMs and their authority in shaping the collective imagination of low-carbon futures. We suggest that such an interaction could contribute to 1) a more equal dialogue and the building of a relationship between modellers and societal actors and; 2) a critical reflection on and an expansion of the futures explored by IAMs.

1) Building more reciprocal relationships between modellers and societal actors

The authority of IAM scenarios is grounded in a sense of 'mechanical objectivity' (Hilgartner, 2000), which disguises the careful negotiations between modellers and policymakers on plausible futures (chapter 3). The quantitative characteristics and formal language of IAM scenarios makes it hard for societal actors to judge their plausibility. This situation is problematic from a democratic point of view, because IAM scenarios are becoming relevant for an increasingly diverse set of societal actors. Scholars have already emphasised the potential of narratives and storytelling to increase public understanding and engagement with complex climate science (Bloomfield & Manktelow, 2021). However, implicit in such recommendations is an echo of the knowledge deficit model, suggesting that publics will act upon received information if it is packaged the right way. In recent years, a shift can be observed towards more participatory forms of knowledge production which may ultimately be more resilient and comprehensive. This requires the building of relationships between climate experts, such as modellers, and relevant publics (Cook & Overpeck, 2019) – a process that is complicated, not in the least place because of differences in expertise and language use. We suggest that fictional stories can be used as a boundary object in this endeavour, levelling the interactional playing field and helping societal actors to judge the plausibility of the future worlds that IAMs project.

Whereas models are abstract, generic, and highly technical, fictional story-worlds provide the possibility to experience possible futures in specific settings through the eyes of emotionally recognisable characters. An example of how this could work in practice is through participatory world-building, such as found in Carbon Ruins (Raven & Stripple, 2021; Stripple et al., 2021). This performance involved a ' museum of the future' of a world set in 2053 in which the 1.5˚C goal had been achieved. The initiators consulted experts to provide parameters such as climatic changes, which provided the boundary conditions for fictional storylines around carbon objects that would become obsolete during this transition. Participatory world-building may allow for a combined deployment of modelling and fiction, drawing on multiple sources of plausibility. Interestingly, both the storylines – involving recognisable objects representing vernacular experiences – as well as the scientific facts were crucial for non-experts to judge the plausible future world as plausible (Stripple et al., 2021). This combined deployment may be facilitated by the fact that both modelling and fiction writers typically engage in an iterative process of story development. Whereas such combinations of science and fiction are far from accepted practice, they do fit into a broader trend of arts-based approaches in global environmental assessments, such as those used by the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) (Pereira et al., 2019).

2) Critically reflecting upon and expanding futures explored with IAMs

If an interaction between modelling and fiction can contribute to the *democratic* quality of the conversation, it may prove equally fruitful from an *epistemic* point of view. We have shown that scientific and fictional storytelling practices are situated on a continuum, with similarities in both process and content and yet enough differences to make the two approaches complementary. Our workshop indicated that modellers and fiction writers work within their own sets of constraints regarding the possible futures they can explore. The relatively larger freedom of climate fiction writers to speculate on possible future worlds offers opportunities to counteract the 'corridor of climate mitigation' that is characterised by predominantly techno-economic futures (Beck & Oomen, 2021). Fictional stories might help to broaden the spectrum of possible futures by pointing towards aspects that modellers would not necessarily pay attention to (see also Braunreiter et al., 2021).

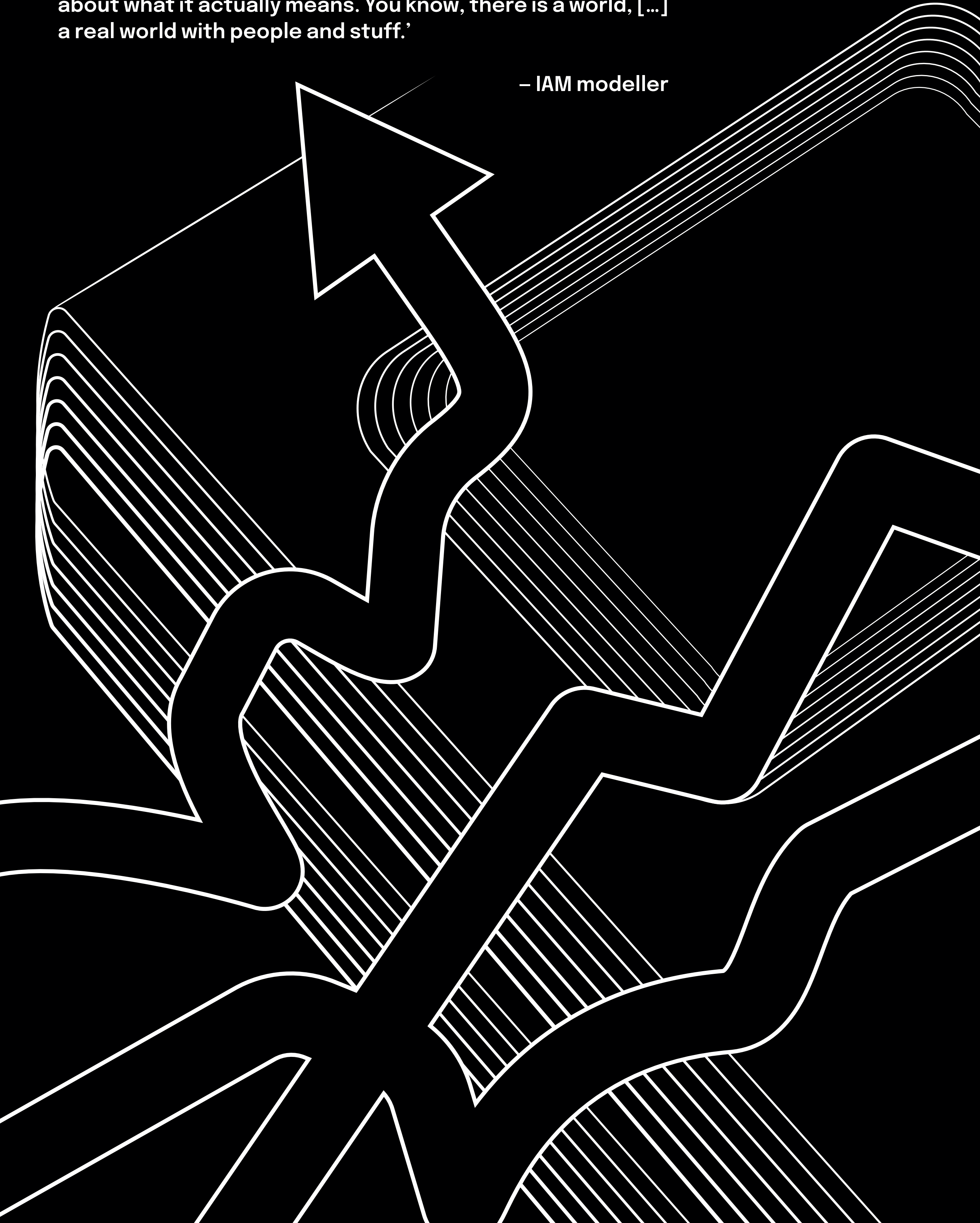
Broadening the possible futures modellers explore could arise from using existing climate fiction novels as inspiration to inform the SSPs, as suggested by Nikoleris et al., (2017). Another example of a potentially fruitful interaction might be to involve fiction writers in the development of these global storylines. The modelling community already increasingly engages stakeholders in their scenario development. Fiction writers' capacity to engage with locality may help to critically scrutinise the plausibility of IAM scenarios, whether the local consequences relate to the non-human parts of our biosphere (e.g. the effects of extreme weather events on different types of people) or to the policy measures taken in reaction (e.g. changes in spatial ordering necessary for climate adaptation). Moreover, in fictional stories, readers experience future worlds through the eyes of characters with diverse motivations and perspectives. As such, fictional story-worlds can thus sketch a more complex image of human agency than the focus on rationality and utility currently used in IAM scenarios (see also Otto et al., 2020). This may be helpful to critically scrutinise the assumed rationality of the 'average Joe' and may also expand the range of modelled futures to those involving non-linear social dynamics.

The epistemic and democratic goals as sketched above are interrelated. Though difficult to attain, they are crucial to strive for now that it has become clear that the authority of IAMs risks that transformative imaginaries become foreclosed (Beck & Oomen, 2021). Or, as stated by Oreskes et al. (1994) 'a model, like a novel, may resonate with nature, but is not a 'real' thing. Like a novel, a model may be convincing – it may 'ring true' if it is consistent with or experience of the natural world. But just as we may wonder how much the characters in a novel are drawn from real life and how much is artifice, we might ask the same of a model.' (p. 644).

Ideally, one could envision an interaction between modellers, fiction writers and societal actors characterised by productive discomfort (Ramírez & Selin, 2014): an interaction that is not necessarily convenient for participants, but allows for the challenging of clichés and the reframing of solutions if necessary. As Groves (2019) argued, there is a need to reconsider the proper role of scientific evidence in debates surrounding the response to anthropogenic climate change and bring a broader range of political and ethical values into the debate to consider the question what constitutes unacceptable loss. In this endeavour, there seems to be an unused potential for an interaction between modelling and fiction writing that stretches far beyond science communication. Climate fiction can induce reciprocal relationships between modellers and relevant publics and critically reflecting upon and expanding the range of storylines of possible futures. Although admittedly not without challenges with regard to ontological and epistemological differences between modelling and fiction, this potential provides a perspective on the future and its relation to present decision-making that is not only richer, but ultimately also more robust and relevant.

'Sometimes you can get lost in calculations and just forget about what it actually means. You know, there is a world, […] a real world with people and stuff.'

– IAM modeller



5.

The Future Models Manual: how artists can incite reflective modelling practices

Abstract

In global climate politics, transformations towards a low-carbon future are typically explored using IAMs. Because of their growing prominence and political influence, critics argue for the need for a more 'reflective' modelling practice. To date, modellers' reflection remains mostly focused on the gaps and limitations of IAMs. In this chapter, I argue that artists may stimulate reflection in ways complementary to academic critique. I report on a collaboration with two artists-in-residence who engaged with an IAM team through group discussions, workshops and interviews that culminated into an artistic intervention: the *Future Models Manual*. This speculative manual takes modellers on a journey through different steps to reflect upon their practice and also help reconsider it. A key finding is that not just the manual itself, but the interactions between modellers and artists that informed its development already incited reflection. Drawing on personal observations and follow-up interviews, I observe how the artists stimulated reflection among IAM modellers by asking unfamiliar questions, identifying generative metaphors describing modelling, and developing visual artefacts. The findings suggest that continued art-modelling collaborations may be fruitful to foster further reflection. However, this potential might be challenged by conflicting views on how artists and scientists should collaborate, both on the part of artists as well as on the part of scientists. Whereas artists explicitly aspired to challenge and transform the meaning and purpose of IAMs, modellers continued to view artists as a means to improve their communication to lay publics. I conclude that while art-modelling collaborations may be fruitful to open-up the possibility space of low-carbon futures, this requires a move from an instrumental approach towards a more reciprocal interaction between modellers and artists.

To be submitted to a peer-reviewed journal.

5.1 Introduction

In the context of global science and policy, pathways towards a low-carbon future are typically explored through model-based scenarios. More specifically, IAMs constitute the primary means of developing global mitigation scenarios by the IPCC. Using mathematics and systems thinking, IAMs represent complex interactions between society and climate change. This capacity to deal with feedback loops and second and third order effects enables policymakers to understand the speed and scope of necessary mitigation and the consequences of different policy pathways. Over the past decades, IAMs have co-evolved with global climate policy (McLaren & Markusson, 2020; chapter 2). IAMs are currently the primary way of constructing global mitigation pathways and have been foundational in putting climate change on the global policy agenda and setting climate targets, including the 1.5°C temperature limit and more recently mid-century net-zero emissions targets (Livingston & Rummukainen, 2020; chapter 3).

With their growing prominence, IAMs are also increasingly criticised (Skea et., 2021). Much of the criticism revolves around the reliance of IAM modelling on CDR (Gambhir et al., 2019 for a review). IAMs are also criticised for their limited ability to account for diverse justice principles (e.g. Jafino et al., 2021; Rubiano Rivadeneira & Carton, 2022). Others have raised concern that their focus on technical feasibility and cost-effectiveness and prominent position in IPCC reports forecloses certain imaginaries of low-carbon futures and social and ethical concerns (Beck & Oomen, 2021; Beck & Mahony, 2018a). The IAM community is addressing some of these criticisms, for instance by exploring lifestyle scenarios (e.g. van den Berg et al., 2019) and interacting with other disciplines such as transitions scholars (e.g. van Sluisveld et al., 2020).

Nevertheless, given their biases and political influence, critics call for a more 'reflective' IAM practice, including reflection on the justice implications of modellers' assumptions (e.g. Rubiano Rivadeneira & Carton, 2022), the discursive structures that shape these assumptions (e.g. Ellenbeck & Lilliestam, 2019) and how stakeholders are involved (e.g. Low & Schäfer, 2020). IAM modellers are already critically investigating the gaps and limitations of their own models (see e.g. Van Vuuren et al., 2011; Gambhir et al., 2019; Keppo et al., 2021). However, so far this critical self-reflection remains predominantly focused on the gaps and limitations of IAMs, lacking a deeper reflection on how assumptions are shaped by underlying worldviews (e.g. Keepin, 1984;

Thompson, 1984), the ethical implications of such assumptions (e.g. Beck & Krueger, 2016), their influential role in shaping policy and society (e.g. Beck & Oomen, 2021; Turnhout et al., 2016) or the ontological and epistemological underpinnings of simulation modelling (e.g. Oreskes et al., 1994; cf. Winsberg, 2010). Perhaps the most reflective exercise so far that addressed these more fundamental concerns has been *Groping in the Dark* (Meadows et al., 1982). In this exceptional book – both in terms of both content and form – modellers look back on the first decade of their practice and discuss what global modelling is (and what is not), what the models can and should be used for (and not used for) and the difficulties that modellers face regarding uncertainties and societies' expectations.

Academic criticism, interdisciplinary exchange and stakeholder engagement are arguably valuable means of reflection among modellers already. However, in this chapter I argue that artists may stimulate reflection in complementary ways. Empirical work reveals for example that arts-based approaches in relation to sustainability can foster new forms of reflection through 'beyond-cognitive' experiences, such as art installations that stimulate reflection on the meaning of sustainability and can help to create 'safe spaces' for inclusive discussion that allow for vulnerability and 'deep sharing' (Bendor et al., 2017; Galafassi et al., 2018; Heras et al., 2021). Lash (1993) made a similar argument that the arts can foster an 'aesthetic' form of reflection on modernity through the use of symbols, images and sounds that draw on intuition and imagination rather than analysis and theory. Moreover, by working from different paradigms, artists can inspire scientists to rethink existing assumptions and methods (Heras et al., 2021; Rödder, 2017).

Given these abilities, this chapter explores the potential of bringing in artists to foster a more reflective IAM practice by reporting on an art-science project that I initiated, involving two artists-in-residence who engaged with an IAM modelling group through group discussions and interviews, which resulted in a speculative manual: the *Future Models Manual*. This manual, in the form of an interactive website, takes modellers on a journey through different steps to reflect on the meaning, use and political influence of IAM modelling and propose suggestions for alternative forms of imagination and collaboration. Although the project was not initially intended to stimulate reflection, this became more and more central throughout the course of the conversations and the development of the artistic intervention. This chapter aims to better understand how the artists stimulated reflection among IAM modellers compared to existing means of reflection, by drawing on personal observations and follow-up interviews. I draw on theoretical accounts on reflection (Beck, Giddens, & Lash, 1994; Forester, 1999; Schön, 1983) and art-science collaborations (Barry et al., 2008; Born & Barry, 2010; Gabrys & Yusoff, 2012) to interpret and critically scrutinise the findings.

First and foremost, these insights contribute to the debate on the prominence and limitations of IAMs (e.g. Anderson & Jewell, 2019; Beck & Oomen, 2021; Gambhir et al., 2019). Rather than reiterating calls for a more reflective IAM practice however, the chapter explores possible a new way in which reflection might be brought about; by bringing in artists. The chapter also offers empirical insights to the growing literature on artistic practices and art-science collaborations in the field of climate change and sustainability (e.g. Gabrys & Yusoff, 2012; Galafassi et al., 2018a; Heras et al., 2021; Rödder, 2017). Art-science collaborations on climate change are upcoming and highly diverse. Some argue that art-science collaborations are most fruitful when the arts are not solely viewed as a means to communicate science, but as a way to challenge and transform scientific practices (e.g. Born & Barry, 2010; Gabrys & Yusoff, 2012; Galafassi et al., 2018b). This chapter particularly contributes to this literature by investigating the 'logics' of interdisciplinarity that were reflected in the collaboration and the associated opportunities and challenges (cf. Barry et al., 2008; Born & Barry, 2010).

In section 5.2, I first introduce the project. Before turning to the analysis of the collaboration (section 5.4), I first introduce the relevant theoretical accounts on reflection and art-science exchanges that I used to interpret the findings. The detailed analysis of how the artists stimulated reflection (section 5.4) is followed by a discussion on the conditions and challenges of art-science collaborations through a reflection on the logics of interdisciplinarity (section 5.5). Here, I also discuss the methodological challenges. Section 5.6 concludes with the key lessons learned and suggestions for future directions.

5.2 An introduction to the project

In this section, I provide the background and aim of the project (5.2.1), a description of the process of the art-science collaboration (5.2.2), and an overview of the manual (5.2.3).

5.2.1 Background and aim

I initiated this art-science collaboration in response to the drawbacks of IAMs, most notably their techno-economic bias and the need for alternative low-carbon imaginaries (see chapter 1). The project built upon previous insights regarding the tight coupling of IAMs and global climate policy (chapters 2 and 3) and the potential of initiating interactions between IAMs and the arts (chapter 4). Based on the experiences with bringing modellers into conversation with fiction writers (chapter 4), a central 'hunch' was that bringing in artists would help to open up the imagination of alternative futures. For the sake of transparency, I describe my personal involvement in the project in Box 1 (see also section 5.5.1). I deliberately framed the project proposal quite openly to explore what artists might bring, but what this proposal did specify was that the artists would closely collaborate with me and have direct access to the IMAGE modelling team at Utrecht University. The IMAGE team is one of the six main global IAM teams that have historically contributed and still contributes significantly to IPCC assessments. Another specification was that the project would result in an 'artistic intervention', without making explicit what this intervention should look like. The reason for this requirement was an assumption that such a goal would stimulate a generative art-science collaboration and would make outcomes of this project tangible. The idea of an artistic intervention was also inspired by successful experiences of the Urban Futures Studio to work with artists, which resulted in a number of generative interventions, including *2050 – An Energetic Odyssey* (Hajer & Pelzer, 2018) and the *Post-Fossil City Contest* (Pelzer & Versteeg, 2019).

5.2.2 A description of the process

As illustrated in the timeline in Figure 12, the project started with a call for artists, which I drafted in collaboration with my supervising team and coordinators of the Jan van Eyck Academy. The latter provided support in drafting the call, distributing the call, selecting artists and provided support in the design of the intervention. The project served as a 'pilot project' to explore collaborations between the Jan van Eyck Academy and the Urban Futures Studio, based on their mutual interest in the climate crisis and ongoing initiatives to bring together artists and scientists around this topic (e.g. the 'Working Group IV', involving various symposia on the role of the arts in climate science). Based on artists' ideas for the collaboration, experience with art-science collaborations and affinity with the topic, two artists were selected

Box 1. Description of personal involvement

The art-science collaboration was fully embedded in this PhD thesis. The idea of an art residency was already included in the outline of the PhD trajectory from the start, which was part of the *CLIMAGINARIES* project. I developed a first proposal of what this collaboration might entail and refined this in collaboration with my supervising team, including an IAM modeller and two other academics with experience in staging art-policy interactions. This project proposal did not specify what my role would be, but on the first day the artists and me decided to work as a team in the artistic research process, where the artists took the lead in deciding the course of the collaboration while I mediated between the artists and the modelling team. The artists defined the set-up and topics of the artistic research, the interviewees and the topics of the group discussions and designing the artistic intervention and I assisted them by pointing to relevant academic sources, organising the group discussions and interviews, posing follow-up questions during these interviews and discussions and suggesting ideas for the artistic intervention. This proved a synergetic collaboration as the artists worked with a more open-minded mindset and worked with different approaches and research methods (see section 5.4) while I could make suggestions on how to best engage with the modellers based on my experience. This mediator role also meant continuously navigating between ensuring artistic freedom (by not pushing the artists in any direction) and ensuring relevance for the modellers (to keep them engaged in the process). Arguably, this mediating role was crucial for its success as it facilitated mutual understanding and engagement in the process. Although I never imposed my views on either the modellers or the artists, by participating in the conversations and the artistic research, the outcomes necessarily reflect my views on modelling. Because we worked as a team, the roles of scientists and artists at times became blurred, which makes it difficult to distinguish my own role in stimulating reflection from the roles of the artist duo. I therefore specifically focus the particular capacities of the artists compared to critical social scientists like myself.

(hereafter referred to as artist 1 and 2). The collaboration started with a kick-off day with introductions to the modelling team, the Urban Futures Studio and developing a project plan. The artist duo proposed a work schedule of four months of artistic research and two months of designing the intervention. They proposed to approach their artistic research on the IAM community through four metaphorical entry points: modelling as ‘translation’ (from physical phenomena to policy

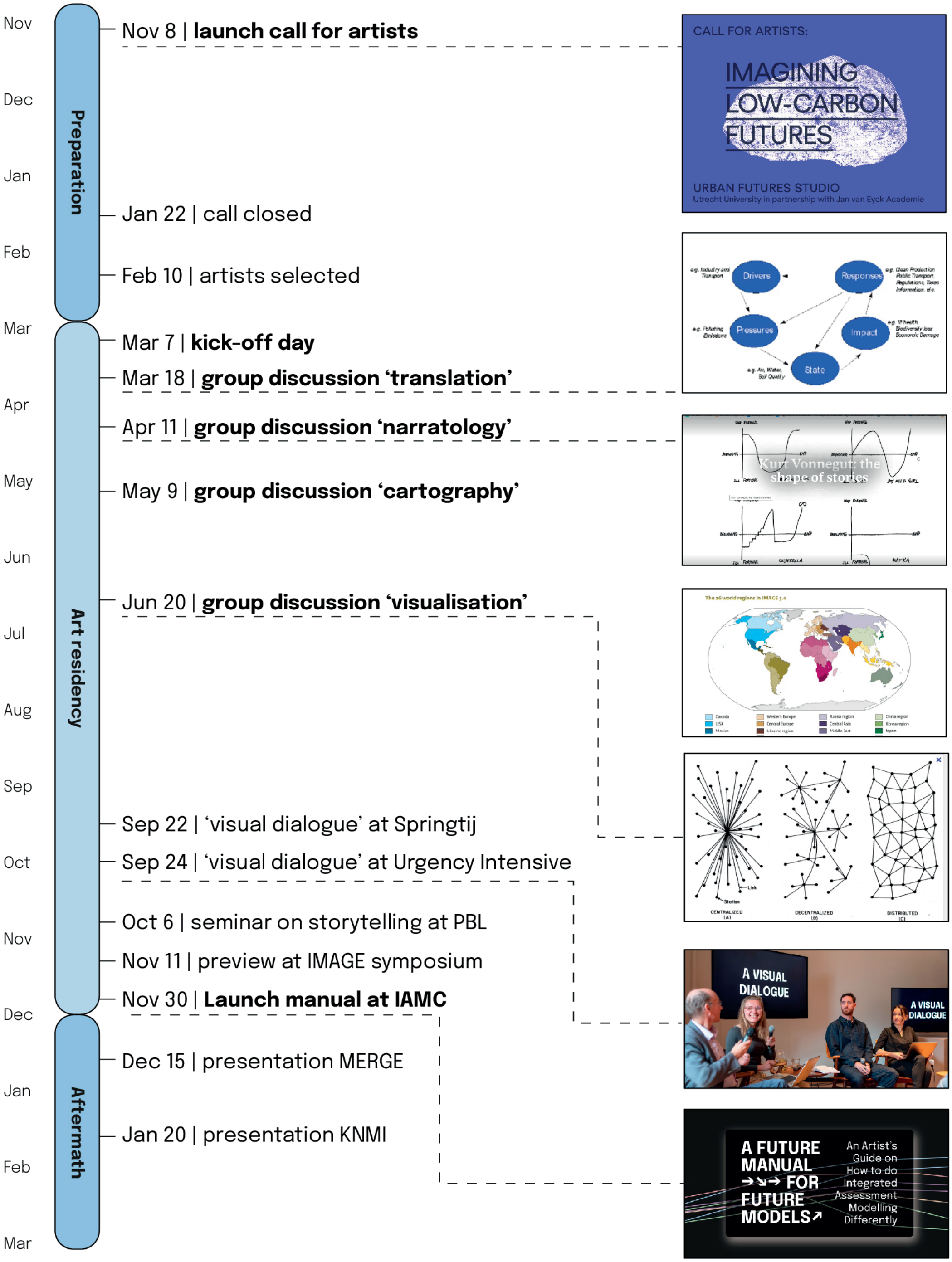


Figure 12. Timeline of the art-science project

legible outputs), modelling as 'narratology' (telling stories of possible worlds), modelling as 'cartography' (making maps of the world) and modelling as 'visualisation' (graphic representation of data). The artistic research involved desk research, 16 individual interviews with IAM modellers and non-modellers and four group discussions with the IMAGE team. The interviews with IMAGE modellers were aimed at generating insights into and perspectives on the IAM practice. The interviews with non-modellers involved journalists (aimed at better understanding how IAM results are interpreted and used) and artists/designers (aimed at insights into possible ways to approach the artistic intervention).

The four online group discussions were chaired and prepared by the artist duo. In each group discussion, the artists showed various images related to one of the four themes on a virtual whiteboard and asking modellers to reflect (section 5.4.3 for more detail on these images). As shown in the timeline (Figure 12), we organised three workshops to test out initial ideas and themes for the artistic intervention with diverse sets of actors. Two of these events involved a 'visual dialogue', where an IAM modeller and the artist duo were on stage in front of an audience: the modeller presented images on a screen, followed by 'counter images' presented by the artist duo on a second screen (see Figure 13 for an example). The visual dialogues were held at Springtij, a forum for sustainability professionals at the island of Terschelling, the Netherlands, and at the Urgency Intensive, a yearly seminar organised at the Jan van Eyck Academy in Maastricht, the Netherlands. We were also invited to organise a workshop at an event organised by the PBL Netherlands Environmental Assessment Agency (hereafter PBL) and The Integrated Assessment Society (TIAS) on the contested status of knowledge in society ('post-truth'). This hybrid event was attended by a diverse range of Integrated Assessment (IA) researchers including IAM modellers and other environmental modellers and researchers. In this workshop, the artists engaged IA researchers in a storytelling exercise to develop a story that is in line with modellers' global storylines known as Shared Socio-economic Pathways (SSPs; O'Neill et al., 2017) that describe global futures of human development including population, land use, urbanisation and consumption.

Throughout the collaboration, the artists came up with various ideas for the artistic intervention, which the artists and I discussed together, with my supervising team and the Jan van Eyck Academy. One of these ideas was to develop a manual for modellers, which emerged from the artists' observation that no manual on how to do IAM modelling existed. This inspired them to develop a speculative manual on what IAMs could be from an artists' perspective. A first outline of the steps and narrative of the manual was proposed by the artists, which they discussed with me, followed by a draft version of each chapter that was sent to a few members of the IMAGE team for feedback. This iterative process was intended to ensure that the text would not contain any misinterpretations or false claims, that nuance was provided where needed and to ensure that the manual would be critical enough while also being inspirational. A few modellers were interested and participated in this iterative process. The manual was launched at the annual meeting of the Integrated Assessment Modelling Consortium (IAMC). The artists and me considered this conference as a perfect venue to launch the manual, given that hundreds of IAM modellers would be present. As we could not be physically present, we prepared the slides, which were presented by an IMAGE modeller. In order to raise awareness about the manual among IAMC participants, the artists also made flyers which were distributed by the IMAGE team during the conference. The presentation was received with excitement among the audience of the presentation; participants for example noted: 'it looks really cool' and 'this is really exciting and interesting' and the manual witnessed a sharp rise in views soon after its launch.

5.2.3 The *Future Models Manual*: an overview

The Future Models Manual is a speculative manual in the form of an interactive website that involves an introduction, five steps and a conclusion that can each be read independently. All steps include a main text (written by artist 2), various (anonymous) quotes from the IMAGE modellers and images (created by artist 1). In step 1, modellers are asked to reflect on what models are based on modellers' own definitions, followed by step 2 where the artists propose alternative metaphors for models from the perspective of a storyteller, a filmmaker and a graphic designer. Steps 3 and 4 bring the political influence of IAMs to the fore, for instance by proposing alternatives for modellers' conceptions of 'useful', 'relevant' or 'feasible' mitigation strategies and challenge their taken-for-granted assumptions such as economic growth. Step 5 invites modellers to reconsider who the community collaborates with and how. The manual concludes by inviting modellers to rethink their role as 'mapmakers' of the future (cf. Edenhofer & Kowarsch, 2015; Edenhofer & Minx, 2014).

5.3 Art-science collaborations and reflection

The potential of bringing in artists into the IAM community as residents remains unexplored.[28] I therefore took an inductive approach in analysing the collaboration to explore this potential. This means that I aimed at finding the 'mechanisms' – understood here as the processes or means through which artists stimulated reflection – which most commonly appeared from the observations and interviews and which were notably different from current forms of reflection within the community. The mechanisms that I identified were the following: 1) asking unfamiliar questions, 2) identifying generative metaphors and 3) the use and creation of visual artefacts (see section 5.4 for more detail on the methodology). I used relevant theoretical perspectives on reflection to interpret the findings (section 5.2.1) and to critically reflect upon the conditions and challenges involved in art-science collaborations (5.2.2).

28 A search on Google Scholar using the terms "integrated assessment model" and "artist" revealed no results. Examples of projects where artists and IAM modellers collaborated include the workshop in chapter 4 and a project at IIASA where artists were invited to envision a 2050 world where climate change was successfully avoided: https://iiasa.ac.at/events/mar-2022/call-for-artistic-imagination-life-in-2050-with-much-less-energy

5.3.1. Reflection and the potential of bringing in artists

Based on the abilities of artists and the focus on reflection within an academic practice, three theoretical accounts on reflection seem particularly relevant to interpret the findings of the art-science collaboration. First, Donald Schön's (1983) account on reflective practice helps to understand how artists stimulated reflection because of his actor-centred approach and focus on knowledge. Schön (1983) observed how practitioners often 'know more than they can say' and are capable of reflecting on this knowing-in-practice (p. vii). This knowledge entails the 'theories-in-use' that practitioners hold regarding how to respond to certain situations, which often remain implicit and unarticulated (Schön, 1983, p. 116; Argyris & Schön, 1974). It is through reflection that such theories-in-use can be made explicit. Artists work with different framings of climate change because they draw on aesthetic, ethical and affective forms of knowledge to understand climate change (Davis & Turpin, 2015; Heras et al., 2021; Yusoff & Gabrys, 2011). Given these fundamental differences, art-science collaborations can be fruitful to encourage reflection among climate scientists by challenging their taken-for-granted assumptions, rethink their methods and forms of communication as they face artists' unfamiliar ways of thinking (Rödder, 2017). Schön's (1983) theoretical insights are therefore particularly useful to understand the *content of reflection* (e.g. framing or theory-in-use). Schön (1983) distinguishes 'reflection-in-action', where practitioners reflect while being in the midst of action from 'reflection-on-action', which involves looking back on the situation. The latter is most relevant in this chapter given that the artists engaged modellers in retrospective reflection.

Second, planning theorist John Forester (1999) supplemented Schön's theory of reflection-in-action by emphasising the importance of deliberative practice: 'reflecting alone, a practitioner learns; deliberating with others, practitioners learn together and craft strategies to act collaboratively' (p. 4). He argued that it is through conversation with others that one comes to see the problem in new light, especially if these deliberative processes are relatively unstructured, informal and open. Empirical research on art-science collaborations in the field of sustainability suggests that artists indeed have the ability to establish different types of conversations and create 'safe spaces' for deep listening, mutual learning and affect (Heras et al., 2021). Forester is complementary to Schön in his focus on deliberation. His theoretical insights are therefore particularly helpful to understand the particular characteristics of the *process of deliberation* that the artists initiated which and how these processes are different from existing deliberative processes within the IAM community (e.g. stakeholder meetings or conferences).

Third, Scott Lash's (1993) notion of aesthetic reflexivity is relevant as he discusses the ability of the arts to foster a non-cognitive form of reflection through aesthetic expression such as symbols, sounds, and images.[29] Lash theorised on reflection in relation to 'reflexive modernisation', which is concerned with how modern societies cope with and reflect on modernity when facing unmanageable ecological risks (Beck, Giddens & Lash, 1994). Unlike Schön and Forester, Lash is concerned with reflection on the societal rather than the individual level. Nevertheless, this theoretical account is still relevant given that IAMs are the primary approach to understanding responses to the global risk of climate change and are a prime example of the modern understanding of risks as being calculable and manageable (cf. Beck, 1992; 1994). Where Beck and Giddens view reflexivity as a predominantly cognitive endeavour, for example through expert systems, Lash argues for an aesthetic form of reflexivity that draws not just on analysis and theory but on imagination and intuition (Beck et al., 1994). Art and design practices may deliberately bring out this aesthetic from of reflection on present day consumerism and capitalism that constitute the root causes of unsustainability (Dieleman, 2008). This distinction between cognitive and aesthetic reflection is useful to better understand how the complementary abilities

29 In his theory on reflexive modernisation, Beck (1994) makes a distinction between reflexivity and reflection, the former referring to the self-confrontation with the impacts of the risk society and the latter referring to a reflection on this self-confrontation. Lash and Giddens (1994) make no such distinction and seem to refer to the latter when speaking of reflexivity. In this chapter reflection refers to a conscious effort to critically reflect on one's practice rather than self-confrontation.

of artists to stimulate reflection compared to academics. In particular, where cognitive reflexivity is concerned with a reflexive subject, aesthetic reflexivity is concerned with reflective 'objects' that are circulated by cultural practices such as films or art works (Lash, 1994). His theoretical insights are therefore helpful to better understand how the *artistic artefacts* stimulated reflection.

5.3.2. Logics of interdisciplinarity in art-science collaborations

The potential for artists to stimulate reflection may strongly depend on the particular set-up and aim of the art-science collaboration, which I critically examine in this chapter (see section 5.5.2). In recent years, climate change has become an increasingly prominent topic in the literary, visual and performative arts (Galafassi et al., 2018a). Scholars have pointed to the potential role of the arts in sustainability transformations, emphasising their abilities to create spaces for creative imagination, bring in questions of values, identity and emotions and creating possibilities for political engagement (Gabrys & Yusoff, 2012; Galafassi et al., 2018a; Galafassi et al., 2018b; Heras et al., 2021). While art projects inevitably engage with climate science one way or another, some of these art projects explicitly involve a transdisciplinary collaboration between artists and scientists. Art-science collaborations on climate change are highly diverse in their aims and form of interaction, ranging from art-scientist pairs, to artists-in-residence in an academic setting to arts-based research (Gabrys & Yusoff, 2012).

As observed by Born and Barry (2010), art-science projects may follow different 'logics' – rationales, motivation or justifications – of interdisciplinarity. A common logic among art-science collaborations is the *logic of accountability*, which refers to the ways in which scientific research is increasingly called upon to hold itself accountable to society (Barry et al., 2008; Born & Barry, 2010). Art-science collaborations following this logic are characterised by a 'subordination-service' mode of interaction where the arts are organised in service of science to render scientific insights more accessible, comprehensible or beautiful to the general public (Ibid.).[30] In contrast, art-science collaborations may also follow a *logic of ontology* where the exchange is oriented at 'effecting ontological change in both the object(s) of research, and the relations between research subjects and objects' (Born & Barry, 2010, p. 105). Here, the interaction is characterised by an 'agonistic-antagonistic' mode where the interaction aims at contesting or transcending

30 As observed by Barry et al. (2008), the relationship may also be inverted: scientists sometimes provide a service to artists to provide resources or equipment to artists.

epistemological and ontological assumptions of research (Barry et al., 2008). Reflection on research practices is arguably more likely in art-science collaborations in which artists and scientists interact through an ontological rather than an accountability logic. In the latter, science is usually taken for granted and it assumes a hierarchy between art and science, which suggests little room for reflection (cf. Born & Barry, 2010). Whereas the theoretical insights from Schön, Forester and Lash help to interpret *how* the artists stimulated reflection (5.4), the logics of interdisciplinary are useful to discuss the conditions for reflection to occur and the potential *challenges* that art-science collaborations may bring that hamper this potential (5.5).

5.4 How artists stimulated reflection: an analysis

In this section, I draw on personal observations of the conversations between the artists and modellers and follow-up interviews to analyse the interactions between the artist duo and the IAM modellers. Table 4 shows an overview of data collection methods and the involved modellers (numbered for the sake of anonymity). Prior to all group discussions and interviews, modellers gave oral consent to record the conversations and to use the transcripts anonymously for the intervention and this research. During the artist-led group discussions, workshops and interviews, I made observational notes on how artists interacted with modellers. Since my capacity to take notes was often limited due to my role as workshop moderator, I also analysed the transcripts and recordings to observe artist-modeller interactions, by first highlighting parts of the conversation suggesting that modellers were reflecting on their assumptions or ways of working and thereafter reviewing what the artists did to stimulate reflection by attending to how they framed and structured the sessions, how they approached modellers and what they showed. Based on these observations, I identified a number of initial 'mechanisms' – means or processes – that repeatedly occurred across the multiple group discussions, interviews and workshops. Thereafter, I conducted semi-structured follow-up interviews with six IMAGE modellers and the artist duo, asking them to reflect upon the art-science collaboration. In the follow-up interviews with modellers, I asked if and how the collaboration stimulated reflection and asked specifically to recall what appeared to them as particularly striking in what artists did compared to their usual means of reflection. I then compared the initially identified mechanisms with the ones mentioned by modellers to arrive at the final three mechanisms. The semi-structured interviews with modellers and artists also included more general questions regarding the expectations, insights, surprises and challenges they experienced during the collaboration, which informed the discussion in section 5.5.2. In what follows, I describe the three mechanisms and provide examples from the group discussions, workshops and interviews.

5.4.1 Asking unfamiliar questions

Seemingly mundane questions

During the interviews and group discussions with modellers, artists posed questions that I – as a critical social scientist – would normally not ask. During the group discussion on 'visualisation' (see Table 4), the artists asked how modellers use their graphic user interface, which I believed was rather mundane at first sight, like asking an accountant how he uses Excel. Yet, what happened was the following:

Artist 1: 'How do you use the MyM graphic user interface, is there a flow diagram that explains how you should work with it?'

Modeller 7: 'I used to have this piece of paper with all model components and how they interact'

Modeller 2[31]: 'I'm a bit more high-tech, I have a PowerPoint slide'

Artist 2: 'Is there like a manual?'

Modeller 2: 'There used to be this folder saying 'don't panic' and that was in principle the manual up until five years ago. In principle the manual is the website and the videos we made with the team. Knowledge distributes amongst people. […] so there is a living manual'

Another example from an interview with a modeller:

Artist 1: 'Do you do code review?'

Modeller 2: 'We have quality control but there is room for improvement. It sounds easier than what it is, because our energy models for instance have 40,000 lines. Who is going to review that?' […] the model that we use

31 The modellers were numbered anew in this chapter and do not match the numbers in chapter 4

Methods	Details	Modellers involved
Personal observation of the interactions between the artist duo and the IMAGE modellers	**Group discussions with IMAGE team**	
	→ 'translation'	modellers 1-6
	→ 'narratology	modellers 3, 7-9
	→ 'cartography'	modellers 1, 2, 4, 7, 9
	→ 'visualisation'	modellers 2, 4, 7
	Workshops	
	→ Visual dialogues at Springtij and Jan van Eyck Academie	modeller 1
	→ Workshop at PBL	modeller 2
	Interviews with IMAGE modellers	modellers 2, 3, 5, 10, 11, 12
Follow-up interviews	With IMAGE modellers and artists after art-science collaboration	modellers 1, 2, 3, 8, 10, 11 artists 1&2

Table 4. Overview of data collection and methodology

now is a little bit of a Frankenstein model. It was just people adding bits to it over the years, […] It's not straightforward.'

While the question about code review appeared to me as somewhat mundane, it actually made modellers aware of their ways of working, such as how the model developed over time and what this implies for its complexity. Indeed, in the follow-up interviews, modellers commented that the artists asked 'unexpected' questions that they would normally 'smooth over' and which made them reflect about their practice (modeller 2, 3 and 8). As argued by Forester (1999), it is through deliberation with others that such unexpected questions can be asked: 'the particulars that others raise can seem irrelevant at first, and they may turn out to be irrelevant – but they may also turn out to be surprising suggesting problems or opportunities. Participants may come to see that what *seemed* unimportant is important, what seemed *not* feasible is feasible after all' (p. 133, emphasis original).

32 The DPSIR framework was developed in the 1990s by the European Environmental Agency as a tool to analyse cause-effect relationships of environmental systems and is widely adopted in environmental research (see Carr et al., 2007).

More fundamental questions

The artists also posed more fundamental questions to modellers. One example is from the group discussion on translation, where the artists asked about the core framework underlying the IMAGE model, the so-called Driver-Pressure-State-Impact-Response (DPSIR) framework:[32]

Artist 2: 'How does this framework shape the kinds of stories that can be told?'

Modeller 1: 'I'm not sure how constraining [the DPSIR framework] is because it is more or less how all natural sciences and most of the economics would look at the world'

Modeller 6: 'I'm not quite sure that's true. I come from a mathematical background [and] the DPSIR is not how I would look at the system.'

The conversation illustrates how artists' fundamental question illuminated misalignments in modellers' understanding that they were not previously aware of. It also made modellers reflect on the underlying norms and values of the model structure. Later on, one modeller commented that 'I don't think I ever realised how normative the DPSIR framework is'. Despite its neutral image, the DPSIR framework has been criticised for reflecting particular biodiversity discourses that fail to recognise the needs of local communities (Svarstad et al., 2008). Others criticise the suggestion of a hierarchy of actors (international organisations or national governments at the top who can influence the drivers and the poor and marginalised at the bottom who can only influence the impacts), thereby reproducing unequal power relations (Carr et al., 2007). Another example of a fundamental question that artists raised during an interview where modellers discussed the purpose of IAM modelling: 'why economics?'. To this question, the modeller responded: 'Economics is about how you value things and what you think drives that. If we weren't using economics, we could say: let's stop coal plants now.' (modeller 3).

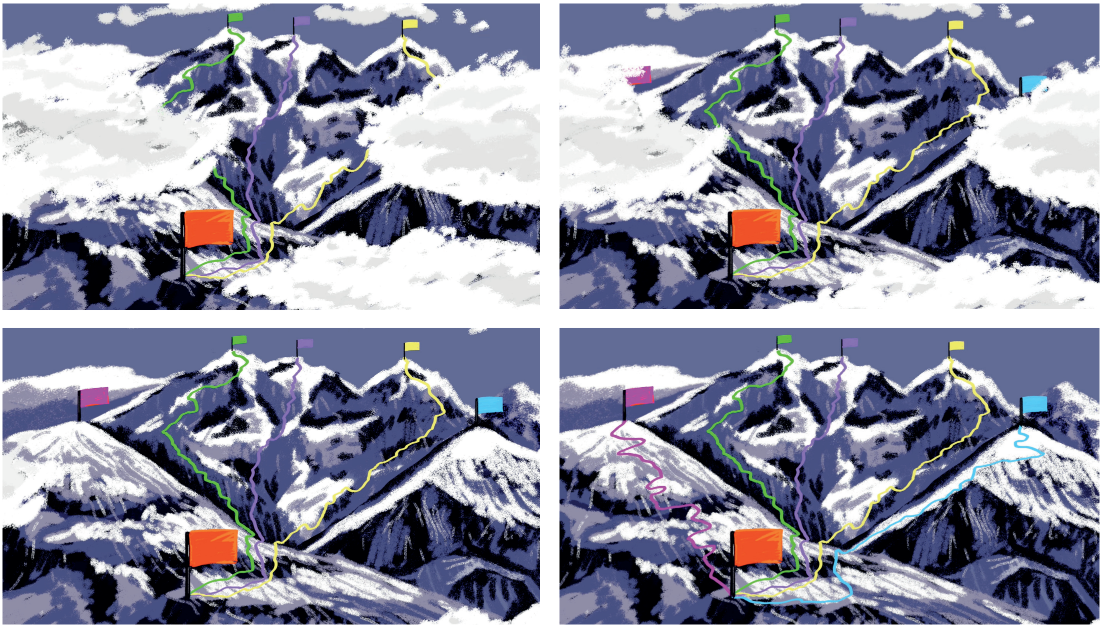
The quotes suggest that the artists' questions stimulated reflection among modellers on the worldviews underlying their 'theory-in-use' (cf. Schön, 1983). This deep reflection could be viewed as what Argyris & Schön (1974) call 'double-loop' learning, reflecting not only upon the means to reach the same ends ('single loop learning') but re-evaluating the ends in themselves, which constitutes a more fundamental reflection on the values and norms underlying one's practice (cf. Schön, 1983). Indeed, modellers commented that they reflected on the purpose of their work; 'this interview makes me think about what I am doing and why' (modeller 3). Another modeller indicated that 'it was one of those moments where you're confronted with this: what are you doing and why are you doing it? We don't ask ourselves that question enough. […] sometimes you can get lost in calculations and just forget about what it actually means. You know, there is a world, not just regions from IMAGE. There's a real world with people and stuff.' (modeller 8). Modeller 3 even referred to the group discussions as 'therapy', noting how powerful the sessions were in inciting introspection.

When I asked modellers what made the interactions with artists different, compared to other dialogues with non-modellers such as stakeholder workshops, they indicated that the artists raised more 'open' and 'honest' questions. As modeller 2 explained, the artists seemed genuinely interested in understanding the IAM practice and came from a 'completely different perspective' that enabled more 'lateral thinking', which took modellers out of their comfort zone (modeller 2). Other modellers also noted how the artists established a 'judgment-free

Figure 13. Example of visual dialogue. An example of a 'visual dialogue', a dual presentation by modeller 1 and the artist duo which were held at the Jan van Eyck and Springtij where the images were shown on two screens. The left image was shown by modeller 1 (and is based on Edenhofer & Kowarsch, 2015) and the right image (which was a moving image in reality) was shown and created by the artists.

→

A. image by IAM modeller



B. 'counter image' by artists

space', enabling modellers to openly reflect on their practice (modellers 3 and 10). The two modellers explained how their stakeholder workshops are usually directed at a specific goal and stakeholders are asked to give their views on specific topics. In contrast, the group discussions with the artists were relatively unstructured and open-ended. As such, they could be understood as what Forester (1999) calls 'participatory rituals', which are 'loosely goal-directed but ritualised performances of sharing stories together, brainstorming possibilities, listing strengths and weaknesses' and typically involve 'structured unpredictability that will help us ask new questions and consider new answers.' (p. 141-146). One of the artists noted that by creating a judgment-free space for conversation, 'the scientists were able to speak *through* us'.

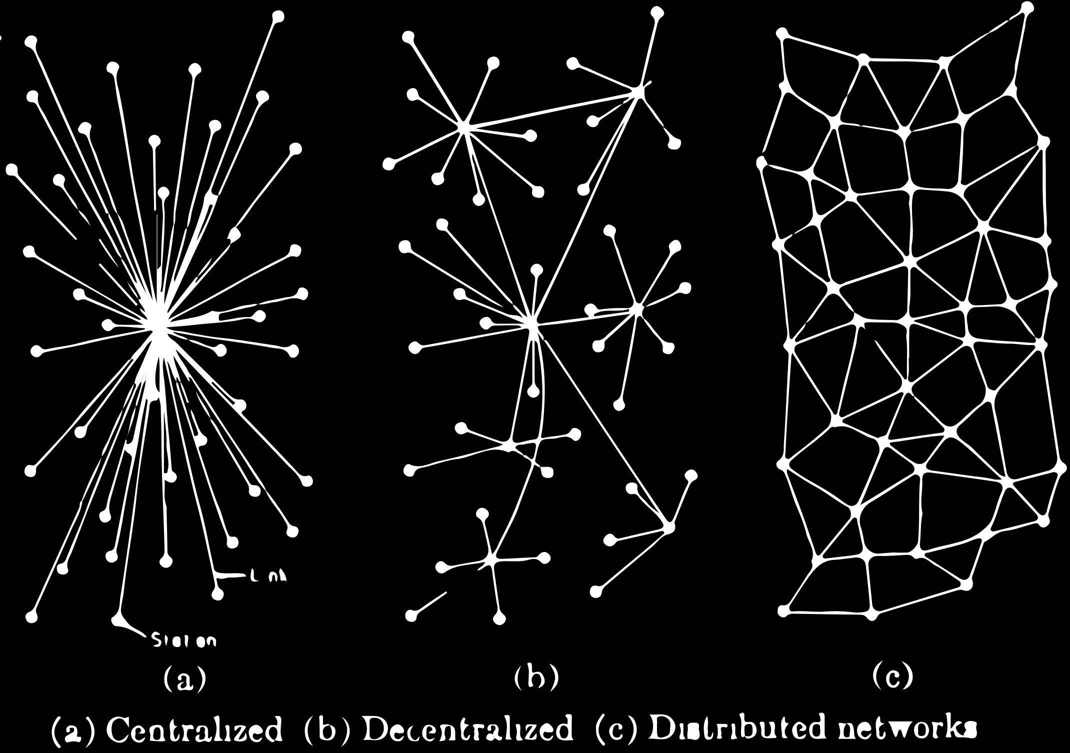
5.4.2 The use of generative metaphors

Throughout the art-science collaboration, the artist duo came up with a range of metaphors to refer to the IAM practice and also made modellers aware of the metaphors they use themselves. Step 1 of the manual reflects various metaphors that were mentioned by modellers during the interviews and group discussions, such as a model as a theory, as Frankenstein or as a system of causal relationships. During the group discussion on 'cartography', the visual dialogues and the PBL workshop, the artists also challenged modellers' metaphor of the 'map-maker'. Figure 13 shows an example of this visual dialogue. Modeller 1 first showed an image of routes to a mountain (Figure 13A), explaining how modellers try to neutrally map out pathways towards the Paris goals, which policymakers can navigate to make decisions (cf. Edenhofer & Kowarsch, 2015; Edenhofer & Minx, 2014). The artists then showed a 'counter image' they created (Figure 13B), a moving image with clouds disappearing and illuminating new pathways. While showing this image, the artists first challenged the map-making metaphor by bringing to the surface two flaws: the assumption that we

Figure 14. Diagrams that artists showed during group discussion on 'data visualisation' and in the manual (B). The image on the left (A) was shown during the group discussion on 'data visualisation' and refers to different structures of communication systems (from Baran (1965). The image on the right (B) represent the 'tree of vices' the 'tree of virtues', which was created by artist 1 and shown in the *Future Models Manual* and based on a manuscript of Speculum Virginum (Walters Art Museum Ms. W.72. foll 25 & 26, dated ca. 1200).

→

A.



B.

know where we are going and how we get there and the assumption that the pathways are neutral. The artists compared IAM modelling to Roman mapmakers who took steps into a *terra incognita*: unknown territory, marking out opportunities and dangers for their followers. They argued how footpaths are forged by walking, they are 'acts on a landscape' (artist 2, during visual dialogue at Springtij). Thereafter, the image transformed into an airplane creating more clouds and a belly appeared with scars, where the artists proposed an alternative metaphor. Namely, to view modellers as dieticians who need to communicate inconvenient messages to society to cut down on excessive fossil fuel consumption, using the analogy of liposuction to refer to IAMs' emphasis on CDR.

The examples above could be viewed as 'frame experiments' (cf. Schön, 1983), where the artists actively challenged modellers' initial problem frames and experimented with alternative framings to open up new questions and ends. As argued by Schön, metaphors are generative framing devices, as they often have strong normative connotations on what should be done and who is responsible (Schön, 1979; 1983; Schön & Rein, 1994). As noted by Schön (1979), metaphors are generative only when they 'generate new perceptions, explanations, and interventions' (p. 137). As indicated by modellers, the metaphors were indeed generative in bringing about alternative ways of seeing IAM modelling (modeller 1, 10, 11). For example, referring to the metaphors in the manual, modeller 10 explained that 'with each one of them I was thinking, that makes sense but does it contradict the first one? And then I would go back to the first one. This kind of thinking was interesting' (modeller 10). One of the PBL workshop participants also mentioned afterwards that the comparison to Roman mapmakers exploring a *terra incognita* was 'straightforward and useful' as it brought awareness about the uncertainty of possible futures and how by carving out paths they not only explore but also define possibilities. At the IAMC annual meeting, modeller 1 also noted: 'something that happened during those dialogues that I started to wonder what my role is with respect to being objective while also trying to influence the future in a direction that I think it should be going. I started to think more and more about that.' This quote suggests that rather than merely addressing modellers' theory-in-use (Schön, 1983), the metaphors also challenged modellers' views on their position towards policy and society. For example, the artists' suggested metaphor of the diet implies a much more advisory role than the metaphor of the mapmaker. Schön (1983, p. 26-27) refers to frame reflection as a process that occurs when the practitioner encounters problems of his or her initial problem frame. However, it seems that modellers were not necessarily aware of their problem framing; it was the artists who made them aware of it.

5.4.3 The use and development of visual artefacts

During the group discussions and workshops as well as in the manual itself, the artists strongly drew on images to stimulate discussion and reflection. The artists guided the group discussions by showing a range of images on an online whiteboard and asking modellers to explain or reflect on them. The images ranged from figures that artists copied from modellers' own website or presentations, such as the image of the map (Figure 14A) to images that the artists created themselves to found images from the internet that related to the topic. An example of the latter was an image of diagrams which the artists showed during the group discussion on 'data visualisation' (see Figure 15A), on which they asked modellers to reflect:

Artist 2:

'Your colleague showed us that TIMER is actually a series of file folders that contains spreadsheets and equations. The man who developed a folder system for computers said that it was developed based on the concept of a tree. So what we get is a complex system as a diagram, which is actually a series of trees [artists show image 15A]. We could say that metaphorically, IMAGE is a forest ecosystem. My question for you is: do you see IMAGE as this set of nested hierarchies or not? And is it evolving over time, from something centralised to something decentralised or distributed?'

Modeller 2:

'Indeed, IMAGE is basically a bunch of submodules that communicate with each other so from these three figures here, I think decentralised is the most appropriate representation, where each node would be a module and they tend to communicate with each other.'

The artists suggested rhizomatic diagrams as an alternative structure for IAMs, which is a non-hierarchical representation of data, and asked modellers about the potential of machine learning to establish such an organisation. In response to this image, modellers reflected on the danger of the model becoming increasingly 'black boxed' when machine learning would be used (modeller 4), how it may lose IAMs' explanatory capacity (modeller 2) and whether it may require expert interpretation (modeller 7). In other words, the diagrams seemed

A.

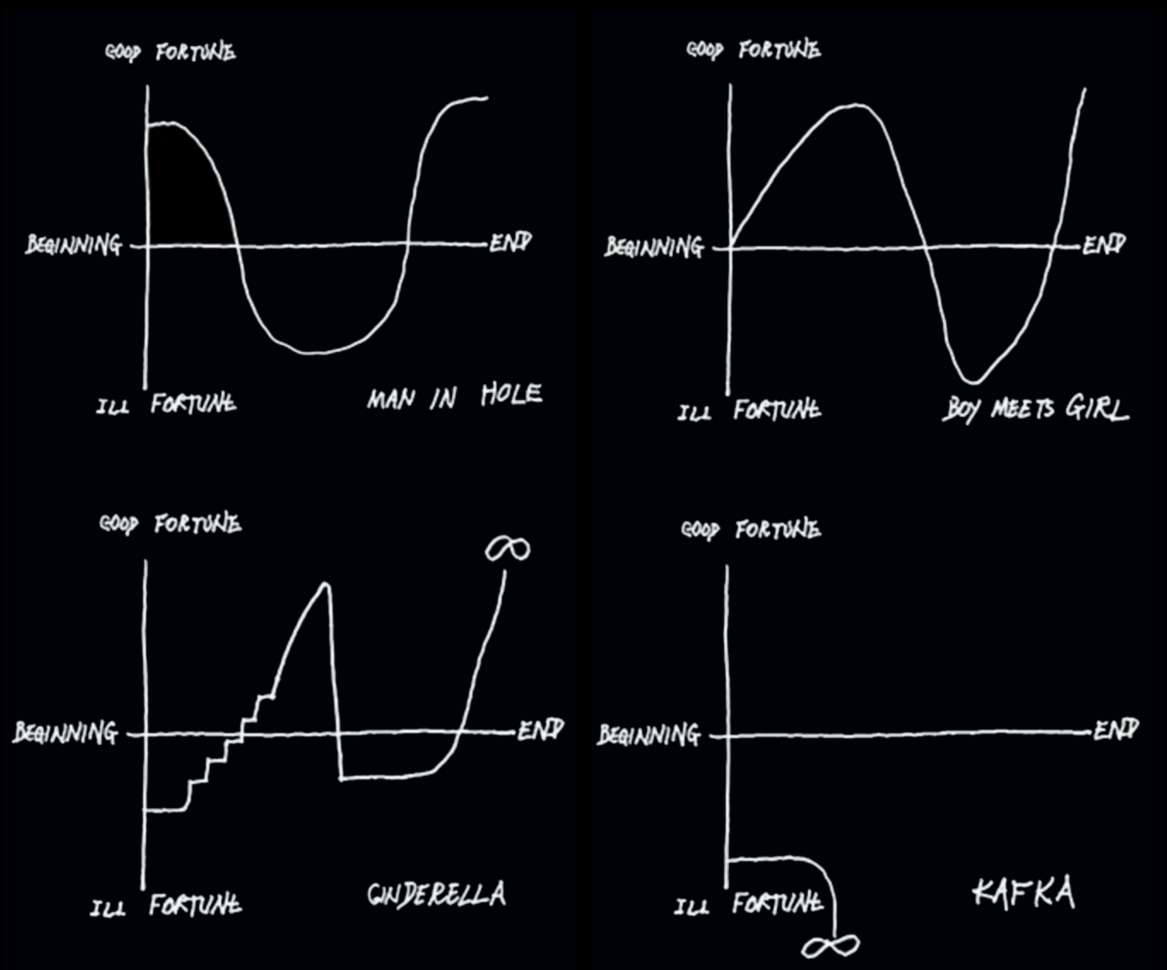
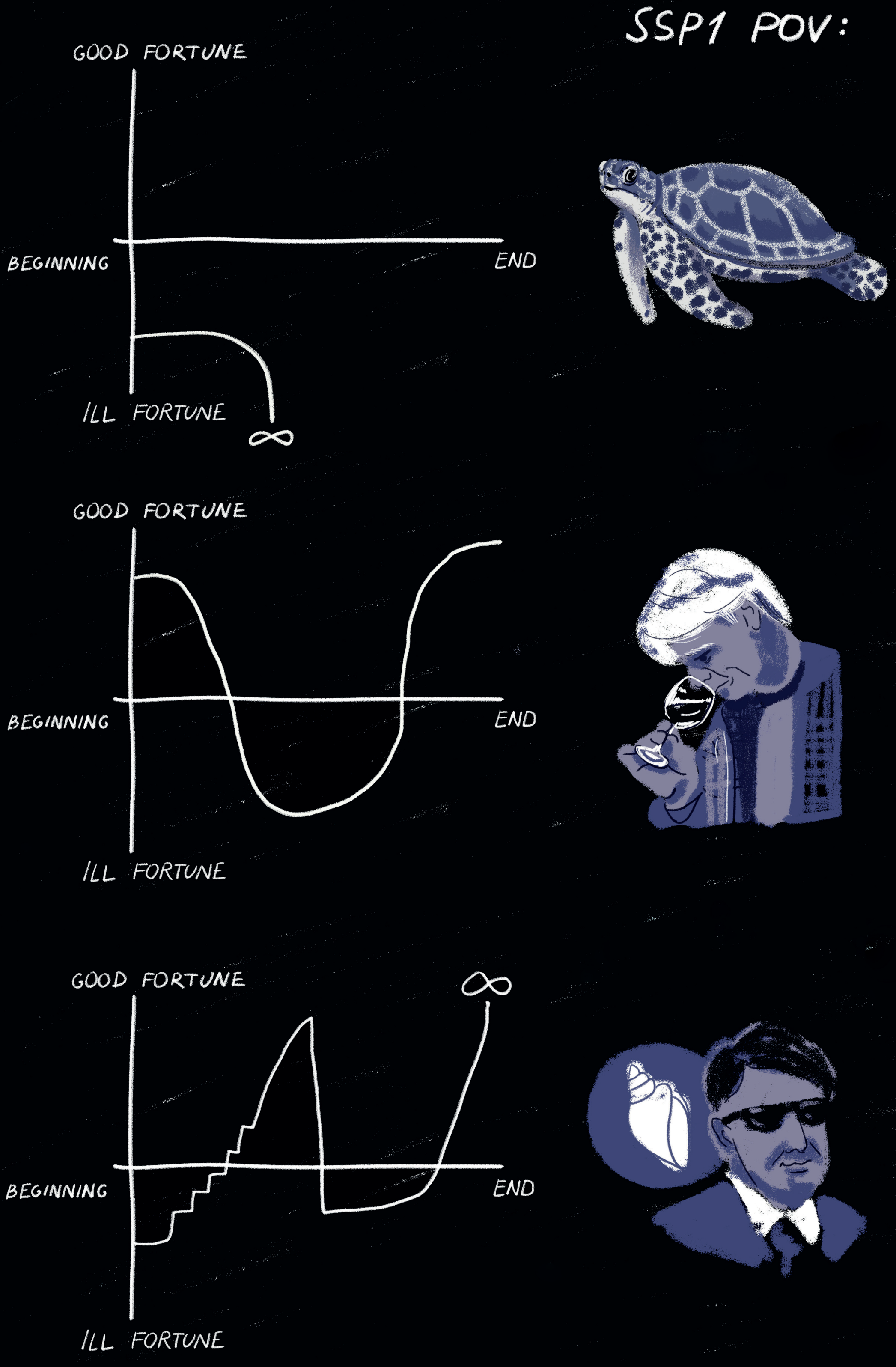


Figure 15. Images that artists showed during group discussion on 'storytelling' (A) and in the manual (B). The image on the left (A) represents the 'shape of stories' from Kurt Vonnegut (1981). The images on the right were created by artist 1 and presented in the Future Models Manual, which represent stories from different characters experiencing the SSP1 storyline from different perspective: a sea turtle (upper), a winemaker (middle) and an oil executive (lower).

B.


SSP1 POV:
GOOD FORTUNE
BEGINNING
END
ILL FORTUNE
∞
GOOD FORTUNE
BEGINNING
END
ILL FORTUNE
GOOD FORTUNE
∞
BEGINNING
END
ILL FORTUNE

to help modellers reflect on how the model structure is intricately connected to its purpose (causal explanation) and what the implications of alternative structures might be. In the manual, the artists also compared modellers' folder system to organise their code to medieval tree diagrams. In medieval times, tree diagrams were used to disseminate truth claims to inform decisions, such as the 'tree of vices' (Figure 14B left) and the 'tree of virtues' (Figure 14B right). The artists explained how similar to IAMs, tree diagrams also disseminate truth claims, but contrary to IAMs, they are *explicit* in conveying ethical judgments. Through the diagrams, the artists drew parallels which could be understood as *mimetic* mediation: reflection through resemblance (cf. Lash, 1994). As theorised by Lash (1993; 1994), aesthetic objects can be mimetic in a more symbolic and iconic sense compared to concepts or theory, and thereby constitute a deeper and more foundational form of reflection.

A second example of an image that modellers often referred to in the follow-up interviews as particularly engaging was the 'Shape of Stories' (Figure 15A), introduced by the American novelist Kurt Vonnegut, which are essentially line graphs that represent emotional dynamics of storylines from ill to good fortune (y-axis) and beginning to end (x-axis).[33] The artists introduced the different story arcs in the group discussion on 'narratology', stimulating modellers to reflect upon their scenarios by asking what the SSPs would look like if they would be plotted along these graphs. Modellers responded:

'The SSPs are more like: what kind of world is it set in? Is it set in a romcom or in a dystopian Kafkaesque world? The point is not that things go up and down. We want to find out how things are in these worlds'

Modeller 3

'I think the SSPs are even described as world-views. I have a hard time to try plotting these along those axes'

Modeller 7

'It also depends very much on the perspective, right? So what is good fortune and what is bad fortune? Is it from the perspective of the climate, from somebody who owns a coal plant or somebody installing solar panels?'

Modeller 9

A discussion followed on whether the SSPs are indeed 'stories', as they lack dramatic tension, a protagonist and a narrator, or that they should instead be viewed as 'story-worlds', the contextual time and space in which stories are set (see Raven and Elahi, 2015 for a distinction between story and story-world). In other words, the images incited

33 Vonnegut introduced this theory in his master thesis in which he claims that popular stories in Western culture follow archetypical emotional dynamics that can be plotted on in a graph, with ill fortune/good fortune for the protagonist on the y-axis and time on the x-axis (Vonnegut, 1981). In a short lecture available on YouTube, he introduces those archetypical storylines: 'man in a hole' (from medium fortune to fall to rise), 'boy meets girl' (from neutral to rise then fall then rise) and 'Cinderella' (from ill fortune to step-wise rise to fall to rise) and 'Kafka' (from bad to worse). See also Figure 15A.

reflection on what the SSPs represent and the attendant implications. Indeed, as noted by modeller 2 in the follow-up interview: 'we never looked at our narratives like that.' Another modeller also recalled how the use of different 'visual prompts' in the discussions gave a new 'angle' on IAMs and stimulate discussion on different perspectives within the team (modeller 3). Inspired by this discussion, the artists developed three different storylines from different perspectives that are set in a 'SSP1 world' where the Paris goals would be achieved (see O'Neill et al., 2017 for details of this global storyline). The three images are shown in the manual and also used as visual prompts for a storytelling exercise in the PBL workshop where modellers were invited to develop a storyline of a character experiencing an SSP1 world and drawing out the associated emotional tensions similar to the images (Figure 16B). Interestingly, one of the modellers shared that he *intuitively* felt resistance to develop a Kafkaesque storyline, feeling uncomfortable to determine the ill-fortune of others. This could be interpreted as 'aesthetic reflexivity'; the images stimulated a form of reflection that draws strongly on *intuition* to evaluate the subjectivity and ethical implications of scenario assumptions, rather than making a cognitive assessment of such implications (cf. Lash, 1993;1994). By making the tensions of the character visible, it could be argued that the visual objects fostered reflection 'on the universal through the particular' (cf. Lash, 1994, p. 111). It is through this particularisation that aesthetic objects can incite a reflection on one's subjectivity that is more foundational compared to cognitive reflection (Lash, 1993).

5.5 Discussion: the potential of artists to stimulate reflection

In this section I first critically scrutinise the main findings (section 5.5.1), followed by a discussion on the conditions and challenges of art-science collaborations that stimulate or hamper reflection (section 5.5.2).

5.5.1. Critical reflection on the key findings

The analysis suggests that the artists stimulated reflection among modellers on their taken-for-granted assumptions, the purpose of their work and their political influence. This is not to say that reflection was previously absent; reflection already occurs within the IAM community through self-criticism on the gaps and limitations of their models, academic criticism, peer review and feedback and interdisciplinary collaboration (modeller 1 and 11). Some issues that artists brought to the surface, such as the flaws of the map-making metaphor, are also raised by academics in scientific journals (e.g. Beck & Oomen, 2021; Haikola et al., 2019). Nevertheless, the findings suggest that the artists simulated a different, more foundational, form of reflection. Modellers repeatedly stressed how the artists stimulated a 'deeper' and 'more explicit' reflection compared to the existing means of reflection, one even referring to the dialogues with artists as therapy (modeller 1, 2, 3 and 11). Using the word 'therapy' suggests that the sessions may have incited reflection beyond one's professional practice, which is the key focus of Schön (1983) and Forester (1999), but the data is too limited to draw any conclusions on this matter.

By drawing on personal observations and follow-up interviews, I identified three mechanisms through which this reflection occurred: by asking unfamiliar questions, identifying generative metaphors and using and developing visual artefacts. Artists' unfamiliar questions illuminated differences in viewpoints regarding their model structure that modellers were previously unaware of. The relatively unstructured and loosely goal-oriented dialogues that the artists established appeared crucial in allowing for a judgment-free space for such questions to be asked and for modellers to openly and honestly reflect on their practice (cf. Forester, 1999). A second mechanism was the identification of new metaphors, which not only generated new perspectives modellers' theory-in-use (Schön, 1979; 1983), but also their position towards policy and society. Third, the artists seemed to incite 'aesthetic reflexivity' among modellers by engaging them into reflective exercises around visual artefacts that drew on modellers' intuition and imagination (cf. Lash, 1993; 1994). These artefacts were helpful in stimulating reflection on the value-based judgements underlying their assumptions. However, it remains unclear to what extent the reflection was indeed purely 'aesthetic' or at times also cognitive; the images that the artists presented sometimes came from scientific websites, the manual is largely text-based and at times quite conceptual. Nevertheless, in the follow-up-interviews the modellers often referred to the visual artefacts when reflecting upon the art-science collaboration as being particularly engaging and insightful.

This chapter focused mostly on how reflection occurred among members of the IMAGE team during the *development* of the manual (the group discussions, interviews and visual dialogues). It therefore only offers a partial understanding of how the manual itself works as a tool for reflection for the IAM community at large or perhaps even other modelling communities as well. Different mechanisms of reflection may apply to the manual itself, especially since modellers saw different purposes for the manual: as an educational tool for new IMAGE modellers (modeller 2), as a tool for introspection and for IAM modellers or other modellers (modeller 1 and 3) and as an educational tool for model users such as policymakers and the general public to understand what models and scenarios are and how they should be interpreted (modeller 2, 10, 11). As of June 2023, the manual has over 11,000 views and 1,500 active users (users that interacted with the website rather than just opening it) and the artists and I were invited to present it to a variety of other modelling teams beyond the IAM community, including the MERGE (ModElling the Regional and Global Earth system) community. Nevertheless, it remains unclear who uses it, how and why. Moreover, modellers may not all be equally receptive to reflective exercises; while some modellers enjoyed the conversations with the artists, others clearly did not. During one of the group discussions for example, one modeller noted that 'this whole philosophical discussion is far outside of my comfort zone. I know it is important but I just find it very difficult.' (modeller 6). As Table 4 shows, some modellers never returned after being part in the first group discussion.

This brings me to some of the key methodological challenges that deserve attention. First and foremost, assessing the 'impact' of the art-science collaboration on modellers' reflection remains problematic. Presumably, reflection is a continuous endeavour that occurs through diverse processes and changes are therefore difficult attribute to a single intervention. Second, the mechanisms that I identified (unfamiliar questions, generative metaphors and visual artefacts) often seemed to work in combination, which makes their outcomes difficult to separate. For example, it was unclear if the reflection on modelling as map-making was stimulated by artists' identification of an alternative metaphor or by showing images. Arguably, it was the combination of all three that was powerful in stimulating reflection. Third, while my personal involvement facilitated the interactions between modellers and the artists, it also implies that the outcomes reflect my views on modelling and that the observation of the process is only partial (see Box 1). In the follow-up interviews, I therefore explicitly asked modellers and artists to critically reflect on the collaboration. However, modellers that were interested in and engaged heavily in the process may have been more inclined to take part in the interviews as well. As a result, the findings of the interviews only provide a partial understanding of modellers' reflections on the collaboration. The fourth key challenge concerns the generalisability of the findings. Although the project could be placed in a tradition of bringing artists as residents into an academic setting, the collaboration could be different because I operated as a 'mediator' between the modelling group and the artists (see Box 1). Moreover, neither the artists nor the modellers are homogenous groups; involving artists from different artistic practices or modellers from different IAM groups could have resulted in different outcomes. For example, while the artist duo was experienced with the use of design to establish inclusive conversations, this may not be true for other artists. Nevertheless, the analysis offered rich insights into the dynamics between modellers and artists when brought into conversation. These insights are valuable to understand potential and challenges of IAM-art collaborations and art-science collaborations more generally.

5.5.2. Challenges and opportunities of art-science collaborations: two conflicting logics of interdisciplinarity

The analysis in this chapter suggested that artists stimulated reflection by challenging existing understandings and providing different perspectives on the meaning and purpose of IAM modelling. Based on this finding, one could argue that the project followed a *logic of ontology*, where artists challenge and transform scientists assumptions and ways of working (cf. Barry et al., 2008; Born & Barry, 2010). At the start of the project, the artists were clearly aiming for this logic. As one of the artists noted in the follow-up interview, 'we weren't looking to create a different plugin for a different user, we were looking to rewrite the code'. Interestingly however, modellers persistently viewed the value of artists as improving the communication of their result, which is more aligned with a *logic of accountability*, in which artists assist scientists in making their results more accountable to lay publics (cf. Barry et al., 2008; Born & Barry, 2010). When I asked modellers in the follow-up interviews to indicate what they saw as the primary value of working with artists, modellers still chiefly saw the primary role for artists to improve the communication of model results to a general audience (modeller 1, 2, 8, 10, 11), for instance by providing an 'emotional hook' (modeller 2). Moreover, modellers were highly surprised when the artists proposed the idea of a manual, arguing it would not be 'recognisable as art' (modeller 1) and expecting 'something more artistic' (modeller 10). The artists repeatedly expressed their frustration of this instrumental view on art: 'very early on the frustration came in about introducing something radical to the model or changing their way of thinking. [...] would not be accepted in an academic sphere. [...] Things that are for us not that radical at all, in their world would just be explosive.' (artist 2). In other words, the two logics of interdisciplinarity seemed to conflict.

These findings could be insightful for future art-science collaborations. First, the findings suggests the need to make the roles of artists and scientists explicit prior to the collaboration. Whereas both an accountability and an ontological logic could be potentially fruitful, they imply different forms of interaction and different purposes (cf. Born & Barry, 2010). Tensions and conflicts between artists and scientists are not necessarily problematic; to the contrary, conflicting ontologies and epistemologies can even give rise to generative art-science interactions. However, differences in expected logics of interdisciplinarity can easily result in frustration and disengagement. In our collaboration for example, some of the modellers withdrew from the process after the first group discussion when it appeared that science communication was not the artists' intention. Second, if the goal of an art-science collaboration is indeed to 'open-up' possible futures, the collaboration may be most fruitful if it follows an ontological logic, where artists are enabled to challenge and transform existing ways of thinking and where the interaction between artists and scientists is reciprocal rather than hierarchical. This brings me to the third recommendation: the need to carefully consider the time investment of art-science collaborations. The artists repeatedly stressed their disappointment with scientists' busy schedules, which made time for discussion and reflection limited. Besides, the manual was launched nine months after the start of the project, whereas the initially proposed project duration was only six months. This exemplifies that crossing boundaries between the arts and science takes time, given their fundamental different ways of knowing and working. Initiators of future art-science initiatives may therefore consider more sustained collaborations over longer periods of time or sequences of initiatives in which lessons learned from previous experiences are considered.

5.6 Conclusion: lessons learned and future directions

This chapter reported on an experimental and guided collaboration between IAM modellers and an artist duo which culminated in an artistic intervention, the *Future Models Manual*, a speculative manual that takes modellers on a journey to reflect on their practice and inspire alternative ways of working. By drawing on personal observations and interviews of the conversations between the artists and modellers, I explored how artists may stimulate a more reflective IAM practice. Based on the analysis, I identified three mechanisms through which the artists stimulated reflection: asking unfamiliar questions enabled by loosely structured conversations, identifying metaphors that generated new perceptions and understandings of the meaning and purpose of modelling and the use of visual artefacts to stimulate discussion on the ethics and epistemological underpinnings of modelling. Although reflection within the IAM community already occurs through various means such as academic criticism, these mechanisms suggest that artists have complementary abilities to stimulate deeper and more explicit reflection. The research faced a number of challenges, most notably regarding the assessment of the 'impact' of the intervention. The results are therefore mostly explorative, but nevertheless offer rich insights into the interactions between modellers and artists. A key lesson learned was that while the end goal of an artistic intervention can generate active engagement of the modellers, not just the end product itself but the process of interaction, including the interviews, group discussions and workshops, was already a form of intervention. Altogether, the findings point to the potential of future collaborations between the IAM and artistic practices to stimulate reflection and transform existing ways of working and thinking. Perhaps the most important lesson learned in this regard is that this potential may be hampered by viewing artists as science communicators. Rather, it requires a non-hierarchal and reciprocal form of interaction.

View the Future Models Manual here:

6.

Exploring alternative dramaturgies of expertise in citizen engagement practices

Abstract

The need for engaging citizens in climate policymaking is increasingly recognised. Despite indications that the form of expert involvement can strongly influence participatory processes, this remains scarcely researched. We analysed two unique and contrasting cases of citizen engagement in national climate mitigation policy: 1) the Irish Citizens' Assembly (ICA), the first national climate assembly involving live expert presentations and face-to-face deliberations; and 2) the Participatory Value Evaluation (PVE) on Dutch climate policymaking, where more than 10,000 citizens compared policy options in an online environment based on expert-based information on policy effects. Taking a dramaturgical approach, we found that the opening-up and closing-down of policy options and perspectives was influenced by the setting, staging and scripting of expertise. Apart from providing information on policy options, experts had significant roles in design choices and formulating recommendations, which shaped citizens' deliberations and policy advice. In deliberative processes, citizens' deliberations can be further influenced by putting experts in a privileged spot and emphasising their authority, whereas in the setting of an online tool, experts' design choices may be masked by the fact-like presentation of expertise. Future research should further investigate the role of experts and expertise across a wider range of practices. Nevertheless, we conclude that the high degree of required technical knowledge in climate mitigation policy naturally implies a strong influence of expert involvement, which concomitantly steers the results. Alternatively, we may search to enhance citizens' engagement in guiding climate policymakers focusing on citizens' normative perspectives.

Under review at *Climatic Change* Van Beek, L., Mouter, N., Pelzer, P., Hajer, M., Van Vuuren, D. (forthcoming). Experts and expertise in practices of citizen engagement in climate policy: a comparative analysis of two contrasting cases

6.1 Introduction

Many countries have formulated ambitious mid-century emissions targets to achieve the Paris Agreement's objective to limit global temperature increase to well-below 2°C and preferably 1.5°C degrees. Policymakers are therefore challenged with developing concrete national climate mitigation plans. Traditionally, climate mitigation policy is strongly informed by expert-based analysis of possible policy pathways, most notably model-based scenarios. However, given the far-reaching consequences of these policies, it is increasingly recognised that citizen engagement is crucial to ensure that newly implemented polices are socially just, acceptable and effective (Wüstenhagen et al., 2007; Langer et al., 2017; Batel, 2020). Against this backdrop, a diverse range of citizen engagement initiatives in climate and energy policy have emerged over the past decade (OECD, 2017; Chilvers et al., 2021; Galende-Sánchez & Sorman, 2021).

This chapter is concerned with the meaning and role of expertise given the recent advance of citizen engagement practices such as deliberative mini-publics like national climate assemblies (Willis et al., 2022). At first glance, citizen engagement may seem to counteract the traditional powerful roles of experts in climate policymaking, which has been widely criticised for devolving political questions into technical ones and favouring techno-economic solution orientations (Demeritt, 2001; Beck & Oomen, 2021; cf. Fischer, 1990). One of the promises of participatory processes is their capacity to 'open up' (Stirling, 2008) towards wider polices and perspectives which experts and policymakers may overlook, alluding to citizens' value diversity, local knowledge and creative capacity to identify policy options (Fiorino, 1990; Stirling, 2008; Pesch et al., 2017). At the same time, access to specialised knowledge is broadly recognised as an essential ingredient of participation in complex environmental policy issues such as climate change (Reed, 2008; Brown, 2014; Lightbody & Roberts, 2019).

However, expert involvement across citizen engagement practices is highly diverse and there is little scholarly agreement on what form this should take (Lightbody & Roberts, 2019). While empirical work on deliberative mini-publics on climate change reveals that expert involvement improves citizens' understanding, experts can also 'close-down' citizens' deliberations by imposing issue framings or forceful communication of policy options (Blue, 2015; Courant, 2020; Muradova et al., 2020). Despite the apparently crucial role of experts and expertise in participatory processes, expert involvement is scarcely researched

(Brown, 2014; Roberts et al., 2020). We address this gap by focusing on the context of climate policymaking, which is particularly relevant given the complexity and required technical knowledge. In line with Stirling (2008), we do not argue that closing-down is problematic, as closure is arguably necessary regarding the urgent need for decisive climate action. Nor do we argue that expert analysis leads by definition to closing-down and participation to opening-up (Stirling 2008). Rather, we are interested in *how* the opening-up and closing-down unfolds in interactions between citizens and experts.

This research intends to answer the following research question: *How does expert involvement shape the dynamics of opening-up and closing-down of policy options and perspectives in practices that engage citizens in climate mitigation policy?* We compare two cases that both involved citizens in national climate policymaking, with contrasting formats of mobilising expertise: the *Irish Citizens' Assembly (ICA)* on climate change, a deliberative mini-public where a randomly selected group of citizens are informed through live expert presentations, and the *Participatory Value Evaluation (PVE)*, a relatively new citizen engagement method recently applied to Dutch national climate policy, in which citizens evaluate and compare policy options based on expert-based information in an online environment (see section 6.4 for theoretical, methodological and practical arguments for our case study selection). In the following sections, we first review theoretical understandings and empirical insights into the role of experts and expertise in citizen engagement in climate policy (section 6.2), which informs our analytical approach to the analysis (section 6.3). After explaining our methodology (section 6.4), we first introduce both cases (section 5) before reporting our results (section 6.6 and 6.7). In section 6.8, we discuss the limitations of our research and the theoretical and policy implications of our findings.

6.2 Experts and expertise in citizen engagement practices: theoretical understandings and empirical insights

Specialised knowledge is widely recognised as an essential ingredient of public participation in complex environmental policy issues, in order to deepen citizens' understanding and support informed dialogue (Reed, 2008; Brown, 2014; Lightbody & Roberts, 2019). A lack of engagement with scientific and technical expertise can easily result in 'negotiated nonsense' (Van de Riet, 2003). Expert involvement has been theorized in-depth, most notably in deliberative democracy literature (e.g. Habermas, 1996; Fisher, 2000). Although the preferred meaning and role of experts and expertise remains debated (Brown, 2014; Roberts et al., 2020), a key rationale to involve experts in deliberative processes is to empower disadvantaged groups to form reasoned arguments (Knops, 2006; Brown, 2014). Empirical work indeed finds improved understanding and shifts in citizens' policy preferences as a result of information provision (Muradova et al., 2020; Elstub et al., 2021).[34] However, expert involvement is also prone to several challenges that may compromise the fairness and effectiveness of participatory processes (Roberts et al., 2020). For instance, issue framing by experts during citizen engagement processes can undermine citizens' plurality of views (Blue, 2015). This may not be intentional. Scientific understandings are never neutral representations, but are inseparable from conceptions of social order (Jasanoff, 2004). Moreover, experts are often positioned in a privileged spot where communication is reduced to a Q&A format, leaving little room for citizens to critically scrutinise experts' claims (Brown, 2014; Roberts et al., 2020). Prioritising scientific expertise over social forms of knowledge blurs the 'cultural/hermeneutic character of scientific knowledge itself' and 'seriously constrains the imagination of new forms of order and of how their social legitimation may be better founded.' (Wynne, 1996, p. 45). Although these studies suggest that expert involvement influence citizen engagement processes in diverse ways, empirical work on this issue remains scarce (Brown, 2014; Lightbody & Roberts, 2019; Muradova et al., 2020).

34 Empirical work on the role of information on opinion shifts in deliberative mini-publics show contrasting results: where some find opinion shifts were influenced more strongly by information rather than deliberation (e.g. Goodin and Niemeyer, 2003), others find the opposite result (e.g. O'Malley, Farrell and Suiter, 2020)

6.3 Analytical approach to analysing expert-citizen interactions

Two premises underpin our analysis. First, we view citizen engagement processes as 'arenas' in which citizens and experts discursively engage in opening-up and closing-down policy options and perspectives (cf. Rydin, 2007). We analyse how the *possibility space* takes shape throughout both cases, defined here as the range of possible policy options and perspectives that are discursively opened-up or closed-down by various actors (section 6.6). With 'policy options' we mean specific policies that are aimed at mitigation climate change, such as subsidies for electric vehicles or giving nature legal rights. With 'perspectives' we mean the normative perspectives of citizens when assessing the desirability of policy options, such as intergenerational equity or ecological impacts (see e.g. Bellamy et al., 2014 for a similar distinction). A second theoretical premise is that the credibility of experts is not pre-given but continuously negotiated depending on the specific institutional context (Fischer, 1990; Jasanoff, 1990; Wynne, 1987). In order to understand the process through which expertise becomes authoritative, we base our analysis on the 'governance as performance' framework developed by Hajer (2009) to analyse how actors gain authority in mediatised policy and decision processes. We apply this framework of dramaturgical analysis through three elements: scripting, staging and setting. *Scripting* involves determining the specific roles and appropriate behaviour of the actors involved (Hajer, 2009), in our case this is operationalised as the scripted roles that were assigned to experts during the design of each case (section 6.7.1). Staging involves the specific organisation and sequence of events of the interaction between actors (Hajer, 2009), here operationalised as the particular way in which experts are introduced and how expertise is presented (section 6.7.2). The *setting* refers to the physical and organisational setting where the interaction takes place (Hajer, 2009). In our cases we only attend to the physical setting (e.g. the room set-up / the format of the online tool: section 6.7.2) and consider the organisational setting as the institutional embeddedness that we describe in the introduction of the cases (section 6.5). Using the governance as performance framework was used to reveal how the scripted roles of experts, the staging of expertise and the physical setting influenced dynamics of opening-up and closing-down the possibility space.

6.4 Case study selection and methodology

6.4.1 Rationale for selecting the cases

Our case study selection was based on theoretical, methodological and pragmatic arguments (Seawright & Gerring, 2008). The first and foremost theoretical argument for selecting the cases was their contrasting forms of expert involvement: a climate assembly involving live expert presentations, Q&A and small-group deliberations

(ICA) vs. an online tool where citizens compare policy options based on expert-based information on policy effects (PVE). The PVE was also selected for pragmatic reasons: author 1 and 2 were personally involved in the development of the PVE application on Dutch climate policymaking, which enabled insights into the design process and access to data. Where author 2 coordinated the PVE content, author 1 provided assistance in its design and took a more critical and reflexive stance, closely observing the design of the PVE and interviewing involved stakeholders afterwards. Moreover, authors 3-5 were not personally involved and therefore had a more critical distance. We recognise that this may not counteract potential biases, yet we considered the direct access to the design process and data outweighed this potential drawback (section 6.8.3 for a reflection on potential biases). A pragmatic argument to select the ICA was data availability, being well-documented compared to more recently emerging climate assemblies. A methodological argument for selecting both cases was their similarity in their goal and scope, i.e. informing climate mitigation policy on the national level. We recognise that our cases might not be representative of other climate assemblies or PVE applications or democratic innovations more generally.[35] We therefore reflect on the biases of our case study selection in section 6.8.3.

35 Both the PVE and the ICA can be considered 'democratic innovations' that are aimed at deepening and expanding the scope of citizen engagement. However, these innovations are highly diverse (Elstub and Escobar 2017) and the democratic quality of deliberative mini-publics is heavily contested (e.g. Curato and Böker 2016)

6.4.2: Methodology: data collection and analysis

The comparative analysis was based on a range of quantitative and qualitative methods (Appendix D1 for more detailed information). The ICA was analysed through document analysis (academic literature, reports and experts' papers and presentations), 12 semi-structured interviews with involved actors (Assembly members, the Secretariat, expert witnesses, the Expert Advisory group and observers), data from a quantitative survey derived from researchers studying the ICA (Farrell et al., 2017) and an analysis of open access video material[36] of expert presentations and Q&A sessions. Documentation on the ICA was used to reconstruct the process and outcomes of the ICA (section 6.5) and the scripted roles of experts during the process (section 6.7.1). Experts' papers and presentations were also analysed to reveal experts' proposed policy options to understand the extent to which citizens' recommendations reflected these proposals (section 6.6). The survey results (Farrell et al., 2017) were used to gain insight into citizens' views on the provided information (section 6.7.1). The video material revealed the room set-up (setting) and enabled analysis of how experts were introduced in opening speeches as well as how

36 This material is available on YouTube and is accessed between January 2022 and November 2022 https://www.youtube.com/channel/UC2DgyetL9aUTMry_F9B9yUw

experts responded to citizens' questions (staging). The interviews were aimed at better understanding how the scripted roles of experts played out in practice and how the setting, staging and scripting influenced citizens' deliberations. The PVE case was analysed through literature review, personal observations, a participant survey and three semi-structured interviews (Appendix D1). The description of the PVE case (section 6.5.2) and the dynamics of opening-up and closing down (section 6.6) were reconstructed through personal observations of the design process (Appendix D4), literature review (academic literature on the PVE method and grey literature such as policy reports and parliamentary debates on this particular case), three semi-structured interviews to gain insight into the use of PVE insights in policy [37] and participant's preferred policy options as reported in Mouter et al. (2021d).[38] The reconstruction of the scripted roles, setting and staging of expertise (section 6.7) was based on the presented information in the PVE as well as survey responses that participants filled in after completing their advice. Given the aim of this chapter, we focused on 2000 responses on two open questions regarding the positive and negative aspects of the PVE, which were analysed inductively by two PVE researchers (including author 1) to reveal the most common responses (Appendix D1), which revealed insights in citizens' perspectives on the preselected policy options (6.7.1) and the information provision (6.7.2).

37 We recognize that 3 interviews may not capture the diversity of stakeholders' views. However these were used to obtain some provisional insights into policy outcomes of the PVE which was not the core interest of our comparison and is only used in the case description (section 5.2). See also Appendix D1

38 The quantitative analysis of preferred policy options of all PVE participants and the qualitative analysis of 2000 of the participants' open questions regarding their arguments for and against policy options as well as the open evaluative questions was performed by a group of 14 researchers including author 1 and 2. The findings are reported in a Dutch report which is used as key reference in our results (Mouter et al. 2021d)

6.5 Introduction to the cases

In this section we provide an overview of the process and outcomes of each case (overview in Table 5 and Figure 16) and provide background on their respective political and institutional setting.

6.5.1 Case 1: the Irish Citizens' Assembly on climate change

Although efforts to make democracy more deliberative and inclusive date back to the 1970s, Ireland is considered a pioneer of democratic innovations for two reasons: first, it is the first country where multiple nation-wide citizens' assemblies were held successively and second, the assemblies produced major political outcomes in the form of multiple successful referendums (Farrell et al., 2019; Courant, 2021). The ICA (2016-2018) followed from two earlier citizen engagement initiatives in Ireland. The We the Citizens project (2011) which was initiated in response to the declining trust in the Irish government in the aftermath of the economic crisis (Farrell & Suiter, 2019). One of its recommendations was to complement representative democracy with deliberative democracy processes, which formed the foundation to initiate a 'pilot' citizens' assembly, the Convention on the Constitution (2012-2014), which resulted in two successful referendums (Farrell & Suiter, 2019). The success of these two processes raised optimism for citizens' assemblies to address politically divisive issues, most notably the Eight Amendment of the Constitution concerning abortion. In July 2016, the ICA was approved by the Irish parliament, consisting of 99 randomly selected citizens and a chair person (a retired Supreme Court judge) to discuss five topics over the course of 12 weekends: the Eighth Amendment to the Constitution, aging population, fixed term parliaments, the way referenda are held and climate change. The Eight Amendment was the most intensively discussed topic and resulted in a successful referendum.

Climate change was thus embedded as one of the five topics of the ICA and was only included after an amendment by the Green Party (Farrell et al., 2019; Harris, 2021). Whereas climate change would initially be addressed as the final topic, Assembly members voted to move it to the third topic and devote two weekends to it instead of one (Courant, 2020). The country had been known as a 'climate laggard' for many years, with the 2017 National Mitigation Plan being highly criticised for lack of ambition (Torney & O'Gorman, 2019). Moreover, the Assembly could provide an independent space to discuss climate policy, which is highly politically charged given the farming lobby in Ireland (Devaney et al., 2020). As illustrated in Figure 16, over the course of two weekends the Assembly engaged in an iterative process of listening to expert presentations, small group discussions and Q&A, culminating in a Ballot Paper that the Assembly members voted upon. Prior to citizens' deliberations, the organizers also invited the wider Irish society to submit ideas or proposals (The Citizens' Assembly, 2018). A total of 1,205 submissions were received by advocacy groups, experts and citizens of which 1,185 were published on the website, which were synthesised and sent to Assembly members alongside short papers of each expert witness.

The ICA on climate change resulted in 13 climate policy recommendations including a more general call to put climate change at the centre of Irish policymaking as well as sectoral policy recommendations across energy, transport and agriculture (The Citizens' Assembly, 2018; Appendix D2 for an overview). The recommendations were far more radical than many expected, especially the suggestion to introduce of a tax on GHG emissions in agriculture (Devaney et al., 2019; Torney & O'Gorman 2019). An all-party parliamentary committee was established that would consider the recommendations and to assess how this may inform Ireland's national mitigation strategy. In their final report, this committee endorsed most of the Assembly's recommendations, except the controversial tax on agricultural emissions (Devaney et al., 2019; Joint Committee on Climate Action, 2019). Nevertheless, the 2019 Climate Action Plan and its amendment in 2021 reflected several of the Assembly's policy recommendations (Appendix D2). Since the ICA, citizen engagement has become a primary component in the Irish national mitigation strategy, including an online public consultation, a stakeholder forum and a youth assembly (Government of Ireland, 2022).

6.5.2 Case 2: the Participatory Value Evaluation on Dutch national climate mitigation policy

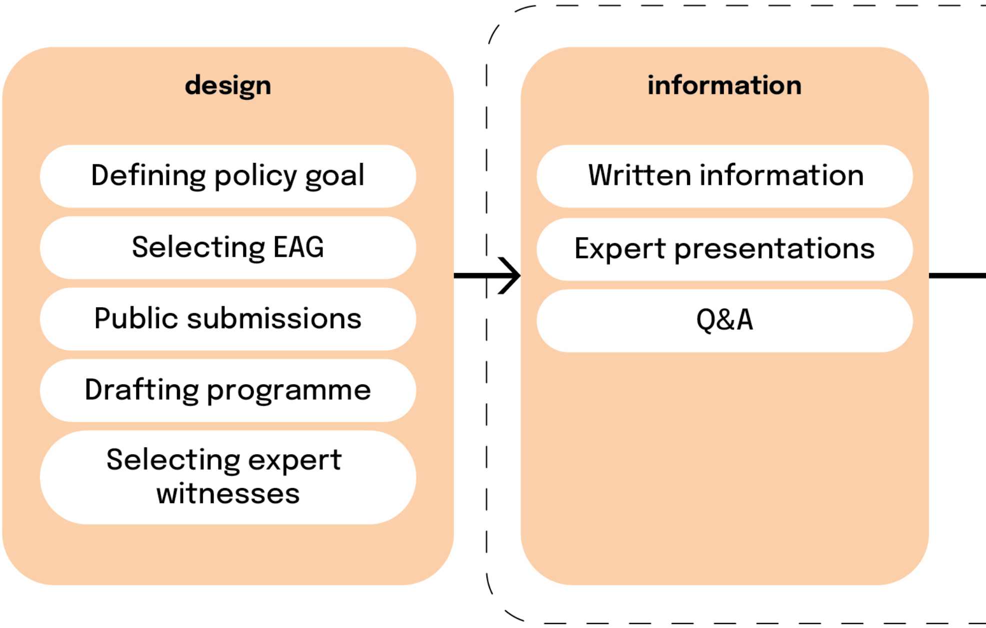
The Participatory Value Evaluation (PVE) is a relatively new citizen engagement method that enables large groups of citizens to advise policymakers on public problems in an online environment, involving a range of policy options and their effects as well as a particular constraint, usually a public budget and a policy target. Citizens 'step in the shoes' of policymakers as it were, experiencing complex policy choices and trade-offs (Mouter et al., 2022). The PVE was explicitly designed to resolve several limitations of the traditional CBAs that predominates Dutch policymaking (Mouter et al., 2021b). The PVE method has recently been applied to various a range of policy issues, including relaxation of national COVID-19 measures (Mouter et al., 2021a), urban mobility investments (Mouter et al., 2021b) and the energy transition (Mouter et al., 2021c; Itten & Mouter, 2022). Since participants usually spend 20-30 minutes evaluating policy options, participation barriers are low and large groups of citizens can participate (Mouter et al., 2021c).

Inspired by previous successes, author 2 initiated its application to national climate policymaking. Compared to the ICA, the PVE was not formally embedded in the policy process, but was developed in close collaboration with representatives of the National Climate Agreement (2019). This Agreement outlines the Dutch national mitigation strategy, which was the culmination of a deliberation process among 150 stakeholders across five 'climate tables' (Rijksoverheid, 2019). However, the National Climate

	ICA on climate change	PVE on national climate mitigation
Year	2017-2018	2020-2021
Number of citizens	99 citizens (population: 4.7 million)	10,810 citizens (population: 17.5 million)
Duration	Two weekends, 26 hours of deliberation	20-30 minutes of evaluation
Question	‘How the State can make Ireland a leader in tackling climate change’	‘How to cut 55% emissions by 2030 compared to 1990’
Initiators	Government	Academic researchers
Institutional embedding	Formally embedded in policymaking process by government committee	No formal embedding in policy-making process, but aligned with National Climate Agreement
Key actors	Secretariat, Expert Advisory Group, expert witnesses, chair, citizens	PVE researchers, policy advisors, government representatives, citizens
Policy recommendations	13 recommendations in three sectors: energy, transport and agriculture	10 policy options in five sectors: energy, agriculture, transport, housing, industry
Policy outcomes	Recommendations reflected in policy strategies	Mostly discursive (results presented in letter to Ministry and presented to members of Houses of Representatives)
Format of providing information	Written papers, live expert presentations and Q&A	Expert-based policy characteristics in online environment

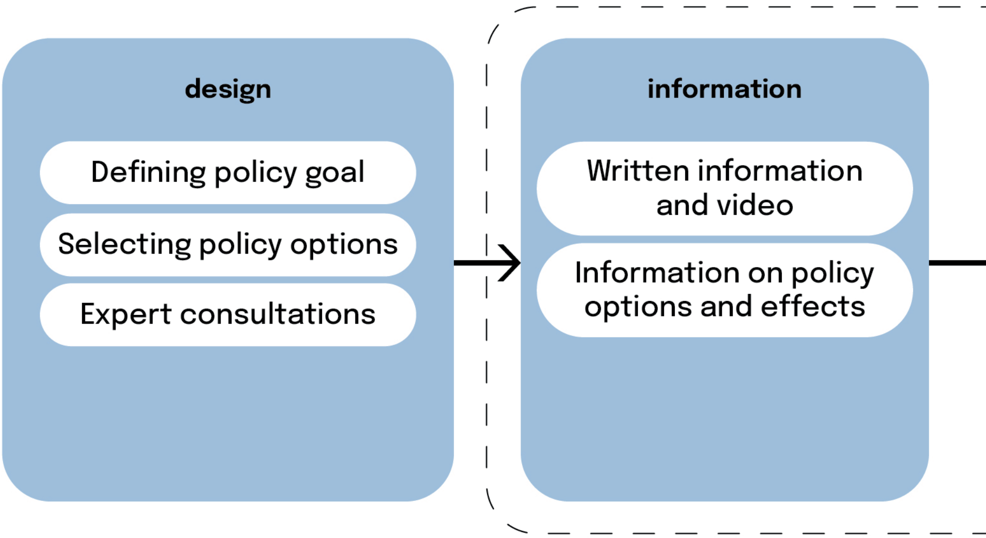
Table 5. Overview of characteristics of both cases

A. ICA on national climate mitigation



Jan – Sep 2017

B. PVE on national climate mitigation



Dec 2020 – Feb 2021

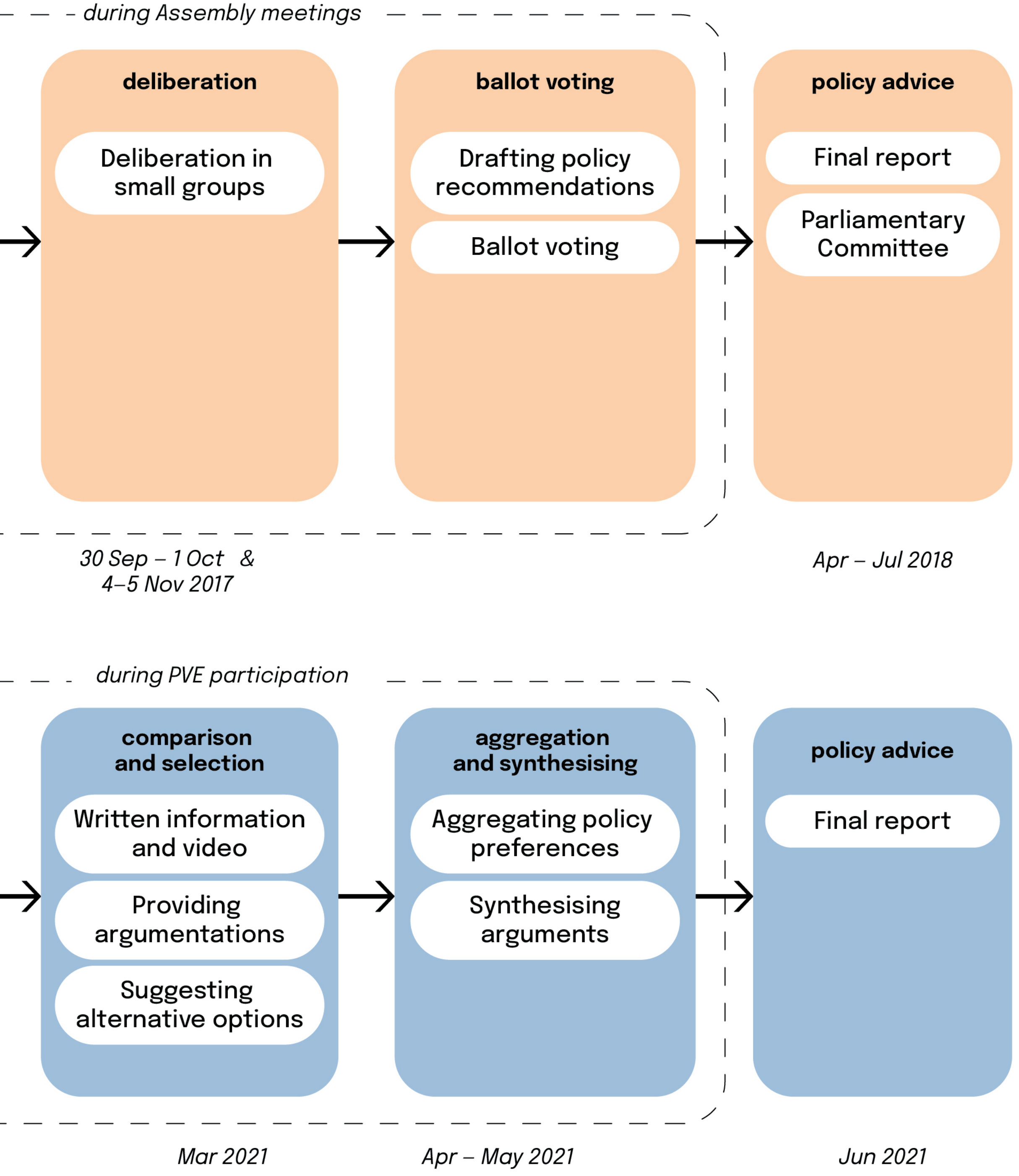


Figure 16. Schematic overview of the phases of the ICA (A) and the PVE (B)

Agreement was assessed as being largely insufficient in achieving its target (PBL Netherlands Environmental Assessment Agency, 2019; 2020). Moreover, following the EU Green Deal, the Netherlands strengthened its national emission reduction target from 49% to 55% by 2030 compared to 1990 levels. In 2020, a Dutch politician filed a motion to consider ways to improve citizen engagement in climate policy, considering the failure to effectively engage citizens and the positive experiences with national climate assemblies in other countries (Mulder et al., 2020). These developments provided the background to initiate the PVE. All Dutch citizens could participate in the PVE through a website link. To ensure representativeness, citizens were also randomly selected by a market research company (hereafter called 'open PVE' and 'PVE panel'), resulting in a total of 10,810 participants. Figure 18b shows the online environment in which PVE participants could evaluate 10 policy options across five mitigation sectors such as a meat tax, off-shore wind and electric vehicle subsidies (see also Appendix D2). Citizens could indicate their preference by using a slider for each options from 'no extra effort' to 'strong extra effort', while receiving real-time information on the extent to which their selected options reached the 55% emission reduction target. Clicking on a policy option revealed information on costs, effectiveness and other policy effects.

As illustrated in Figure 16, participants first received an introduction text and video about climate change and EU and national climate policy prior to their evaluation and selection of preferred policy options. After their selection, citizens provided written arguments for or against policy options and could propose alternative suggestions, followed by a survey to evaluate the PVE (Appendix D2). The policy options were also divided across the five mitigation sectors to align with the National Climate Agreement. Furthermore, the PVE results needed to be finished in time for the national elections in May 2021, serving to gain political support for citizen engagement, alongside another report that recommended the establishment of a citizens' assembly (Brenninkmeijer et al. 2021). The preferred set of policy options that citizens selected were aggregated, resulting in a percentage of citizens that are for or against each policy option (Mouter et al. 2021d). The PVE researchers also collected all written arguments for and against each policy option and performed a qualitative analysis to distil the key most often recurring normative principles for public support for ambitious climate policy: 1) policies that personally affect citizens are only acceptable if climate measures to large polluters are visually taken, 2) protect citizens with lower incomes, 3) the polluter pays and 4) benefits of policy options should outweigh the costs. The report was presented to Members of Parliament and handed over to the coordinator of the National Climate Agreement. This coordinator presented it to the Minister of Economics and Climate in an official letter and commented that the report was 'highly relevant to politics'. PVE researchers also presented the results to members of Parliament. As of spring 2023, policy outcomes of the PVE are less clear compared to the ICA, but the four key principles were highlighted in various media (Appendix D4 for timeline), reflected in policy debates (interview 13, 14)[39] and used by lobbyists (interview 15). In a parliamentary debate in November 2022 the Minster of Climate promised to consider the four principles in upcoming climate policymaking and stressed the importance of citizen engagement more generally.

39 The interviewees were numbered anew in this chapter and therefore do not match the numbers attached to interviewees in chapters 2 and 3

In the following sections, we first present a reconstruction of the processes of opening-up and closing-down of climate policy options in the ICA and PVE (section 6.6), followed by a detailed dramaturgical analysis of how the setting, scripting and staging of expertise in each case and shaped these dynamics of opening-up and closing-down (section 6.7).

6.6 Comparison of dynamics of opening up and closing down the possibility space

As schematically illustrated in Figure 17, we observed that in both cases the possibility space was gradually closed-down by various actors throughout the phases, yet in contrasting ways. The Irish government tasked the ICA with the broad policy question: *'How the State can make Ireland a leader in tackling climate change'*. In contrast, PVE participants were faced with a much narrower framing, namely how the Netherlands could cut 55% emissions by 2030 compared to 1990, which already shaped the types of policies that were relevant. In both cases, the possibility space was further shaped by the choice to focus on specific mitigation sectors (interview 8; Mouter et al. 2021d). A stark difference between the cases is that where PVE participants could only choose between 10 policy options that were preselected by PVE researchers and policymakers, expert witnesses in the ICA identified approximately 60 policy options.[40] Despite the limited set of options, participants in the PVE could freely propose policy suggestions in an open question after their comparison, resulting in radical

40 Policy options that were provided textually by experts in their papers and slides or orally during their presentations were counted. This is an estimated number of policy options, taking into account the possibility of double counting.

policy proposals such as giving legal rights to nature and decreasing child benefits (Mouter et al., 2021d). A sample of the additional ideas and policy proposals that citizens proposed were also included in the report, but not in the key conclusions as PVE researchers faced difficulties assessing inclusion criteria, hence indicated as a dotted line in Figure 18. In contrast, although citizens in the ICA were able to propose alternative policy options beyond the ones presented by experts, in practice, all citizens' sectoral recommendations reflected policy proposals suggested by one or multiple experts (see also Muradova, Walker & Colli, 2020). All 13 recommendations on the ballot reached a majority of votes of at least 80%, which the highest across all five topics (Devaney et al., 2019). In the PVE, citizens' preferences were aggregated resulting in 7 policy options that were preferred by most participants (50%< in both open and sample PVE, Appendix D2). The report included four key recommendations (section 6.5.2).

6.7 Comparison of scripting, setting and staging of expertise

In this section, we compare how the scripted roles of experts (6.7.1) and the particular setting and staging of expertise (6.7.2) affected the dynamics of opening-up and closing-down.

1) Scripted roles of experts in the ICA and PVE

ICA

A Secretariat consisting of civil servants was assigned to develop the work programme, oversee the process and write the final report. The ICA involved two types of experts, each with different scripted roles:

Figure 17. Schematic illustration of the processes of opening-up and closing-down of the possibility space in both cases (y-axis illustrates possibility space (range of policy options and perspectives) and x-axis illustrates time (phases). The figure provides an illustration rather than an exact representation).

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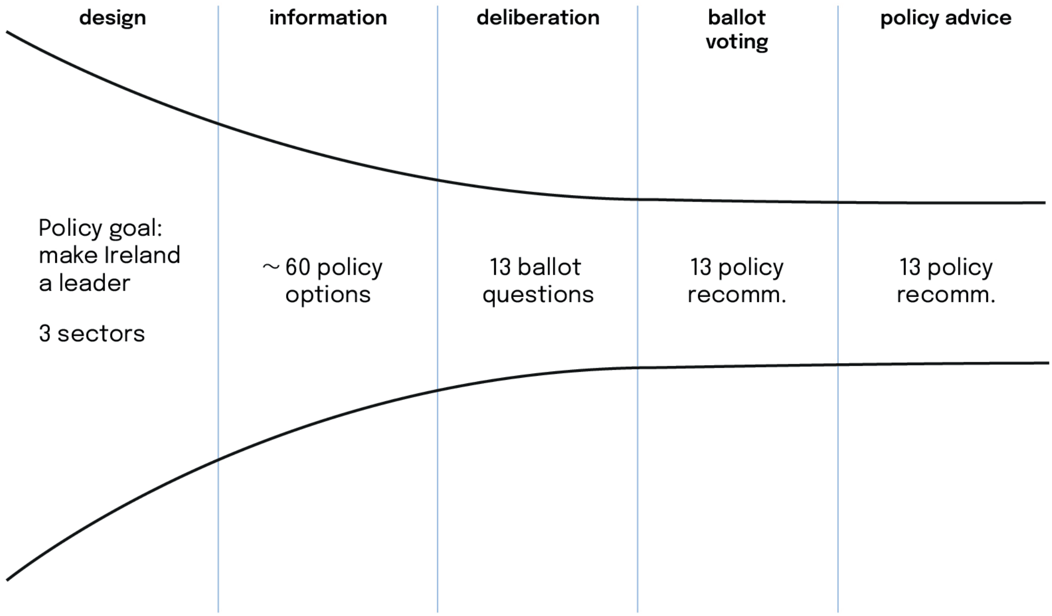
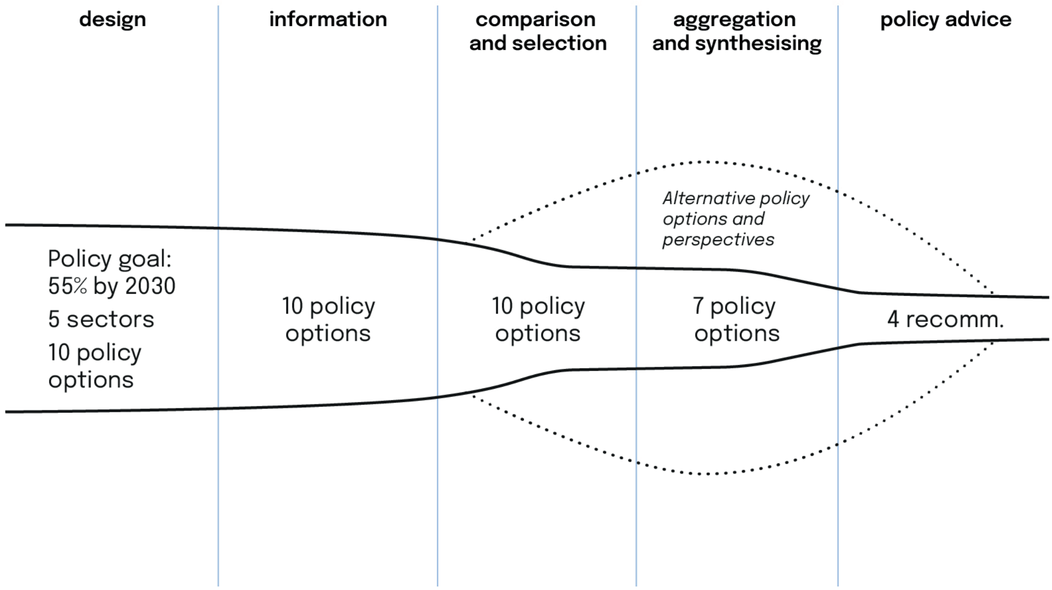
A. ICA
on national climate policy



B. PVE
on national climate policy



1) expert witnesses that would provide presentations and answer questions during the information phase, and 2) an Expert Advisory Group (EAG) consisting of six experts with expertise on designing deliberative processes as well as climate experts from diverse disciplines (The Citizens' Assembly, 2018; Appendix D3 for types of experts and expertise). The two scripted roles of the latter were 'process designers', as the EAG assisted the Secretariat in designing the work program and selecting expert witnesses as well as 'technical assistants', assisting Assembly members in assessing the technical feasibility of policy options when drafting the questions (The Citizens' Assembly, 2018).[41] Citizens could provide feedback on the information programme during its design. Nevertheless, design choices such as the focus on specific sectors influenced citizens' deliberative space:

41 The names of 'process designers' and 'technical assistants' were not named as such in the report but identified here based on their responsibilities

'There wasn't that holistic looking at the system that would contribute to the climate crisis. It looked just at different sectors. […] There was just a very narrow lens and there wasn't room for creativity, innovation or radical alternatives' (interview 11, Assembly Member).

Moreover, although the EAG was instructed to operate as technical assistants, the interviews suggest they took a more influential role as 'recommendation formulator'. The Assembly members could propose initial topics in the first weekend, followed by iterative drafts by the Secretariat and EAG and feedback by Assembly members in order to ensure citizens 'took ownership of the ballot' (The Citizens' Assembly 2018, p. 12). However, our interviews suggested that experts had a significant role in drafting the recommendations:

'It was certainly a collaboration between the citizens and the Expert Advisory Group but I would say the Expert Advisory Group raised the bulk of the recommendations that were voted upon in reality.' (interview 10, EAG member)

The 15 expert witnesses included 9 academics and researchers from other scientific institutes and governmental agencies as well as 6 'advocates championing low-carbon transitions' such as a representative of local energy community initiative, a firefighter who initiated the first carbon neutral fire station and a social enterprise tackling food waste (Devaney, Torney, *et al.*, 2019, p. 6). The witnesses involved diverse forms of expertise, including process expertise on designing deliberative processes as well as technical and scientific climate expertise, expertise on policy and law as experiential expertise on initiating on-the-ground initiatives (Appendix D3 for types of experts

A.

B.

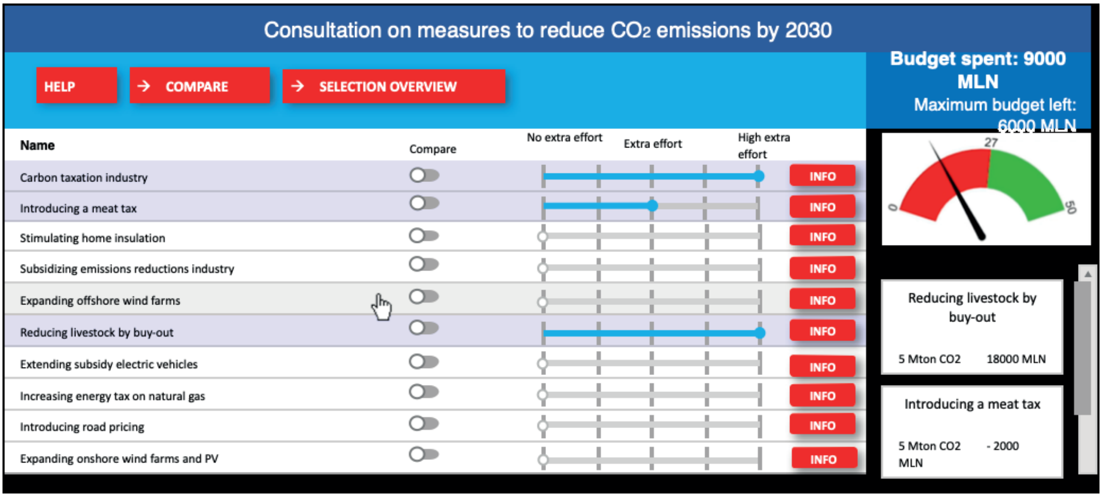


Figure 18. Physical setting of the ICA (A) and the PVE (B).

and expertise). Assembly members found the provided information understandable, balanced and of high quality (Farrell et al., 2017, Appendix D1). However, both experts and citizens found two weekends highly insufficient given its complexity (interview 3, 4, 7,8). Due to time limitations, only a small set of experts could be involved for each sector and the limited amount of experts therefore largely influenced the outcomes:

'Citizens have limited time to be informed or to get informed. Inevitably who you ask to do the informing does have an influence on the outcomes.' (interview 2, expert witness).

'[the recommendations] very much reflected the information that we had been told.' (interview 11, Assembly member).

Although citizens could propose expert witnesses, some of which were indeed invited (interview 8, Secretary), the majority of expert witnesses were selected by the EAG using a number of criteria (The Citizens' Assembly 2018, p. 54). Moreover, although the expert witnesses were instructed to act as 'honest brokers', providing a range of policy options, they sometimes stepped out of this role and acted as 'issue advocates', strongly advocating for specific policy options (cf. Pielke, 2007). Examples of issue advocates include a highly respected economist who strongly emphasised carbon taxation in his presentation (interview 2, 7, EAG members) and a mobility expert who strongly argued for investment in public transport during a Q&A session (video Q&A session 1, September 30th 2017). Our interviews and analysis of proposed policy options suggest that options that were either strongly advocated by experts or presented by multiple experts were likely to end up in citizens' recommendations (see also Appendix D2), which is in line with Muradova et al. (2020).

PVE

The PVE also involved two types of experts with different scripted roles: 1) a team of PVE researchers (led by author 2), including experts on designing the PVE as well as climate experts (Appendix D3) who coordinated the PVE design and developed the report and 2) external climate experts who provided feedback on the policy options and effect representing various disciplinary fields (Appendix D3). Similar to the EAG in the ICA, the PVE researchers were thus involved as 'process designers', with an even stronger influence on the design as they were coordinating the process. Designing the content and parameters of the PVE, including defining the quantitative target, government budget constraints, policy options and the information on policy effects (such as costs, effectiveness, health and biodiversity) involved an iterative process between PVE researchers, policymakers and policy advisors and external experts to ensure both policy relevance and credibility (see Appendix D4 for a timeline). The selection of the final 10 policy options was further informed by the five mitigation sectors in the Netherlands as well as a special government report on the effectiveness of policy options to achieve the 55% emission reduction target (Van Geest, 2021). Where the EAG involved in the design of the ICA were only implicitly framing citizens' deliberations, PVE researchers shaped the possibility space more explicitly by selecting a small set of policy options. Among PVE participants' responses, the most often mentioned negative aspect was the limited range of options (N=148), commenting for instance that they were 'steering too much' (see also Appendix D1). Apart from the design, PVE researchers also had a significant role in formulating policy recommendations. Out of all alternative policy options that citizens identified, the researchers selected a small sample to be presented in the final report (Mouter et al., 2021d). The selection was aimed at showing policy makers the creative capacity of citizens to identify 'out-of-the box' proposals. Moreover, the PVE researchers also aggregated citizens' preferences into percentages of support for each policy option and analysed 2000 of participants' responses to identify recurring arguments for and against policy options which they synthesised into key guiding principles (Mouter et al., 2021d). In other words, PVE researchers essentially closed-down the diverse perspectives of more than 10.000 citizens into four key guiding principles.

2) Setting and staging of expertise in the ICA and PVE

ICA

The ICA took place in the formal setting of a conference room, enabling two-way face-to-face interactions between experts and citizens. As indicated by the video material, when experts spoke, they stood on a pedestal and citizens were placed at small roundtables (Figure 18a). During expert presentations, this setting may have casted citizens as passive recipients of knowledge provided by experts. Although citizens could ask questions during the Q&A sessions, the experts were still on the podium. This privileged position of experts may have hampered citizens' ability to critically scrutinize experts' claims and introduce alternative policy options to those experts suggested in their presentations. Although citizens occasionally introduced alternative policy options, such as incentivising seaweed production as an alternative to animal protein, citizens predominantly asked experts for clarification (videos of Q&A sessions of first weekend). As an expert witness noted: 'citizens didn't come up with their own ideas' (interview 6). Instead, citizens asked experts to make recommendations:

'a lot of the time, we were sort of asking the experts: tell us what to advise, we don't know enough on this. Please tell us what recommendations we need to make because you are the experts and we are complete novices to this.' (interview 11, Assembly members).

This tendency of citizens may have been enhanced through the particular staging of expertise, as the Chair introduced expert witnesses as 'explainers' of causes and solution orientations of climate change, highlighting their leading positions in authoritative scientific institutes and policy councils (opening speech and introduction of experts by the Chair).

PVE

In contrast to the ICA, in the PVE the setting was an individualised engagement with an online interactive tool where citizens evaluated a small set of policy options towards a quantified emissions target and a constrained budget presented on the screen (see Figure 18b). The setting of a relatively simple online tool allowed large groups of citizens to participate. However, it allowed a limited set of policy options to be evaluated, which strongly predefines the possibility space and also prevents citizens from interacting with experts or critically scrutinise expertise. The expertise was staged as a small number of quantitative and qualitative policy effects, which many citizens found sufficient and clear (See Appendix D1). However, the expert-based policy effects were staged as non-negotiable facts, e.g. 'building off-shore wind creates job opportunities', 'road pricing will reduce commuting time and improve reliability', with links to several authoritative reports such as those by the Netherlands Environmental Assessment Agency (PBL). This fact-like presentation of expertise and absence of a personified expert may have created a form of 'mechanical objectivity' (cf.

Hilgartner, 2000), which may close-down citizens' diverse perspectives on desirable policy options. Moreover, this mechanical objectivity risks masking the explicit choices that PVE researchers made in selecting policy options and their judgments of relevant policy effects.

6.8 Discussion

In this section, we reflect upon the theoretical and practical implications of our two key findings (6.8.1 and 6.8.2) and propose recommendations for future research and practices of citizen engagement (6.8.3).

1) Experts' prominent roles in shaping the outcomes of citizen engagement practices

A key finding of our research was that expert involvement largely shaped the process and outcomes of both cases. Experts not only provided information, but made critical design choices which framed citizens' deliberations and had significant roles in formulating the recommendations (see section 6.7.1). This finding is in line with earlier empirical work on the Irish and French climate assemblies (Courant, 2020; Muradova et al., 2020; Giraudet et al., 2022a) but it contrasts findings of the UK climate assembly, in which expert information was only marginally discussed (Elstub et al., 2021). Although research on expert involvement in PVE applications is lacking, PVE researchers typically have a strong coordinating role, defining the scripted roles of external experts as well as how expertise is staged (see e.g. Mouter et al., 2021a; Mouter et al., 2021d). However, citizens' deliberations are not just shaped by experts. Government officials often set the boundaries within which citizens can deliberate, such as the choice of the topics and what happens with the recommendations. In both cases governments decided upon the policy question (as illustrated in Figure 17), which already framed citizens' deliberations. The policy question varies across citizens' assemblies, from a specified quantitative target (e.g. France, UK) to a more open question (e.g. Ireland, Germany, Scotland). Another factor that may have shaped the outcomes is that the ICA was more formally embedded compared to the PVE. A stronger institutional embeddedness may enhance citizens' willingness to push for alternative options. Time constraints may also influence the outcomes, potentially intensifying experts' influence.

In the ICA for instance, only a few experts could be involved which enhanced the influence of individual experts. More time could have limited this influence. The French and UK climate assemblies for instance, involved seven and six weekends respectively and citizens were assigned to different working groups to ensure sufficient time for each topic. However, in the French citizens' assembly, experts still significantly influenced the outcomes (Courant, 2020; Muradova et al., 2020; Giraudet et al,. 2022a). In the UK climate assembly experts' influence remains unclear, but expertise was only marginally discussed during small-group deliberations (Elstub et al., 2021).

Altogether, it can be concluded that experts significantly shape the outcomes of citizen engagement practices in national climate mitigation policy. This may not necessarily be problematic. More informed opinions are even viewed as a desirable outcome according to deliberative democracy theorists. It becomes problematic however, if policy recommendations are presented as citizens' own identified ideas whereas in reality these reflected experts' proposals. Our findings thus reiterate that the strong involvement of experts makes citizen engagement processes susceptible to manipulation (Böker & Elstub, 2015; Roberts et al., 2020). Our findings thus call into question the promise of citizen engagement practices to 'open-up' policy debates (cf. Fiorino, 1990; Stirling, 2008). According to Stirling (2008) closing-down means assisting incumbent policymakers by highlighting a small courses of action, as opposed to opening-up of how courses of action appear preferable under a wide range of perspectives. Both dynamics where at play. On the one hand, both cases showed a gradual closing-down towards a small set of recommendations (see Figure 17). On the other hand, despite the small set of preselected policy options, the PVE opened-up new normative principles that Dutch policymakers were not fully aware of (interview 13-15). Likewise, despite the small set of recommendations in the ICA, some of the recommendations were highly controversial. In other words, it matters *what* is opened-up (policy options or normative perspectives) and *compared to what* (e.g. incumbent policymakers or experts' identified possible policy options).

2) Dramaturgies of expertise and dynamics of opening-up and closing-down

A second key finding of our comparative analysis was that the particular setting, staging and scripting of experts and expertise affected the dynamics of opening-up and closing-down policy options and perspectives. In both cases, two types of experts were involved: 1) *embedded experts* (PVE researchers / the EAG), which included expertise on the process design as well as climate experts on from various disciplines and 2) *external experts* (externally consulted experts / expert witnesses) that were invited to provide information. Two scripted roles of the embedded experts were 'process designers' as well as 'recommendation formulator' which both largely shaped citizens' deliberations (see section 6.7.1). Most national climate assemblies so far involve embedded experts in the form of an expert advisory panel or alike that makes design choices and assists citizens in formulating ballot questions (see KNOCA, 2022 for overview). Earlier empirical work already stressed the critical role of such a panel (Lightbody & Roberts 2019; Roberts et al., 2020). PVE researchers also typically have a coordinating role in scripting the roles of experts and citizens, designing the PVE and formulating the recommendations (see e.g. Mouter et al., 2021a; 2021c), except one case where citizens could both define the policy options and recommendations themselves (Itten & Mouter, 2022). The scripted roles of the external experts was that of 'honest brokers' (Pielke, 2007), where experts were tasked to identify a range of policy options and effects. In the ICA case these involved a diverse set of expert witnesses, ranging from academics to politicians to representatives of on-the-ground initiatives. On the one hand, it could be argued that these expert witnesses 'opened-up' citizens' deliberations by identifying options that citizens were not previously aware of. On the other hand, our research shows that citizens did not identify options themselves and experts sometimes forcefully communicated options, which is line with earlier research on the Irish and French climate assemblies (Courant, 2020; Muradova et al., 2020; Giraudet et al., 2022b). The latter may have been enforced by putting experts in a privileged spot (setting) and emphasising their authoritative roles (staging), which emphasises the 'knowledge deficit' model of expert-citizen interactions, which has been criticised for disregarding citizens' relevant contextual and experiential knowledge (cf. Bulkeley, 2000; Fisher, 2000). Although research on different room set-ups across citizens' assemblies is lacking, plenary expert presentations seems common practice across national climate assemblies so far (KNOCA, 2022 for an overview). In the PVE case citizens' deliberations were more clearly closed down: although experts (both embedded and external) presented a range of options and effects as honest brokers, the fact-like staging of expertise risks masking their preselection of a small set of options.

A different scripting, setting and staging may have resulted in different dynamics of opening-up and closing-down. For instance, experts may not be tasked to present specific options, but merely some solution-orientations to inspire citizens. In the climate assembly in Austria for instance, experts provided a number of 'leverage points' for citizens to brainstorm on policy options (KNOCA, 2022). This may reduce the risk of experts' forceful communication of policy options. A different room set-up may also limit experts' influential role. In the UK climate assembly for instance, experts were often visiting small groups, allowing for a more reciprocal dialogue (Elstub et al., 2021). Experts may also be staged as 'enablers' or 'participants' rather than 'informers' (see e.g. Lightbody & Roberts, 2019) to stimulate citizens' capacity to identify alternatives. With regard to the PVE, the setting of an online tool is necessarily limited to a small range of options to ensure its accessibility. Nevertheless, citizens could have been enabled to evaluate more options, for instance by first selecting 10 out of 100 options, followed by more detailed evaluations. Moreover, a less fact-like staging may counteract experts' influence, such as in the recent PVE application to the Dutch energy system where citizens divide points to a number of normative principles with more generalised effects. Although our research is limited to only two cases, it can be concluded that the choice of the scripted roles of experts largely shapes the opening-up and closing-down of citizens' deliberations on climate policies, which may be enforced by the particular setting and staging of expertise. Although our findings need to be confirmed by investigating a larger set of cases, our research highlights that it matters not just *what* experts are involved (the forms of expertise) but also *how* they are brought in (their scripted roles during different phases of the process, the physical setting and how expertise is staged).

6.8.3 Limitations and recommendations for future research and practices

Our research involved various biases and limitations, most notably in case study selection. Our findings regarding the significance of expert involvement more generally (8.1) is in line with earlier empirical work and the scripted roles (8.2) are relatively similar to other cases. However, the particular setting and staging across other cases remains largely unclear. We therefore recommend that future research further investigates how a different setting and staging of experts and expertise influences citizens' recommendations across more PVE and citizens' assembly cases. We also recommend the investigation of a more diverse set of citizen engagement practices, including for instance also citizens' juries, collaborative governance and participatory budgeting, given that expert involvement is highly diverse (Lightbody & Roberts, 2019). Our research also only superficially engaged with the different forms of expertise (e.g. process vs. knowledge or different disciplinary fields), which may have different effects on the opening-up and closing-down of policy options. Our research also indicates that future research should not only focus on the information phase, since experts can have diverse scripted roles across multiple phases. Methodological limitations could also have influenced our results. The personal involvement of author 1 and 2 may have biased the results of the PVE, for instance by overlooking design choices such as framing of the problem resulting from their own expertise or neglecting critical choices made in formulating policy recommendations. The critical stance of author 2, involvement of three authors with a more critical distance, the survey by PVE participants and interviews were aimed at counteracting these biases (see also section 6.4). The personal involvement also implied a difference in methods, which may have resulted in an unequal comparison (e.g. more diverse perspectives in the ICA compared to the PVE due to a larger number of interviews). Moreover, our data was too limited to separate the influence of the setting, staging of expertise, the types of experts and expertise or external influences on citizens' deliberations.

Our research also revealed some practical considerations for organising participatory processes. First and foremost, organisers should carefully consider the goal of engaging citizens (e.g. identifying normative perspectives or policy options) and adjust the appropriate setting (e.g. deliberative or online) as well as the scripted roles of experts accordingly (see section 6.8.2). Given the complexity and required technical knowledge in climate mitigation policy, the strength of engaging citizens might be their diverse normative perspectives, in contrast to a local and more tangible policy issue where citizens have factual knowledge about their local area. Apart from the governance level, the goal of citizen engagement may also depend on the policy stage: e.g. identifying policy options during agenda-setting and normative perspectives during implementation (cf. Wells et al., 2021). Secondly, a more honest and equal staging of expertise can improve the fairness of citizen engagement processes. In a deliberative setting, experts could physically be put in a less privileged spot, allowing for a more interactive and equal dialogue (cf. Roberts et al., 2020; Elstub et al., 2021). Third, citizens could be tasked with a narrower topic. Focusing on a specific mitigation sector for instance, allows for the inclusion of a larger number and more diverse types of experts on this topic, which reduces the influence of views of individual experts (cf. Lightbody & Roberts, 2019). A narrower topic may also be more tangible for citizens and might be less likely to cognitively overload them, which can support their creative capacity to identify policy options. Fourth, to limit the exclusionary expert framing, citizens' agency in the selection of experts and expertise could be enhanced (cf. Roberts et al., 2020; Itten & Mouter 2022). Risks of the latter might be that relevant forms of expertise are excluded from the process and only publicly known experts become involved.

6.9 Conclusion

We compared two contrasting cases of citizen engagement in climate policymaking to better understand the role of experts and expertise. In both cases, citizens' recommendations largely reflected experts' proposals of possible policy options. Experts were not only involved in providing information but had diverse and critical roles in design choices and formulating recommendations. Future research should further investigate the role of experts and expertise across a larger number of cases and a wider variety of practices. Nevertheless, it can be concluded that the complexity of national climate mitigation policy and the required technical knowledge necessarily implies a significant role of experts. We found that the particular setting, staging and scripting of experts and expertise can result in different dynamics of opening-up and closing-down. Our findings suggest that where a citizens' assembly allows for a larger range of policy options to be scrutinised, the PVE produced insights into more diverse normative perspectives. The dynamics of the possibility space is further shaped by the particular scripted roles of experts and staging of expertise. Organisers of citizen engagement processes should therefore carefully consider *what* should be opened-up (policy options or normative perspectives), by *whom* (citizens or experts) and *how* (scripted roles and staging of expertise). This may depend on the scale, complexity and stage of the policy issue.

7.

Synthesis and conclusion

7.1 Rationale and thesis overview

Modelling has been an integral part of the process of environmental policymaking ever since the *Limits to Growth* (Meadows et al., 1972) report. Indeed, its powerful and straightforward message, backed by quantitative projections, caused a major paradigm shift at the time. For the first time, the environment could be understood on a global scale and authoritatively presented a *global* threat requiring international cooperation (Warde, Robin, & Sörlin, 2018). At its 50th anniversary in 2022, various books, news articles, conferences and seminars were devoted to the report, many of them looking back at the frustratingly slow progress over the past 50 years given that 'we had been warned' (e.g. Tielbeke, 2022; Bardi & Alvarez Pereira, 2022; Kahn, 2022). However, the fact that *Limits to Growth* marked the start of the widespread use of global modelling received surprisingly little attention. Whereas prior to the 1970s the idea of global modelling to project long-term futures was 'considered thoroughly audacious if considered at all', the worrying projections of the *Limits to Growth* suddenly made the idea of global environmental change imaginable to governments and the public worldwide (Ashley, 1983, p. 496). When it comes to modelling, the *Limits to Growth* caused a sea change. Indeed, simulation models have become so prominent that some view them as 'virtually a knee-jerk' response to understanding environmental change (Edwards, 2010, p. 358; Heymann et al., 2017).

In this thesis I analysed a specific type of simulation model used to explore global pathways towards the climate targets: Integrated Assessment Models (IAMs). IAMs allow for the simulation of interactions between the climate system and society on a global and long-term scale, which enables the understanding of different policy pathways and their associated effects. Since the early 1990s, IAMs have been at the heart of IPCC's mitigation scenarios and have supplied crucial input to the UN climate negotiations. Since the Paris Agreement in 2015, the IPCC has shifted its focus even more from problems to response strategies, which implies that IAMs are likely to continue to have a prominent role in the years to come. However, climate change is no longer merely discussed within the institutional bounds of the UN climate negotiations, but is handled via 'polycentric governance' instead (Bäckstrand et al., 2017; Jordi, 2015). National governments, cities, businesses and organisations all over the world are busy exploring and implementing climate strategies. It is unclear if and how IAMs, which have been successful in serving the needs of multilateral environmental diplomacy, can cater to the knowledge needs of the growing plurality of actors. Moreover, how to respond to climate change is now a primary issue of societal debate. Citizens and activists are also becoming increasingly vocal through climate protests, demanding rapid and radical action while simultaneously reframing the issue to call for climate justice. Due to their orientation towards cost-effectiveness and technological innovation, there is an ongoing debate on the capability of IAMs to conceive of radical transformations (see e.g. Anderson & Jewell, 2019) and address justice considerations (see e.g. Rubiano Rivadeneira & Carton, 2022). Both these limitations and the plurality of actors and perspectives in climate politics suggest the need to pluralise and democratise the 'possibility space', defined in chapter 1 as 'the range of future actions, solution-orientations or policy options that are discursively and imaginatively opened-up and closed-down'. In other words, while IAMs have become the primary approach to explore low-carbon futures in the global climate science-policy interface, the plurality of actors and perspectives in climate politics challenge their prominence. In this thesis, I explored this tension by focusing on the following research question:

How do IAMs shape the possibility space of possible low-carbon futures, and how could this possibility space be pluralised and democratised?

As illustrated in Figure 19, this thesis was structured in two parts, each focusing on two sub questions. In **Part I**, I took a retrospective approach in analysing the past and current role of IAMs in climate policy. Observing their spectacular rise to prominence, I first aimed to understand how global simulation modelling could gain such an authoritative position by analysing the historic co-evolution of IAMs and global climate policy (**chapter 2**). This historic analysis was not only focused on *describing* the different roles of IAMs over time but also on finding *explanations* for their prominence. To better understand how IAM pathways become persuasive, the following chapter (**chapter 3**) looked more closely at interactions between the IAM and policy community around the SR1.5 report (IPCC, 2018). In both chapters, I took a practice-oriented approach to analysing IAMs: my analytical focus was not on the characteristics of the models per se, but on how they function as a Technique of Futuring (ToF; Hajer & Pelzer, 2018; Oomen et al., 2021). This analytical lens brought into view how, through the practice of IAM modelling, particular imagined futures become collectively shared and shape actions in the present (see **chapter 1**).

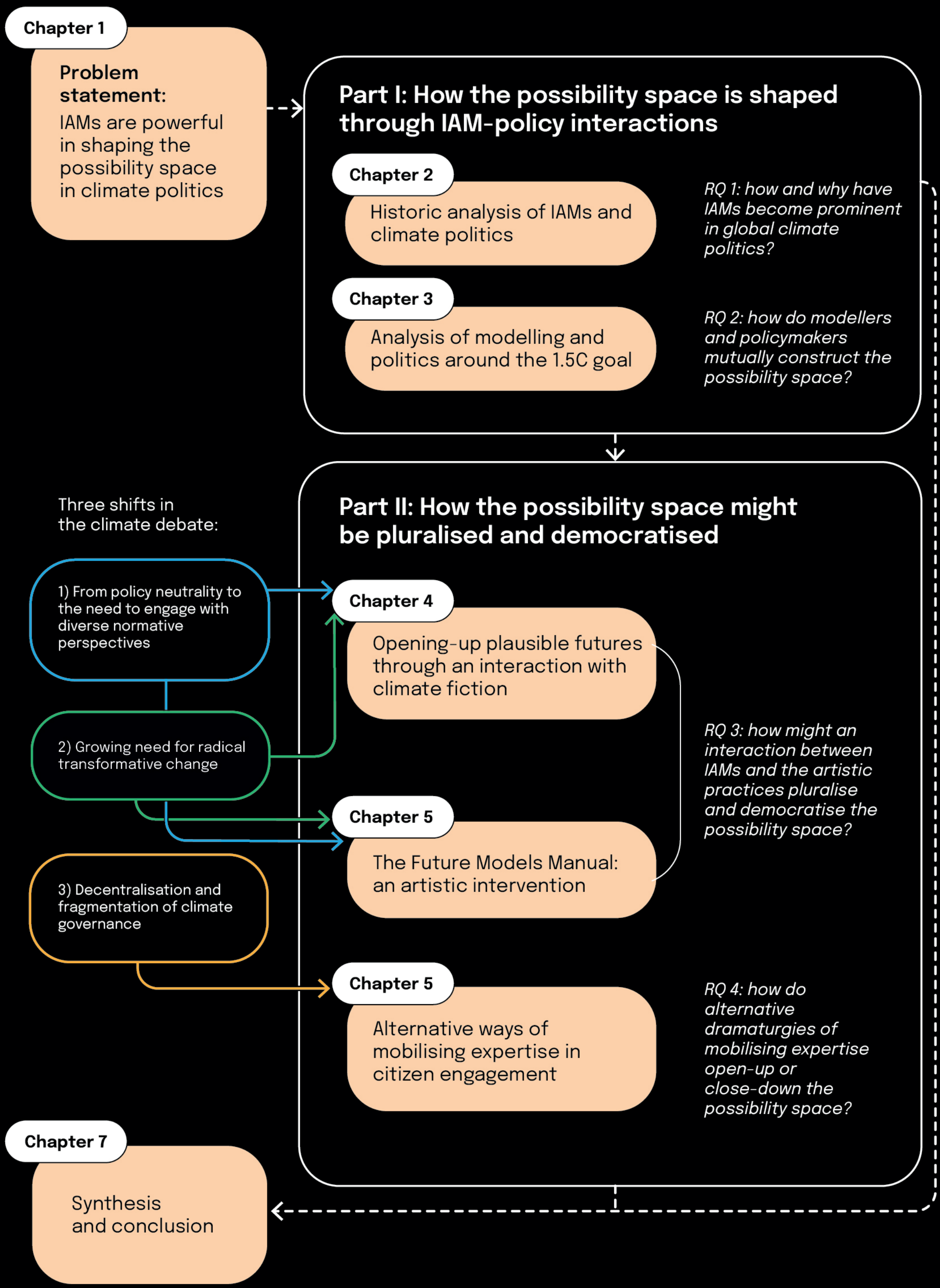


Figure 19. The structure of the thesis (see also chapter 1)

In response to their prominence and limitations, the future of IAMs is subject to a heated scholarly debate. Three prominent perspectives include *discarding* IAMs, *improving* IAMs or *complementing* IAMs with other tools (Gambhir et al., 2019). However, rather than viewing IAMs as a tool, in **chapter 1** I argued that it may not be the IAMs themselves that are the problem, but rather how they interact with climate politics. I argued that addressing the previously mentioned shifts in climate science and politics – from problems to solutions, from a centralised to a polycentric governance response and the growing call for transformative change – required a different perspective. In **Part II**, I therefore took a forward-looking approach by experimenting with alternative interactions between IAMs, policy and society in order to explore possible ways to pluralise and democratise the possibility space. **Chapters 4-6** reflect on transdisciplinary exchanges between the IAM practice and artistic practices and also explored alternative forms of mobilising expertise in participatory practices.

Section 7.2 synthesises the findings by answering the four sub questions. In section 7.3, I explain how the combined findings of Part I contributed to understanding how IAMs function as a ToF. Building on the key findings and reflections, section 7.3 formulates an answer to the research question. Section 7.4 reflects upon the methodological challenges of this research, its scientific and societal contributions and sketches areas for future research. By way of outlook, this final chapter ends with a reflection on the future of IAMs in light of the growing imperative of climate justice (section 7.5).

7.2 Synthesis of key findings

7.2.1 Part I: understanding IAMs in climate policy

Part I offered insights into how IAMs function as a ToF (Hajer & Pelzer, 2018; Oomen, Hoffman, & Hajer, 2021). Oomen et al. (2021) formulated an analytical framework to analyse ToFs: *storylines* through which futures are represented, the *dramaturgy* of interactions between actors and the organisational and discursive *structure*. Shifting the focus of analysis from the models themselves to how through the practice of modelling particular imaginaries arise. These three dimensions are therefore used here to summarise the findings of chapters 2 and 3, as shown in see Table 6.

Characteristics of IAMs as ToF		Function in shaping climate policy	Challenges to pluralise and democratise the possibility space
Structure	Epistemic legitimacy of global and quantitative knowledge and strong organisational capacities of the IAM community in establishing institutional links with the policy community	Putting climate change on global political agenda and stimulating efficient IAM-policy interactions	Potentially excluding alternative knowledge communities and societal actors from knowledge-making and decision-making processes
Dramaturgy	'political calibration': continuous anticipation of and adjustment to knowledge needs and discourses of the policy community	Enabling policy-relevant modelling insights in the face of changing discourses and knowledge demands	Focus on policy relevance risks overlooking radical imaginaries and societal perspectives
Storylines	Concrete storylines and quantitative graphs (e.g. 'net-zero by 2050')	Highlighting the need for increased mitigation efforts and promoting stringent climate targets	Impression of apolitical and value-neutral pathways hampers political debate on desirable futures

Table 6. Overview of how IAMs function as ToF based on findings of chapters 2 and 3

RQ1: how and why have IAMs become prominent in global climate policy?

The historic analysis of the co-evolution of IAMs and climate policy in **chapter 2** revealed that between 1970 and 2015, IAMs became increasingly prominent and adopted various roles from agenda-setting to target-setting. A **key insight** was that their prominence in climate policy cannot be explained solely by material conditions (e.g. computer technology and data availability) or the analytical qualities of

IAMs (e.g. their flexibility, breadth and hybrid nature), but can, rather, be found in the more structural legitimacy of global and quantitative forms of knowledge in global climate policy as well as the proactive modelling community who deliberately performed 'institutional work' to establish their policy relevance and central position in the IPCC (cf. Lawrence & Suddaby, 2006). In other words, the prominence of IAMs could thus be explained from structural characteristics of the science-policy interface, IAMs' quantitative representation of storylines and the particular way in which modellers interact with policymakers (cf. Oomen et al., 2021). The historic science-policy interactions suggest that the prominence of IAMs is not set in stone and should be actively evaluated in light of the continuously shifting knowledge demands, actors and perspectives.

RQ2: how do IAMs shape the imagined possibility space in global climate policy?

Chapter 3 provided a more detailed look at how IAM pathways shape the possibility space by bringing certain possible futures into view while foreclosing others and thereby guide policymaking. With my co-authors I focused on the IPCC SR1.5 (2018) as a specific case to analyse the interaction between modellers and policymakers. A **key insight** was that modellers continuously readjust the focus of modelling efforts to fit the requirements of the policy community, a process we defined as 'political calibration'. This political calibration could be viewed as a key characteristic of the *dramaturgy* of interactions between IAM modelling and policymaking through which a particular possibility space is constructed (cf. Oomen et al., 2021). While this political calibration makes IAM scenarios relevant, modellers also face dilemmas as they need to continuously navigate political sensitivities and their scenarios tend to become more powerful than intended.

As summarised in Table 6, the findings of chapters 2 and 3 revealed the characteristics of how IAMs function as a ToF, how these characteristics facilitate close interactions between modelling and policymakers, and how these interactions shape climate policymaking. In both chapters, I showed how the concrete and quantified storylines of IAMs promoted stringent climate targets. However, the three shifts that are outlined in Figure 19 also raise questions about IAMs' proximity to the policy community. For example, in chapter 3, we argued that modellers may need to 'calibrate' to broader societal demands, as exemplified by the request for more transformative 1.5°C pathways by NGOs and civil society groups during the preparations of the IPCC SR1.5. In this chapter we also stressed that while the organisational capacities of the IAM community facilitate robust and efficient knowledge assessments, it may disadvantage other knowledge communities with less powerful anticipatory capacities (cf. Groves, 2017).

7.2.2 Part II: pluralising and democratising the possibility space

The close interactions between IAM modelling and climate policymaking and the associated challenges were the point of departure for Part II. Chapters 4 and 5 experimented with alternative exchanges between modelling, policy and society to pluralise and democratise the possibility space.

RQ3: how might an interaction between IAMs and artistic practices pluralise and democratise the possibility space?

Chapter 4 departed from the seemingly apolitical character of IAMs, which can potentially hamper a democratic debate on low-carbon futures, as well as the need for more radical imaginaries (see Figure 19). In this chapter, my co-author (a celebrated novelist) and I argue that an interaction between modellers and climate fiction writers could address these challenges. We brought modellers and fiction writers into conversation and compare their respective storytelling practices. A **key insight** was that while both modelling and fiction writing are practices of storytelling of plausible future worlds, they rely on contrasting mechanisms to build plausibility. Where models rely on historic trends, expert judgment, transparency and rationality, fiction writers draw on resonance with readers' experience, recognisable protagonists and concrete and emotionally meaningful details. Yet, both practices explore what-if questions, develop stories through a gradual and iterative process and plot their stories through a 'logical' order of events to ensure internal coherency. Based on these findings, we propose that exchanges between both practices may 1) *pluralise* the possibility space as fiction writers can challenge and expand the range of plausible futures that modellers explore, and 2) *democratise* the possibility space by bringing modellers and lay publics in reciprocal dialogue through participatory world-building exercises that draws on multiple mechanisms of plausibility.

Inspired by potentially fruitful exchanges between modellers and artistic practices, in **chapter 5** I collaborated with two artists-in-residence to interact with an IAM team, which resulted in an artistic intervention: the *Future Models Manual*. This speculative manual takes modellers on a journey to reflect upon their practice and inspire new ways of imagining possible futures as well as new forms of collaboration. The manual reflects previous insights of this thesis, such as the political influence of IAMs (chapter 3) and alternative forms of storytelling (chapter 4). Drawing on personal observations and interviews, a **key insight** that emerged concerned how artists stimulated reflection by asking unfamiliar questions, bringing in generative metaphors and by developing and using visual artefacts. In addition to the manual itself, the interaction with modellers during the artistic research were critical elements to 'intervene' in the IAM practice and stimulate reflection on the meaning of IAMs, taken-for-granted assumptions and their political influence. The findings pointed to the potential of future exchanges between modellers and artists to *pluralise* the possibility space of low-carbon futures. It would require, however, that the instrumental view of artists as science communicators is overcome.

RQ: how might alternative dramaturgies of mobilising expertise democratise the possibility space?

Chapter 6 compared how different dramaturgies of mobilising expertise in citizen engagement practices influenced the opening-up and closing-down of the possibility space. Rather than focusing on IAMs and climate policy on the global level, this chapter took a further step in focusing on the national level where mitigation strategies are currently formulated and implemented. Against the backdrop of the rise in citizen engagement practices, the prominence of modelling is called into question. In this chapter, we explored this future role by investigating how expertise is mobilised in citizen engagement practices by comparing two contrasting cases: 1) an application of the PVE method, an online participation method that bears similarities with IAMs in its approach, and 2) the Irish climate assembly, a deliberative mini-public where experts and citizens engage in deliberation. Although the two cases were not representative of the diverse forms of citizen engagement in climate policy, a **key insight** was that experts strongly influence the outcomes of these processes. This finding casts doubts on the often reiterated promise of citizen engagement to 'open-up' policy debates (cf. Fiorino, 1990; Stirling, 2008), and highlights the importance of critically scrutinising expert involvement. More precisely, it suggests that the uses of IAM knowledge strongly depends on the particular way in which expertise is connected to the deliberation in practices of citizen engagement.

7.3 Answer to the main research question

How do IAMs shape the possibility space of low-carbon futures in climate policy, and how could this possibility space be pluralised and democratised?

With regard to the first part of the research question, I conclude that IAMs are influential in shaping the imagined possibility space of low-carbon futures in global climate politics. Their quantitative and concrete storylines reside in an epistemic trust in quantitative future-oriented knowledge in global climate policy (cf. Heymann et al., 2017; Porter, 1996). This authority makes IAMs influential in shaping which low-carbon futures are imaginable and unimaginable. Carbon dioxide removal (CDR), such as bioenergy with carbon capture serves as a case in point, as these mitigation options typically feature prominently in IAM scenarios. The authoritative projections of IAMs played a large part in the rapid normalisation of the necessity of CDR as a necessary mitigation strategy, despite the ongoing debate surrounding their feasibility and the social and ecological consequences.

Importantly, however, it is not just IAMs that shape this possibility space in which low-carbon futures are imagined. Analysing the actual models as part and parcel of a broader 'technique of futuring' revealed that the possibility space is mutually constructed through a process of 'political calibration' where modelling efforts are continuously adjusted to fit the demands of the policy community. The role of IAMs in environmental politics is also subject to continuous negotiation. While the mutually reinforcing interactions between and climate policy makes IAM modelling policy-relevant, it also risks foreclosing alternative ways of knowing and governing climate change and overlooking social and ethical considerations (cf. Beck & Oomen, 2021; Lövbrand & Stripple, 2011; Miller, 2004; Shackley & Wynne, 1995). As I showed in chapters 2 and 3, in their co-evolution with global climate policy over the past decades, modellers have continuously 'calibrated' their modelling efforts to dominant discourses and emerging knowledge needs. I therefore share the growing concerns that IAMs and the IPCC are reproducing dominant discourses of economic growth, market-based mechanisms and techno-economic rationalities (Beck & Oomen, 2021; Ellenbeck & Lilliestam, 2019; McLaren & Markusson, 2020; Stoddard et al., 2021).

However, these critiques often overlook the fact that IAMs have been foundational in agenda and target setting. The projections of the *Limits to Growth* and later the IPCC drew a picture of a global environmental crisis in need of international cooperation. IAMs were also critical in providing scientific support for stringent climate targets such as the 1.5°C and net-zero emissions, which are now being set by countries, organisations and cities worldwide. These are tremendous achievements. Moreover, modellers are also not blind to their techno-economic focus in previous work, as exemplified by the advancement of lifestyle scenarios. In other words, rather than freely exploring possible futures, modellers walk a 'tight rope' as they continuously navigate political sensitivities.

Nevertheless, this process of political calibration and navigation is no longer visible once their scenarios appear in IPCC reports. There, IAM pathways appear value-neutral and as objective representations of potential futures, masking the mutual construction of this possibility space through IAM-policy interactions. As such, the seemingly neutral possibility space may depoliticise the debate on plausible and desirable responses to climate change (cf. Swyngedouw, 2011). In my view, this depoliticisation is particularly problematic given the growing plurality of actors in climate politics and their diverse viewpoints on desirable futures. After all, although IAMs became prominent in the science-policy interface, their role in the science-society interface is far less self-evident. Their influence in shaping the imagined possibility space in global climate politics should therefore be urgently reconsidered.

Against this backdrop, I explored ways to pluralise and democratise this possibility space by initiating transdisciplinary exchanges. I focused on transdisciplinary encounters between modelling and artistic practices because of their potential to bring in more 'radical imagination' in climate politics (cf. Hammond, 2021). I found that climate fiction might be a particularly interesting artistic practice to seek such encounters, given that both fiction writing and modelling practices engage in storytelling of plausible future worlds (chapter 4). Bringing in artists as 'residents' was also fruitful as it stimulated reflection among modellers and inspired alternative ways of imagining futures, as I showed in chapter 5. These findings point to the potential of future exchanges between modelling and artistic practices to *pluralise* the possibility space.

Be that as it may, bringing in artists does not *guarantee* more radical imagination. Artists arguably have more freedom to speculate on radically different futures compared to modellers, as they are not walking an institutional 'tight rope' in navigating political sensitivities. Yet, their freedom is not unlimited either. The artists I engaged with repeatedly stressed how they too need to comply with existing discourses, ethics and genres of their own artistic practice. In other words, modelling and artistic practices work within different institutional, epistemic and discursive structures and therefore operate within different 'possibility spaces'. A key question is therefore what type of art-modelling configurations would be most fruitful to cross these institutional boundaries. This thesis only gives partial answers to this question, but points to a potential tension between exploring radical futures and maintaining policy relevance, as I demonstrated in chapters 3 and 4. Furthermore, as argued in chapter 5, pluralising this possibility space may require a move from an instrumental view of artists as science communicators towards a non-hierarchical forms of collaboration in which artists can challenge and transform scientists' existing ways of thinking (cf. Barry et al., 2008; Born & Barry, 2010).

Seeking interactions with the arts may also help to *democratise* the possibility space in global climate politics, and open-up new possibilities of political engagement, given artists' abilities to draw on a fuller range of emotional, spiritual and embodied ways of knowing (cf. Gabrys & Yusoff, 2012). In chapter 4, I found that, compared to modellers, climate fiction writers use different mechanisms to build plausibility by connecting to people's values and lived experiences. Applying such mechanisms to the IAM practice could potentially address the apolitical nature of IAM scenarios and enable lay publics to judge the plausibility of their scenarios. Nonetheless, mixing science and fiction is not without risk, as it may also damage IAMs' political and scientific credibility, which is particularly precarious against the backdrop of an emerging post-truth culture (cf. Groves, 2019). How this tension between bringing in values and safeguarding scientific credibility may be navigated remains open for debate and research.

The often reiterated move towards a more polycentric climate governance (Jordi, 2015; Lövbrand et al., 2017) suggests the need to open-up the possibility space towards more diverse actors and views. In the final empirical chapter, I explored what democratising and pluralising the possibility space implies on the national level, where modelling[42] also tends to take centre stage while at the same time climate policy-making remains far removed from the hopes and demands of citizens.

42 With 'modelling' here I refer to model-based approaches that are used to inform climate mitigation policy on the national level, which include national IAMs and the combined deployment of sectoral models such as land-use, transport and energy models.

Arguably, the political calibration between modelling and climate policy may be even more problematic here, given that the negotiated national climate strategies have direct consequences for citizens. The rise of citizen engagement practices suggests the need to reconsider the prominence of modelling informing climate policymaking. For example, modelling could inform climate policymaking *alongside* citizen engagement practices or become an *input* to these practices. In case of the latter, I found that experts can strongly shape the outcomes of citizen engagement practices, either through a fact-like staging of evidence or by putting experts in a privileged spot. The former arguably particularly applies to quantitative forms of expertise like IAMs, which tend to suggest a 'mechanical objectivity' (cf. Hilgartner, 2000). In other words, while these practices may 'open-up' policy debates to alternative policy options and views (cf. Fiorino, 1990; Stirling, 2008), my findings underscored how engaging citizens does not *guarantee* an opening-up of the possibility space, given the strong influence of experts. We therefore need to not only reconsider the role of modelling, but perhaps rethink what counts as relevant expertise and what new forms of interactions between modellers, citizens and the state might look like.

7.4 Main contributions to research and practice

In this section, I discuss the main findings of this thesis in light of their scientific contributions to the literature on the politics of expertise, anticipatory governance and the sociology of the future (see also section 1.7). Analysing IAMs as a 'Technique of Futuring' (Hajer & Pelzer, 2018; Oomen et al., 2021) contributes to the literature on the politics of expertise by shining light on the structural, discursive and dramaturgical dimensions of how knowledge is negotiated in political settings. First, the findings of chapter 6 revealed how experts' authority depends on the particular setting, staging and scripting of expertise (cf. Hajer, 2009). Second, this thesis illuminated not only *how* knowledge is negotiated, but also *why* particular forms of knowledge-making become powerful (see chapter 2). The third contribution to this literature is the practice of 'political calibration' in chapter 3. This finding not only gave a more refined understanding of how modelling and climate policy are co-produced (cf. Demeritt, 2001; Lövbrand, 2011;

Miller, 2004; Shackley & Wynne, 1995), but also illuminated how these mutually reinforcing interactions between modellers and policymakers make certain possible futures either imaginable or unimaginable. This contributes to the growing STS scholarship on how collective imaginations of the shape actions in the present (Borup et al., 2006; Appadurai, 2013; Ezrahi, 2012; Jasanoff & Kim, 2015), by illuminating *how* certain images of the future become persuasive. By focusing on how *future-oriented* knowledge is constructed and becomes persuasive, this thesis tied together literature on the politics of expertise (cf. Fischer, 1990; Jasanoff, 1990; Wynne, 1987) and the politics of anticipation (cf. Granjou et al., 2017; Groves, 2017). Through the ToF lens, my analyses also contributed to literature on anticipatory governance, by demonstrating how 'anticipatory approaches' (Muiderman et al., 2022) are always situated within a particular practice: modelling derives its authority from policymakers' trust in quantitative knowledge and drive for cost-effectiveness whereas citizen engagement practices typically feature in democratic societies and cultural contexts where collaborations between citizens, experts and policymakers are seen as legitimate (chapters 2, 3 and 6). Yet, I extended the anticipatory governance literature by focusing on futures approaches beyond governance processes such as climate fiction. This brings me to the fourth and final main contribution of this thesis: the conceptualisation of the 'possibility space' (see chapter 1) as a politically negotiated, rather than an empty, space waiting to be explored (cf. Groves, 2017). This conceptualisation contributes to futures studies more broadly, which is concerned with the diverse sets of methods to imagine possible futures (cf. Andersson, 2018; Bradfield et al., 2005). It is not only the futures methods themselves, but also the practice in which they are situated determines the possibility space that can be imagined. After all, modellers work with a different possibility space than artists (see chapter 4 and 5). Altogether, the two key theoretical concepts, *Techniques of Futuring* and *possibility space*, were helpful in offering insights into and tying together these diverse literatures. Yet, because of their novelty and broad interpretability, I critically examine the analytical value and methodological challenges of both concepts in section 7.5.2.

Apart from contributions to academic literature, the insights of this thesis are also relevant beyond academia. The finding that futures methods are always situated in a particular discursive, organisational and epistemic structure (chapters 2, 3 and 6) implies that futures method are not simply tools in a toolbox that can be taken out of their context and be applied somewhere else. Futures practitioners should therefore carefully consider how their methods relate to these structural characteristics. An insight for organisers of citizen engagement practices specifically is the strong influence of experts, which implies the need to not only carefully consider *what* experts and expertise is brought in but also *when* (which phase of the process) and *how* (experts' role and the staging of expertise) and *where* (the setting in which interactions take place). Making experts' roles explicit, involving citizens in the design and facilitating reciprocal and non-hierarchical dialogues may counteract experts' strong influence. Furthermore, a key insight for modellers is that their scenarios can easily become much more persuasive than intended (chapter 2 and 3). This insight is not necessarily new (see e.g. Ashley, 1983). Nonetheless, this thesis reiterates that simply stating that scenarios are 'illustrative' and non-predictive in IPCC reports is apparently insufficient to prevent their scenarios from normalising potentially harmful futures. Supporting a political debate on desirable futures may therefore not only require a different form of communication, but also deeper reflection on the values and worldviews underlying scenario assumptions and model structures and to fundamentally rethink interactions with policy and society (see section 7.6.2). This reflection arguably applies not only to modellers, but also to policymakers who tend to have too much faith in model projections. Further collaboration between the IAM community and artistic practices may stimulate such mutual reflective exercises, provided that artists are viewed as more than science communicators (see chapter 5). This point is also relevant for initiators of art-science collaborations: artists and scientists may have conflicting expectations on the 'logic' of interdisciplinarity, which can hamper the outcomes (cf. Barry et al., 2008). These different logics also presuppose a different set-up: an ontological logic where artists challenge and transform scientists' assumptions may require a reciprocal and longer-term collaboration compared to an instrumental logic where artists are involved to communicate science to lay publics. It is therefore crucial to make the roles and aims explicit prior to the collaboration.

7.5 Reflections on the research design and lessons for future research

This thesis presented a comprehensive analysis of IAMs in climate politics. Nevertheless, there are some noteworthy gaps and remaining questions for future research (7.5.1). Below, I also discuss the methodological limitations which may also be addressed in future research (7.5.2.).

7.5.1 Gaps and remaining questions

Here I point to the most crucial gaps and remaining questions following the analyses in this thesis. First, this thesis focused predominantly on global IAMs. Although their prominence in the climate science-policy interface justified this focus, the model-based approach to climate policymaking is dominant on other levels as well, most notably on the national level (see chapter 6). Why model-based approaches have become prominent across diverse environmental policy contexts more generally could be further explored (see e.g. Heymann et al., 2017). This thesis focused primarily on the global and only partly on the national level, but cities have come to play a critical role in climate governance (Bulkeley, 2010). This thesis gives only partial answers to the role models at these different geographical scales (see Mahony & Hulme, 2016 and Pelzer et al., 2017 for the use of modelling on respectively the national and urban level). A remaining question is for example why models have been far less prevalent on the urban level (but see Te Brömmelstroet, Pelzer & Geertman, 2014). Another remaining question involves whether the practice of 'political calibration' is also found across geographical scales, given that its implications might be more adverse on the national or local level given the direct consequences for citizens. More generally, I focused only on a particular form of expertise, one that is quantitative, mathematical and rooted in systems thinking. The cases in chapter 6 suggest that the types of expertise relevant to climate mitigation are highly diverse and may differ across geographical scales or cultures. What counts as relevant expertise and how these types of expertise should inform climate policymaking across different contexts therefore requires further investigation. For example, it remains unclear to what extent citizens should be considered experts, whether this may depend on the geographical scale (local or national) and what implications this may have for the design of citizen engagement processes. Third, I focused on encounters between only a limited set of futures practices (see Appendix a for a set of examples) and therefore offers only a partial understanding of what type of encounters may advance transformative change. As demonstrated in chapters 4 and 5, interactions between scientific and artistic practices may be particularly fruitful. Yet, this thesis focused only on two possible forms (transdisciplinary workshops and artists-in-residence). Given that art-science collaborations are highly diverse (see e.g. Gabrys & Yusoff, 2012), future research could further explore what type of collaborations would be most fruitful in advancing transformative change. Lastly, the analyses in thesis only superficially engaged with climate justice. Given its growing importance in climate politics (Newell et al., 2021), future research may further explore the justice implications of modellers' assumptions (see e.g. Beck & Krueger, 2016) or how IAMs may account for diverse justice considerations (see e.g. Rubiano Rivadeneira & Carton, 2022). Given its critical importance, I reflect upon the future of IAMs through a justice lens (see 7.6).

7.5.2 Critical reflections on theoretical concepts

As argued in chapter 1, the key concepts in this thesis are complementary in understanding futures practices: whereas *possibility spaces* describe what futures are imagined, *ToFs* is concerned with both how futures are imagined and by whom. Both concepts are relatively broad, which appeared valuable for a comprehensive understanding of IAMs in climate politics, an understanding and comparison of contrasting futures approaches and tying together diverse literatures (see section 7.4). However, the breadth and flexible interpretability of both concepts also posed challenges for its operationalisation and analytical value, which I discuss in the following paragraphs.

While the flexible interpretability of the *possibility space* allowed for comparison across diverse futures practices (such as in chapter 5), the concept also lacks clarity on what 'possible futures' are, for example whether this refers to visions, strategies, policy options or points of view, which complicates its operationalisation. The operationalisation was different accross chapters. In chapters 2 and 3 it referred to an imagined space constructed through political calibration between modellers and policymakers. In chapter 6 it refers to the dynamics between experts and citizens that culminate into a final set of policy proposals within specific participatory initiatives. Where the former is in line with the descriptive understanding of co-production as the inevitable links between representation and social order as defined by Jasanoff (2004), the cases in chapter 6 could be viewed as deliberate attempts to bring scholars and stakeholders in interaction to design questions and produce outcomes, in line with the normative understanding of co-production as a framework to improve (sustainability) science (cf. Milller & Wyborn, 2018). Although both uses of the possibility space concept may be justifiable, it is important to distinguish between the two given these fundamental differences in interpretation.[43]

43 Along similar lines, Lövbrand (2011) distinguishes between the descriptive and prescriptive interpretation of co–production.

Because of its breadth, *ToFs* served as a useful analytical concept for diverse purposes in this thesis: for explaining the prominence of IAMs (chapter 2), describing interactions between modellers and policymakers (chapter 3) and comparing different futures practices (chapter 4 and 6). Yet, throughout this thesis I also drew on alternative theoretical concepts when the ToF concept fell short in its analytical value. Chapter 2, for instance, drew on the concept of 'institutional work', which constitutes an actor-centred approach to understanding institutional change (Lawrence & Suddabay, 2006). Although this concept is commonly used in organisational studies rather than to interpret science-policy interactions, it was useful to understand the purposive action of IAM modellers to create and maintain their position in the science-policy interface. Institutional work could thus be viewed as a key mechanism that explains why certain futures methods are prominent within a particular context. Or, put differently, how ToFs are reproduced and maintained. I could have drawn on the institutional work concept to explain the emergence of other futures practices as well, such as the citizen engagement practices in chapter 6, but this was beyond the focus of this thesis. The institutional work concept could also have been helpful to understand how artists challenge and transform the IAM practice by stimulating reflection in chapter 5, especially given that reflexivity is indicated as a typical characteristic of institutional workers (see Lawrence & Suddaby, 2006, p. 219). However, how institutional workers become reflective and how this reflexivity in turn evolves into agency to change institutions remains unclear (Modell, 2022). Moreover, the collaboration with the artists in itself was in itself unlikely to be significant enough to induce institutional change. I therefore drew on theoretical accounts on reflexivity (Beck et al., 1994; Schön, 1983; Forester, 1999) to better understand the potential of artists to stimulate a more 'reflective' IAM community. Because of their actor-centred approach, the theoretical accounts on reflexivity and institutional work could enhance the ToF concept by moving the focus from how ToFs operate to how they are reproduced and maintained. This is crucial for climate governance given that the particular way futures are anticipated influences the steering mechanisms in the present (Muiderman et al., 2022).

7.5.3. Methodological challenges

Before discussing the methodological challenges of this thesis, let me first reiterate its methodological strengths. First and foremost, the diverse set of methods offered comprehensive and novel insights into IAMs and other futures practices. The interviews, literature review and document analyses in chapters 2 and 3 were complementary in their strengths and therefore resulted in a comprehensive analysis of IAMs in climate politics. The diversity of methods in chapter 6 also offered novel insights into how expertise is mobilised in citizen engagement practices. Besides, by initiating unique transdisciplinary encounters, including the staging of conversations between modellers and fiction writers (chapter 4), initiating an artist-in-residence project (chapter 5) and the co-development of an innovative participation tool (chapter 6), this thesis went beyond traditional critical social science research. My personal involvement in these initiatives not only enabled me to closely study these transdisciplinary exchanges, but also gave practical insights into their associated challenges and opportunities (see section 1.6 for a discussion on positionality).

Nevertheless, a number of methodological challenges deserve attention. First, the interviewees in chapters 2 and 3 provided viewpoints from mostly European and North -American countries. This is not surprising given that a large share of the interviewees were IAM modellers, who are predominantly located in these areas (see also 1.2.1). Nevertheless, a more geographically diverse set of actors may have given a more nuanced perspective on how and why IAMs became prominent and why other knowledge communities, especially those situated in non-Western countries, have been shut out (chapter 2). In chapter 3, interviewing more non-Western actors could have also offered deeper insight into how and why the 1.5°C goal was legitimised, especially because the target was initially promoted by small island states. Second, the interactions between modellers and artists in chapters 4 and 5 only involved the IMAGE team and a limited number of artists. The findings may not be representative for the IAM community as a whole, especially given that the term 'IAM' refers to a diverse range of models with different levels of detail, focus and structure (see e.g. Krey et al., 2019). Chapter 4 engaged a limited number of fiction writers and therefore does not account for the variety of literary genres; chapter 5 would presumably have resulted in entirely different outcomes had we selected different artists. Along similar lines, although the cases in chapter 6 were compared to other cases using a similar method to draw conclusions, the findings may not be representative of citizen engagement in climate policy given the diverse forms of expert involvement (cf. Lightbody & Roberts, 2019). Hence, the generalisability of the findings of chapters 4-6 are relatively weak. Yet, the aim was merely to experiment with alternative configurations rather than to reveal generalisable findings. Nevertheless, the significance of the potential of interactions between the IAM community and artistic communities should be further established in future research. Future research may also investigate a more diverse set of citizen engagement practices to better understand the role of experts and expertise. Third, the relatively non-traditional analytical and transdisciplinary approaches in chapters 4-6 resulted in methodological challenges. For example, it was challenging to operationalise the dramaturgical analysis in chapter 6 in such a way that it could be applied to contrasting cases. This makes the cases difficult to compare, and the choice of operationalisation may have influenced the results. Along similar lines, we also faced methodological challenges in comparing modelling and fiction writing in chapter 5 given the absence of pre-existing analytical frameworks. Future research may further explore how the dramaturgy of expertise may be operationalised and how contrasting futures practices may be compared. Fourth, my personal involvement in the transdisciplinary initiatives in chapters 4-6 necessarily influenced the outcomes and perhaps made me underestimate how my own role as an expert shaped the design of the online participation tool (chapter 6) or to overstate how the artists stimulated reflection among modellers (chapter 5). Apart from the active roles in the process, I therefore also took a deliberately critical stance towards the initiatives in all three chapters and made my own positionality and its implications clear (see section 1.6).

7.6 The future of IAMs in climate politics from a justice perspective

Equity and justice have been fundamental principles of the UNFCCC ever since its establishment. In the Paris Agreement in 2015, countries agreed 'to reflect equity and the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances' (UNFCCC, 2015, Article 2.2.). Yet, in recent years, the issue of climate justice has become increasingly imperative, as is evident from the increasing attention to just transitions in the climate negotiations, calls for climate justice by social movements and a growing scholarship on energy and climate justice (Biermann & Kalfagianni, 2020; Newell et al., 2021). Climate justice also appears as a common thread across the three shifts I introduced in the first chapter. The shift towards a solution-oriented mode of the IPCC inherently implies the need to engage with justice considerations, given that the risks, costs and benefits of climate mitigation are not evenly distributed across time and space. Justice concerns also often feature in discourses of radical transformative change, such as a redistribution of wealth in the case of degrowth. The shift towards a polycentric governance architecture also immediately raises questions on fair and legitimate decision-making, including the involvement of non-state actors in the climate negotiations or citizens on the national and sub-state level. It thus seems appropriate to reflect on the future of IAMs from a justice perspective. Ideas about justice are highly varied and several typologies of justice principles currently exist in the climate justice literature (Okereke & Dooley, 2010 for an overview). Before going into the future of IAMs (7.6.2), I first briefly discuss a number of justice dimensions that are particularly relevant in the context of IAMs and climate politics (7.6.1). In the final section of this thesis, I discuss the argument for democratisation in a time that calls for rapid and decisive climate action (7.6.3).

7.6.1 Climate justice: diverse dimensions and principles

A distinction is often made between distributive, procedural and recognitional justice (e.g. Agyeman, 2005; Bulkeley et al., 2014b; Fraser, 2010). Distributive justice is concerned with the distribution of outcomes among people across temporal or geographical scales. In the context of climate mitigation, distributive justice usually concerns the risks and benefits of climate change and the responsibilities of mitigation efforts, such as the 'effort sharing' among countries (e.g. Ekholm et al., 2010; Van den Berg et al., 2020). Procedural justice refers to the fairness and legitimacy of decision-making processes, which has been a key concern in international climate negotiations, such as Global South countries calling for more effective participation (e.g. Okereke & Coventry, 2016). Recognitional justice concerns the cultural or symbolic injustices as manifested in the inadequate recognition to certain groups in society as a result of formal institutions, cultural norms or legitimacy of certain forms of knowledge over others (Fraser, 1999; 2010). Recognition has traditionally been somewhat neglected in the climate justice literature (Bulkeley et al., 2014b), but has recently received increased attention, not in the least in the rapidly growing scholarship on decolonisation in relation to climate change (e.g. Bronen & Cochran, 2021; Johnson et al., 2022). The three dimensions can be further divided into subcategories. For example, Okereke and Dooley (2010) identify six distributive justice principles in relation to climate policy: utilitarianism, liberal egalitarianism, market justice, mutual advantage, communitarianism and meeting needs. Another useful distinction in the context of climate politics is between *intra*generational (within generations) and *inter*generational justice (across generations), which can arguably be relevant to distributive, procedural and representational justice. Rather than a systematic overview of IAMs in relation to these diverse justice dimensions and sub categories, which are provided elsewhere (Jafino et al., 2021; Rubiano Rivadeneira & Carton, 2022), in what follows I reflect more generally on the future of IAMs with regard to distributive, procedural and recognitional justice.

7.6.2: Reconfiguring IAMs as a 'Technique of Futuring' from a justice perspective

In this section, I argue for a *contextual reconfiguration* of IAMs in climate politics. According to the Oxford dictionary, to reconfigure means 'to make changes to the way that something is arranged to work, especially computer equipment or a program'. As the reader may expect, my suggestion would not concern computer code, but rather a rearrangement of IAMs in climate politics. Viewing IAMs as a Technique of Futuring (Hajer & Pelzer, 2018; Oomen et al., 2021) – as a futuring practice characterised by a particular way of representing storylines, dramaturgy and structure – may offer some useful guidance to what such a reconfiguration might mean. In this section, I discuss how IAMs as a ToF may be reconfigured and connect these three dimensions to distributive, procedural and recognitional justice (see Table 7).

From apolitical to justice-oriented *storylines*

Reconfiguration may involve changing IAMs' *storylines*. IAMs have been criticised for addressing a limited set of distributive justice concerns (Jafino et al., 2021; Rubiano Rivadeneira & Carton, 2022). IAMs typically aim to find the most cost-optimal mitigation pathway towards climate targets, in which justice assumptions are rarely made explicit.[44] The latest IPCC report (2023), for example, states that 'most [global pathways] do not make explicit assumptions about global equity, environmental justice or intra-regional income distribution' (p. 9). However, their focus on cost-effectiveness has profound inter- and intragenerational justice implications. For example, some argue that IAM pathways implicitly perpetuate global inequalities by assuming future expansion of bioenergy in the Global South to satisfy disproportionally high energy

44 Although cost-optimal scenarios may assume such inequalities are resolved through financial compensation, that compensation is arguably unlikely given the broken promises of climate finance in the recent past (Timperley, 2021)

demands of the Global North (Hickel & Slamersak, 2022). Another key example is the discount rate (see also chapter 1), which has implications for the assumed need for CDR and disproportionally shifts the burden of mitigation efforts to future generations (Emmerling et al., 2019). Such criticism points to the need for IAMs' *storylines* to move away from a fixation on cost-effectiveness to explicitly engaging with diverse *distributive justice* considerations. Recent developments in the IAM scenario practice suggest that such a shift in focus might be already underway. Examples include scenario analyses that move their focus away from cost-effectiveness, such as 'good practice' scenarios that assume cross-country learning (e.g. Fekete et al., 2015; Roelfsema et al., 2018; van Soest et al., 2021) or lifestyle scenarios (e.g. van den Berg et al., 2019; Van Vuuren et al., 2018). Moreover, some IAM studies even explicitly explore scenarios based on justice principles, most notably the assessment of different effort-sharing approaches across countries (e.g. Chen et al., 2021; Leimbach & Giannousakis, 2019; van den Berg et al., 2020). However, the IAM community still largely ignores diverse distributive justice concerns (Rubiano Rivadeneira & Carton, 2022). A final limitation that is noteworthy is the degree to which IAMs underestimate the costs of inaction and extreme events, while these impacts are known to exacerbate global inequalities (e.g. Asefi-Najafabady et al., 2020; Pindyck, 2013; Weitzman, 2009; 2011).[45]

45 This issue has been given relatively little attention in this thesis because the focus was primarily on process-based IAMs that are used to simulate mitigation pathways rather than CBA-IAMs, where the focus is more strongly on the damage costs of carbon dioxide emissions (known as the social costs of carbon).

Altogether, these limitations suggest that IAMs will be unlikely to answer all distributive justice concerns (especially given that the meaning of justice differs strongly across cultures). The scholarly debate on IAMs and climate justice seems to revolve around whether and how IAMs *could* answer justice questions, for instance by 'better equipping' the models (Jafino et al., 2021). While I agree that IAMs can and should do a better job at accounting for justice considerations, perhaps an even more pressing question is whether justice questions should be left solely to IAMs. Or, in the words of Rebecca Willis (2019), 'economists may be good at crunching numbers, but should we leave it at them to decide who gains – and who loses?' (p. 3). My answer to this question would be a firm no: leaving questions of justice entirely up to the IAM community runs the risk that only those questions that IAMs can answer are the ones that come to matter most, especially given their seemingly apolitical projections. Or, to use a tired phrase, 'when your only tool is a hammer, it is tempting to treat everything as if it were a nail'.[46]

46 This phrase, also known as 'Maslow's Hammer', originates from *The Psychology of Science: A Reconnaissance* by Abraham Maslow (1966)

Towards fair and inclusive dramaturgies of interactions between modelling, policy and society

A reconfiguration should therefore not be limited to the storylines themselves, but necessarily also involve rearranging the *dramaturgy* of interactions through which imagined futures are imagined and become persuasive. The findings of this thesis suggest that the current 'political calibration' that currently occurs behind closed doors and involves only modellers and policymakers is no longer tenable. From a *procedural justice* perspective, perhaps what is needed is a 'recalibration': rethinking which actors are involved in scenario development processes and why (cf. Van Mosselaer, 2023).[47] Although modellers have already started to engage civil society groups in scenario development, marginalised groups such as indigenous communities or small island states still remain ignored. As argued in chapters 4 and 5, involving artists may be a fruitful direction to explore, given their complementary abilities to engage with justice concerns while staging inclusive conversations between academic and non-academics.

47 The term 'recalibration' was introduced by Mosselaer (2023) in the context of urban planning, referring to a process where the presumed roles in planning processes are reconsidered (p. 85).

Importantly, the dramaturgical approach in this thesis highlighted that it not only matters *who* is involved, but also *how* actors are involved, such as what stage of the process, with what mandate and with which responsibilities (cf. Van Mosselaer, 2023). Having been part of some of these stakeholders sessions myself,[48] I can attest that the communication often seemed to flow one-way, where stakeholders and experts' views being used as inputs for modelling exercises rather than critically scrutinising the use of models, pointing to blind spots and raising new questions. As mentioned before, collaborating with societal actors should arguably adopt a more 'ontological' logic of interdisciplinarity characterised by a non-hierarchical and 'antagonistic' form of collaboration in which existing framings and assumptions can be challenged and transformed (cf. Barry et al., 2008). On the national level, a rearrangement of the dramaturgy of interactions between experts (including modellers), citizens and the state may be required. The cases in chapter 6 showed that such new arrangements are already underway, but also pointed to the difficulty of establishing truly reciprocal dialogues given the strong influence of experts. Initiating such dialogues therefore requires a careful consideration of the roles of experts and citizens (scripting), how expertise is introduced and presented (staging) and where the interactions take place (setting) (cf. Hajer, 2009).

48 These included stakeholder sessions in the Sustainable Lifestyles Project https://www.iamsustlifestyles.com/ and the SHAPE project https://shape-project.org/

Deep reflection on the *structural* injustices implied in discourses, formal institutions and epistemologies

Arguably, such a reconfiguration would also require more structural changes in formal institutions, discourses and epistemologies. It is these formal and informal structures in society that give rise to the fundamental *misrecognition* of certain groups, which in turn influences how outcomes are distributed and how procedures are established (Fraser, 1999; 2010; Bulkeley et al., 2014b). Along similar lines, Oomen et al. (2021) explain how ToFs are always situated in particular discursive, organisational and epistemic structures that determine whose interests, views or knowledge counts and who can participate. As observed by Rubiano Rivadeneira and Carton (2022) it is precisely this recognitional dimension of justice that remains ignored in the scholarly debate on IAMs and climate justice. The authors argue for the need for more 'cognitive justice' to address the predominantly Eurocentric knowledge systems underlying global scenarios, arguing particularly for the recognition of the knowledge of indigenous communities given the epistemic violence they have historically faced. This argument is in line with earlier calls for epistemic diversity underlying climate research and assessments, most notably the increased involvement of the social sciences and humanities to better understand values, aspirations, interests, needs and responsibilities related to global environmental change (e.g. Castree et al., 2014).

Indeed, recent IPCC reports involved more authors from the social science and humanities compared to previous ones and also saw geographical and gender biases addressed. The IPCC has also made progress in the incorporation of indigenous and local knowledge groups. However, the latest IPCC report (2023) has led me to believe that epistemological diversity alone is insufficient. The report devotes an entire section to equity and justice, but only after IAM pathways are projected that are supposedly justice-neutral. Treating justice separately is unhelpful, if not deeply problematic, given that the cost-optimal IAM pathways already make *implicit* justice assumptions. Moreover, others have argued how the involvement of indigenous groups in itself may be insufficient, given that their voices could be 'sampled' to assist global forms of knowledge or that assessments project simplified identities onto those groups (Beck et al., 2022). For the IPCC to support transformative change, the IPCC itself may require transformation towards a more reflexive institution that opens up towards more diverse forms of knowledge and deliberation (Ibid.).

It is far from self-evident however, how such structural changes may come about. As argued in chapter 5, a first step might be deeper reflection upon the ontology and epistemology of modelling, given the justice implications that are already implied in model structures and framings (see e.g. Carr et al., 2007). However, reflection arguably should not be limited to modellers alone, given that model assumptions are shaped by policy discourses (Ellenbeck & Lilliestam, 2019). As argued in chapter 5, collaborating with artists may help to stimulate deep reflection on the epistemological and ontological underpinnings and the associated ethical implications. More reflection may be needed more broadly among environmental scientists on what interests their research is serving and what knowledge or views are excluded (Turnhout & Lahsen, 2022). Perhaps the polycentric character of climate governance would even require entirely different types of knowledge institutions that are better equipped to cater to the plurality of knowledge needs. The cases in chapter 6 also point to the need to more generally reconsider what counts as relevant expertise, such as the expertise of citizens. Altogether, reconfiguring IAMs as a ToF may thus require changes on the level of storylines, dramaturgy and structure, each of which address a complementary justice dimensions, as outlined in Table 7.

7.6.3 Democratisation and acceleration: contradiction or synergy?

The need for democratising and pluralising the possibility space, which has been a key argument in this thesis and is refined in the previous section, followed particularly from two shifts I describe in chapter 1; both the move towards a solution-oriented mode of climate science (1.2.1) and the diversification of actors in climate politics (1.2.3) inherently imply the need to engage with diverse viewpoints on justice. For the growing call for transformative change (1.2.2), however, this argument is less self-evident. At first sight, the need for radical transformations even seems contradictory to democratisation and pluralisation, given the suggested need for decisive action. I therefore end this thesis with a reflection on the supposedly contradictory calls for democratisation and acceleration in the face of climate change. Has the time come to stop debating where to go and just start acting?

The slow progress on decisive climate action by democratic societies has led some to believe that democracy is simply not up to the task of responding to climate change. Along those lines, Earth scientist

ToF dimensions	Justice dimensions	Suggestion of reconfiguration
Storylines	Distributive justice	Explicit engagement with *diverse distributive* justice principles including mitigation efforts and climate impacts within IAMs' *storylines*
Dramaturgy	Procedural justice	Alternative *dramaturgy* of interactions between modelling, policy and society to improve *procedural justice*
Structure	Recognitional justice	Deep reflection on the *structural* discourses, epistemologies and institutional structures to account for inadequate *recognition* of societal actors or knowledge communities

Table 7. Suggestions for reconfiguring IAMs as a Technique of Futuring in light of climate justice

James Lovelock, famous for his Gaia theory, has stated that 'climate change may be an issue as severe as a war. It may be necessary to put democracy on hold for a while.' (in Hickman, 2010). Such reasoning was also on display during the COVID-19 pandemic where the urgency of controlling the virus seemed to justify bypassing a democratic debate (Afsahi et al., 2020).

I, however, want to argue against this rationale for several reasons. First of all, radical mitigation policies without involving those that are affected are likely to encounter resistance and therefore become ineffective, as the Yellow Vests movement in France clearly exemplifies. Secondly, democratic processes can actually result in radical proposals. Citizens' assemblies in France and Ireland for example, resulted in policy proposals that were far more radical than many expected, such as a law banning ecocide or the controversial tax on agricultural emissions (e.g. Devaney et al., 2020; Willis et al., 2022). Third, transformative change is unlikely to result from a single actor with a single vision. The shift towards a more polycentric climate governance architecture proves this point. Fourth, authoritarian regimes do not necessarily deliver better climate outcomes than democratic ones. On the contrary, empirical evidence shows that democracies tend to outperform autocracies in their environmental outcomes (Pickering et al., 2022).

These points emphasise how democratisation and acceleration are not necessarily contradictory. In my view, the answer to this situation lies not in an increasingly technocratic response where modelling continues to take centre stage in climate policy. Such a response will likely only worsen the already declining public trust in governments. Rather, what is needed is an alternative role of models that would strengthen the democratic response to climate change. Or, as stated by Willis (2019), 'what is needed is *more* democracy, not *less*' (p. 4, emphasis original).

Nevertheless, this does not mean that processes should always be solely directed at 'opening-up'. On the contrary, I concur with Stirling (2008) that closing-down is 'simultaneously necessary, inevitable, and desirable' (p. 284). Closure is arguably essential in the case of the climate crisis, which desperately calls for decisive action. It becomes problematic, however, when only a small set of futures are considered that privileges solely economic considerations and incumbent interests, as it tends to result in locking-in into undesirable futures (Stirling, 2008). Relying solely on IAMs may risk this type of closure due to their prominence in climate policymaking and their focus on technical feasibility and cost-effectiveness. However, this does not mean that the use of IAMs *necessarily* leads to closing-down (or any form of expert analysis for that matter, as argued by Stirling, 2008). Perhaps the question is not whether pathways towards a low-carbon future should be opened-up or closed-down, but *how and by whom* certain pathways are rendered more persuasive than others. By asking this question we can begin to understand how a radical and just low-carbon transformation might be realised.

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Appendices

Appendix A. Examples of futures approaches in the context of climate mitigation and examples

Methodology to 'map' futures practices in the context of climate mitigation

The mapping of futures approaches involved three steps. In step 1, I first looked for existing reviews of futures approaches, which included futures methods (Adam & Groves, 2009; Borjeson et al., 2006; Muiderman et al., 2020; Swart et al., 2004) and made a first list of approaches. Step 2 involved a literature search on Google Scholar and Scopus using the terms 'climate mitigation' or 'low-carbon' or 'post-fossil' in combination with 'tool', 'method' or 'approach' and in combination with the specific futures approaches identified in Step 1. These resulted in additional futures approaches as well as examples of futures approaches. For the sake of this thesis, in step 3, I classified the futures approaches into 'expert-based', 'participatory' and 'artistic' based on their key characteristic.

It soon became clear that the terms that are used for futures are highly diverse, which complicated the mapping. Moreover, presumably many more futures approaches exist than the ones that appear in academic literature. Furthermore, as also observed by Muiderman et al. (2020), methods are often used in combination (e.g. integrated assessment with participatory back-casting in the Georgia Basin Futures Project). Besides, the categories of approaches nor the classification into expert-based, participatory and artistic are mutually exclusive (e.g. MESSAGE is identified by some as an energy model and by others as an IAM and experiential futures often involve a combination of arts, science and participation). Altogether, the mapping should therefore be considered an incomplete set of examples that is merely intended to illustrate the diversity of futures approaches that exist.

Expert-based approaches

Approach	Description	Examples of cases	References
IAMs*	Global computer models that simulate climate-society interactions (Weyant et al., 2017 for a review)	Study that assesses pathways towards the 1.5°C goal based on multiple IAMs	Rogelj et al., 2018
		Case IPCC 2018	IPCC, 2018
		Case IPCC 2022	IPCC, 2022
Energy system models**	Computer models that represent the energy system	MARKAL model to UK policy: an overview of its role	Taylor et al., 2014
		PRIMES model in the EU to explore decarbonisation pathways	Siskos et al., 2018
		TIMES model application to study decarbonisation of transport sector in China	Zhang et al., 2015
Agent-based modelling	'an individual-based microsimulation approach that can integrate relevant aspects of human behaviour and diversity', which is widely applied to climate and energy policy (Castro et al., 2020 for a review)	ENGAGE: agent-based modelling framework to simulate interactions between international treaties, national policies and domestic systems	Gerst et al., 2013
		Multi-agent-based model of China's electricity market to simulate impacts of carbon tax on future power generation portfolio and carbon emissions	Chen et al., 2013
		Agent-based model to simulate market penetration of electric vehicles based on various influences such as gasoline prices and battery range.	Eppstein et al., 2011
Energy forecasting	'forecasting the supply, demand and price of electricity, gas, water, and renewable energy resources' (Hong et al., 2014)	Wind energy forecasting (review)	Zhang et al., 2014
		Electricity price forecasting (review)	Nowotarski & Weron, 2018
		Global Energy Forecasting Competition 2014	Hong et al., 2014
Energy back-casting***	Scenario method introduced by Robinson (1982) as a response to energy forecasting approach	Resilient energy systems	Kishita et al., 2017
		Sustainable development in Stockholm	Höjer et al., 2011
Cost-benefit analysis****	Assessment of costs and benefits of policy options	Building retrofitting in China	Liu et al., 2018
		Forest Conservation in Malaysia	Raihan & Said, 2022
		ETS in the EU	Tol, 2012

Approach	Description	Examples of cases	References
Delphi analysis	Iterative expert elicitation technique in which experts give their opinion and learn from opinions of other experts	Nuclear energy in France: experts' forecasts of nuclear energy projects	Hussler et al., 2011
		Renewable energy in China: use of Delphi to assess pathways towards 2030	Chen et al., 2020
		Bioenergy: factors that influence forest energy business	Pätäri, 2010
Multi-level perspective (MLP)	Analytical framework to understand analyse socio-technical transitions (Geels 2012 for explanation)	Study of niche development of sustainable mobility in the UK and Sweden	Nykvist & Whitmarsh 2008
		Analysis of UK low-carbon electricity transition	Geels et al., 2016
		Analysis of the role of the agriculture sector in renewable energy systems	Sutherland et al., 2015

* Previous reviews distinguished quantitative from qualitative scenarios approaches (Swart et al., 2004). However, more recently these are most often combined in a so-called 'story-and-simulation' approach (Alcamo et al., 2000), which reflected for instance in IPCC scenarios, and GEO scenarios.

** for recent overview of energy system models (Lopion, Markewitz, Robinius, & Stolten, 2018)

*** energy back-casting are often (but not always) performed in consultation with stakeholders and therefore often fall in the category of participatory visioning/ backcasting. The examples here involved only experts

**** some IAMs are also performing CBAs (so-called CBA-IAMs), the example cases here are non-modelling CBAs

Participatory approaches and example cases

Approach	Description	Examples of cases	References
Participatory integrated assessment	Approaches characterised by the explicit engagement of stakeholders into integrated assessment (Salter et al., 2010 for a review)	Georgia Basin Futures Project: five-year collaboration between scientists, NGOs, government representatives and private sector combining computer modelling and back-casting to assess policy options to achieve sustainable futures in the Georgia Basin region in Canada	Robinson, 2003; Robinson et al., 2006; Tansey et al., 2002
		TransWind: participatory IA on wind energy development in Austria with stakeholders (e.g. policymakers, NGOs, trade unions) based on modelling, workshops, interviews, focus groups and questionnaires.	Scherhaufer et al., 2018
		Road construction in Sweden: participatory IA to assess mitigation potential of road construction in Sweden with industry representatives and experts based on models and stakeholder workshops	Karlsson et al., 2020
Participatory visioning and/or back-casting	Mix of qualitative and qualitative analysis that involves the participatory visioning and/or backcasting of the future (Robinson 2011 for a review)	Sustainable Futures Scenarios Phoenix: participatory scenario framework applied to the Central Arizona Phoenix area based on scenario workshops involving policymakers, community leaders, NGOs and academics	Iwaniec et al., 2020
		Anthropocene Visioning Workshop: participatory scenario workshops in Cape Town following from the Seeds of the Anthropocene project, a database collecting 'seeds' (innovative transformative projects)	Pereira et al., 2018
		Retrofit 2050: participatory visioning process on retrofitting in cities involving experts, local and national government representatives and civil society organisations	Eames et al., 2013
Participatory modelling	Participatory process in which modellers and stakeholders collaborate to understand systems (Voinov et al., 2016 for a review)	Windmaster: participatory modelling process to identify energy infrastructure in Port of Rotterdam	Cuppen et al., 2021
		Solar Energy in Future Societies: participatory modelling of future local energy system in Stocksbridge, UK involving experts and citizens	Krzywoszynska et al., 2016
		Housing, Energy and Wellbeing project: participatory systems dynamics modelling to assess causal maps of housing, energy and wellbeing involving local policy organisations, experts, industry and NGOs to assess future housing retrofitting potential	Eker et al., 2017

Approach	Description	Examples of cases	References
Simulation gaming	Policy simulation tools in which policymakers, industry actors and/or citizens take decisions and a computer model simulates the effects (Mayer 2009 for a review)	World Climate: role-play simulation game that simulates UN negotiation used intensively worldwide	Sterman et al., 2015
		Tipping Points Negotiation Game: a role-play simulation that was developed to affect climate negotiators' knowledge and risk perceptions of climate tipping points	Van Beek et al., 2022; Vervoort et al., 2022
		Go2Zero game: role-play simulation game that represents energy transition process of residential energy systems where players take on different roles to make their district carbon-free.	Bekebrede et al., 2018
Deliberative mapping	A method that combines multi-criteria analysis with stakeholder deliberation in which participants select options and select criteria to evaluate these options	Geoengineering UK: deliberative mapping of geoengineering proposals with citizens and experts to assess the performance of various carbon and solar engineering options	Bellamy et al., 2016
		Nuclear Waste UK: deliberative mapping involving citizens, specialists, stakeholders and policymakers in possible courses of nuclear waste management	Chilvers & Burgess 2008
		Sociotechnical visions of energy futures: deliberative mapping to assess citizens' and experts' views on various energy futures	Bellamy et al., 2022
Citizens' assemblies	Deliberative mini-public in which citizens are randomly selected, are informed by experts and deliberate in small groups	Irish citizens' assembly on climate change	Devaney et al., 2020
		Oxford citizens' assembly on climate change	Wells et al., 2021
		Citizens' convention for the climate France	
Citizens' juries	Deliberative mini-public in which citizens are randomly selected and deliberate on policy issues (similar to climate assemblies, but often smaller in number of citizens and applied on the local level)	Leeds citizens' jury on climate change: citizens' jury commissioned by the Leeds Climate Commission to engage citizens in Leeds' Climate Emergency Strategy involving 25 citizens	Wells et al., 2021
		Helsinki citizens' jury on climate change: citizens' jury engaging 33 citizens in Helsinki's Medium-term Climate Change Policy Plan in which	Kuhla et al., 2022
		Kendal citizens' jury on climate change: citizens' jury engaging 20 citizens of Kendal to inform Kendal Town Council's Carbon Neutral Kendal Group	

Approach	**Description**	**Examples of cases**	**References**
Deliberative polling	Deliberative method designed by James Fishkin (1991; 1995) in which large amounts of citizens are randomly selected, who receive briefing materials and discuss material in alternating small groups and with experts and develop policy proposals. A survey is taken before and after to gain insight about the influence of information and deliberation.	WorldWideViews: global public engagement on climate change that in its design is similar to a deliberative poll	Blue & Medlock 2014
		Deliberative poll on nuclear energy	Hall et al., 2011
		National deliberative poll on energy futures in Japan	Ngar-yin Mah, 2021
Online public engagement tools	Range of participation methods that engage citizens on a large scale, involving an interactive interface	Participatory Value Evaluation (PVE), an online citizen engagement tool where citizens express their preference for policy options, application to regional energy transition	Mouter et al., 2021
		My2050: online scenario simulator where citizens select mitigation measures to achieve 80% of carbon emissions reductions in 2050 developed by Department of Energy & Climate Change UK	Allen & Chatterton, 2013; Pidgeon et al., 2014
Experiential scenarios	'creating real memories of virtual events by combining futures inquiry methods such as scenarios with human-centred, experiential, empathy-inducing and performative approaches of artistic and design research'	The People Who Vanished: workshops with artists, students, performers and anthropologist to co-develop a transmedia scenario of Phoenix various artefacts and performances	Candy & Dunagan, 2017
		2050 An Energetic Odyssey: an interactive art installation showing an imaginary of off-shore wind energy in the North Sea	Hajer & Pelzer, 2016
		Sustainability in an Imaginary World: interactive art installation involving several rooms to articulate and challenge people's deeply held beliefs about sustainability	Bendor et al., 2017

Artistic approaches and example cases

Approach	Description	Examples of cases	References
Participatory theatre	Heras & Tàbara (2014) for a review	Review of cases of participatory theatre in environmental contexts	Heras & Tàbara 2014
		"You, me, and our resilience.": a public engagement project applying participatory theatre to empower community resilience	Brown et al., 2017
Climate fiction	Johns-Putra (2011; 2016) for reviews	Analysis of five climate fiction novels and comparison with SSPs including Solar (Ian McEwan), Science in the Capital (Kim Stanley Robinson), Carbon Diaries (Saci Lloyd), Flight Behavior (Barbara Kingsolver)	Nikoleris et al., 2017
		Analysis of two climate fiction novels: The Water Knife (Paolo Bacigalupi) and Green Earth (Kim Stanley Robinson)	Milkoreit, 2017
		Elaborate explanation of the use of science fiction to explore energy futures	Raven (2017)
Speculative design/design fiction	'a practice of creating imaginative projections of alternate presents and possible futures using design representations and objects' (DiSalvo, 2012)	Vitiden: a design speculation based on Swedish energy policy scenarios involving various artefacts in a book form such as a pizza menu and a diary	Wangel et al., 2019
		Post-fossil city contest: a contest where artists and designers were invited to submit ideas and finalists developed an exhibition showing art-works and object that speculate on possible post-fossil futures	Pelzer & Versteeg, 2019
		Carbon Ruins exhibition: an exhibition looking back from 2053 showing objects that have become obsolete in the transition towards a low-carbon future	Stripple et al., 2019

*Some argue that climate fiction is a subcategory of science fiction whereas others view climate fiction as any fiction with a central focus on climate change.

Appendix B. Methodology of Chapter 2

We employed a combination of literature review, quantitative document analysis and expert interviews to analyse the historic IAM-policy interactions, which are described in the following paragraphs.

B1. Literature review

Literature included academic articles and books that report on the history of international climate governance or global (climate) modelling as well as literature on their interactions between modelling and policy, most notably in the field of Science and Technology Studies (STS). Additional literature reviewed to trace the history of IAM-policy interactions included institutional reports, most notably each subsequent IPCC reports that describe the use of IAM in IPCC's assessments, and to a lesser extent workshop or conference proceedings such as IIASA modelling workshops or COPs. Our aim was not a systematic literature review, but rather to gather relevant insights in literature relevant to our research question. Based on this review, A first identification of historic phases characterized by a shift in IAM-policy interactions could be made, which was discussed during the interviews and altered in an iterative process. Vice versa, statements from the interviews were checked in other interviews and literature sources. The literature also provide relevant scope of our analysis: starting with the 1970s until today. The decision to stop our historic analysis at the year 2015 was based on the fact that the Paris is likely to be a turning point that marks a new phase in which, at the time of writing, we are presumably still situated and therefore creates a bias towards reflecting on what this phase is characterized by.

B2. Quantitative document analysis

In order to identify the historic evolution of IAM research in climate research and assessment, two analyses were performed. First, a Scopus analysis was performed to analyse the amount of IAM publications in scientific literature over time. The following query was used to identify climate research: (TITLE-ABS-KEY("climate change") and the following query to identify IAM research on climate change: (TITLE-ABS-KEY("climate-economy model" OR "integrated assessment model" OR "integrated assessment modeling" OR "integrated assessment modelling" AND "climate"). The analysis was performed in March 2020 and included all years until (and including) 2019. A limitation of our analysis is that the term 'integrated assessment model' has not always been the widely used term to define the field. Only the latter was included in our search query because this term was used to refer to models we know characterize as IAMs, whereas the latter refer to other types of models as well. Additional terms are for instance global modelling, integrated modelling and climate economy modelling. Another limitations is that we only considered the amount of articles, rather than how often each article has been cited, since this was beyond the scope our research. Furthermore, we relied on Scopus to do this analysis and relevant articles may have been left out as these might not be part of this database.

Second, the relative contribution of IAM analyses to IPCC Synthesis Reports over time between 1990 and 2015 (AR1-5) was investigated by Van Beek and Van Vuuren by means of estimating the amount of information based on IAM results for each page and calculating the average percentage. A limitation of our analysis is that IPCC reports are always collaborative efforts and often involve multiple methods to derive at conclusions. In order to overcome this bias, we only counted information in the text where it was clear that it was derived from IAMs (such as the scale, scope and timing of necessary mitigation) and left information where this contribution could by no means be traced out. For figures that were constructed with multiple methods (such as combined GCM-IAM figures) the relative contribution of IAMs was estimated based on the goal and position of the figure. For instance, A figure showing emissions scenarios used for GCMs to project temperature changes in a WGI section was not counted as IAM contribution. The document analyses can thus be considered a rough estimate of the trend observed in the role of IAM in research and assessment over time. These analyses were primarily used for constructing Figure 3 of this thesis.

B3. Interviews

We conducted 18 semi-structured interviews with current and former IPCC authors and UN climate negotiators. IPCC authors mostly involved WGIII authors from the IAM community and also WGI authors from the GCM community, including Coordinating Lead Authors (CLAs) and Lead Authors (LA). The interviewees covered six nationalities (USA, Canada, the Netherlands, Italy, Germany, Austria). The interviews with the WGIII / IAM community involved (current or former) affiliates from a wide range of institutes that constitute the IAM community, such as IIASA, PBL (or former RIVM), PNNL, Carnegie Mellon, CMCC and PIK and the Stanford EMF (due to confidentiality, the interviewees remain anonymous). A limitation of our research is that it covered only representatives of North-American and European modelling teams, which may have neglected other modelling teams that are relevant. Current and former UN negotiators involved only Dutch interviewees, which may have biased our results.

Interviews involved questions regarding the origins of IAMs, the organisation of the IAM community, their position in IPCC WGIII assessments, and their (historic) interaction with international environmental policy (e.g. UNEP and later UNFCCC). The interviews lasted approximately 1 hour and were conducted either live or through video calling technology. Interviewees provided verbal informed consent on the research goals and interview recording before proceeding to the interview. The interviews were recorded and transcribed in order to gain insights in our historical analysis and were used to derive quotes to exemplify developments in description of the historic phases. Moreover, the interviews were used to verify findings in the literature review or statements by previous interviewees in order to improve the credibility of the insights.

Appendix C. Methodology of Chapter 3

C1. Research strategy

Our reconstruction is based on a combination of interviews and document analysis, which were used in an iterative fashion. This entails that documents were first searched to develop an initial understanding of the sequential steps that led to the publication of the IPCC SR1.5, which mainly involved academic literature on the SR1.5 (e.g. Livingston and Rummukainen, 2020), IPCC documentation and documentation of the UNFCCC negotiations. The interviews were then conducted to gain deeper insights into the role of IAM pathways in those science-policy interactions, for instance by asking how certain events influenced interviewees' perceptions regarding the feasibility of the 1.5˚C goal. Subsequently, insights from the interviews were also used to further analyse documents, for instance to derive the reasoning behind criticism on NETs by expert reviewers of the SR1.5. Additionally, statements from interviewees were also checked in documentation.

C2. Methodology of semi-structured interviews

Interviewee selection and invitation

We conducted 22 semi-structured interviews with IPCC SR1.5 authors (including IAM modelers), other actors that were involved in the preparation of the SR1.5, UNFCCC and government representatives and external experts (see table below for list of interviewees). This diversity roles was chosen to gain insights from a broad range of perspectives on the science-policy interactions around the SR1.5 and the role of IAMs in those interactions. Interview candidates were selected using the IPCC SR1.5 author list or identified through interviews and invited via email. The interviewees covered 7 nationalities (Australia, Austria, India, France, Germany, UK, the Netherlands). The majority European interviewees (16 out of 21) may have biased our results.

Data collection and analysis

Prior to the interview, interviewees received a document outlining the goals and aims of the study and our process of data collection including recordings and provided their informed consent before proceeding to the interview. The interviews were conducted by two authors, lasted approximately 60 minutes and were conducted face-to-face or online via video calling technology. Interviews were recorded, transcribed and analysed to develop the reconstruction and exemplify results with interview quotes.

Role in SR1.5		**Interview #**	**IAM modeller**
Author (10)	CLA	1	
		4	x
		10	
		17	
	LA	5	x
		6	x
		7	
	CA	2	x
	Chapter scientist	3	x
		9	
Expert reviewer (4)	Scientist	11	
		12	
		14	
		18	
Civil society organisation (1)		8	
IPCC Bureau (1)	IPCC co-chair	5	
Government representative (4)	IPCC focal point	13	
		16	
	Policy-maker	21	
		22	
External experts on climate policy and mitigation (2)		15	
		20	
UNFCCCC Secretariat (1)		19	
Total: 22			

C3. Methodology of document analysis

We analysed a mix of academic literature, policy documents, IPCC reports and proceedings to reconstruct the science-policy interactions around the SR1.5 and the 1.5˚C goal between 2015 and 2020 (see table below for overview of purposes of the documents).

Type of document		Purpose in reconstruction
Academic literature		Obtain general insights into the science-policy interactions around the SR1.5 and the 1.5˚C goal
		Compare and interpret the role of IAMs in those science-policy interactions
IPCC SR1.5		Obtain insights in the use of IAMs to generate outputs such as figures and graphs
		Compare IAM outputs with information in other chapters on mitigation
IPCC SR1.5 report drafts	First Order Draft (chapter 2,4,5, SPM) Second Order Draft (chapter 2,4,5) Final Government Draft (chapter 2,4,5, SPM) Draft for SPM approval (chapter 2,4,5, SPM)	Compare drafts to gain insights into the changes in the content of the SR1.5, including the number and content of IAM pathways
IPCC SR1.5 expert and government reviews and responses	First Order Draft (chapter 2,4,5, SPM) Second Order Draft (chapter 2,4,5) Final Government Draft (chapter 2,4,5, SPM)	Analyse amount and content of comments on IAM pathways and negative emissions (e.g. 'overshoot' 'NETs', 'BECCS', 'CDR', 'CCS')
		Analyse response of authors to criticism on IAM pathways and negative emissions.
IPCC meeting reports		Obtain general insights in the sequential steps underlying the development of the SR1.5
		Identify the range of actors involved in the SR1.5 to invite for interviews
		Obtain insights in content of discussions among IPCC authors regarding the 1.5˚C and main areas of criticism by reviewers
Earth Negotiation Bulletin reports (IISD)		Obtain insights in the negotiations during COPs on the long-term global goal and the request to the IPCC to draft a report
		Obtain insights into discussions during the SPM approval on the 1.5˚C, climate mitigation and IAM pathways specifically

C4. Methodology quantitative literature analysis

In order to identify the evolution of amount of academic literature on the 1.5°C as well as IAM literature on the target specifically, we used Scopus on 1.1.2021 using the following search queries:

> general literature: (TITLE-ABS-KEY(“1.5°C” OR “1.5 degrees” OR “1.5°C” AND “climate change”))
>
> IAM literature: (TITLE-ABS-KEY “ “1.5°C” OR “1.5 degrees” OR “1.5°C” OR “1.5 C” OR “1.5°C” AND “integrated assessment” OR “energy-economic model” OR “integrated model” OR “integrated assessment model” OR “IAM”))

Appendix D. Methodology and detailed results of Chapter 6

D1. Methodology

Data collection methods

	ICA	PVE
Literature	academic literature, reports, policy documents, experts' papers and presentations	academic literature, reports, policy documents, parliamentary debates
Survey data	survey results derived from Farrell et al. (2017)	survey among PVE participants
Interviews	12 semi-structured interviews with involved actors	3 semi-structured interviews with involved actors.
Personal observations		Personal observations during meetings with experts and policymakers
Video material	Videos of plenary Assembly sessions, including opening speeches, expert presentations and Q&A sessions	

Interviewees

	ICA		PVE		
#	**Role in ICA**	**Type of affiliation**	**#**	**Role in PVE**	**Type of affiliation**
1	Expert witness	Research agency	13	Co-designer	Policy advisor
2	Expert witness	Academic institute	14	External	Ministry representative
3	Observer	Academic institute	15	External	NGO representative
4	Observer	Academic institute			
5	Observer	Academic institute			
6	Expert witness	Academic institute			
7	Expert Advisory Group	Academic institute			
8	Secretary	Civil service			
9	Expert Advisory Group	Academic institute			
10	Expert Advisory Group	Academic institute			
11	Assembly Member	Citizen (none)			
12	Assembly Member	Citizen (none)			

Survey among PVE participants

The survey among participants of the PVE, which participants filled in after completing their recommendations, contained two open questions regarding how participants' positive and negative evaluations of the PVE. Responses of 2000 participants were analysed (1000 of the PVE panel and 1000 of the open PVE) by two coders, including author 1 and another researcher from the PVE team. Both researchers first coded the first 100 responses of the PVE panel. The coding was then compared and an elaborate codebook was developed including the code name, code description and a number of examples from participants' responses. Another subset of the PVE panel (100 responses) was codified individually by the two coders using this codebook and compared to establish the intercoder reliability (Cohen's kappa = 0.91). A subset of the open PVE (100 responses) was also codified individually by the two coders using the same codebook and compared (Cohen's kappa = 0.93). The most often recurring responses are shown below. Since not all participants filled in the two open questions, no percentages were calculated.

Positive	N	Negative	N
Accessible for a large group of citizens	270	Number of policy options is insufficient	148
Sufficient and clear information provision	277	Information provision was insufficient	76
Gives a sense that my voice is heard	267	Not accessible for a large group of citizens	63
Brings awareness of personal agency	171	No representation of diverse perspectives	33
Improves understanding of governments' choices	80	Too little possibility for nuanced arguments	32
Other	137	Other	258*

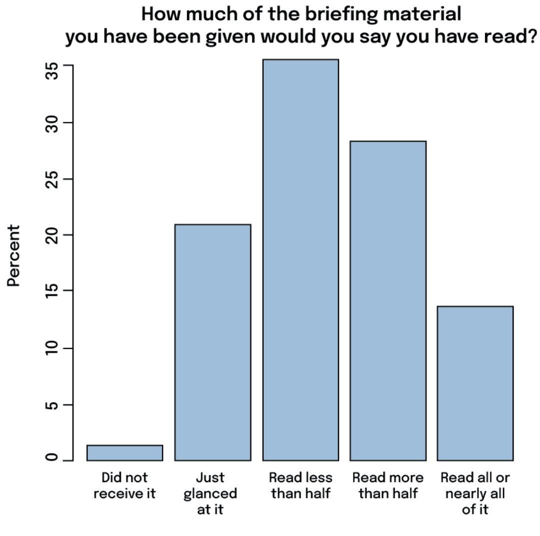
*many of the remaining negative responses concerned the interface (e.g. that it did not work on a mobile phone or that certain features were not responding) and responses regarding climate policymaking in the Netherlands more generally (e.g. that climate change is a global rather than a national problem)

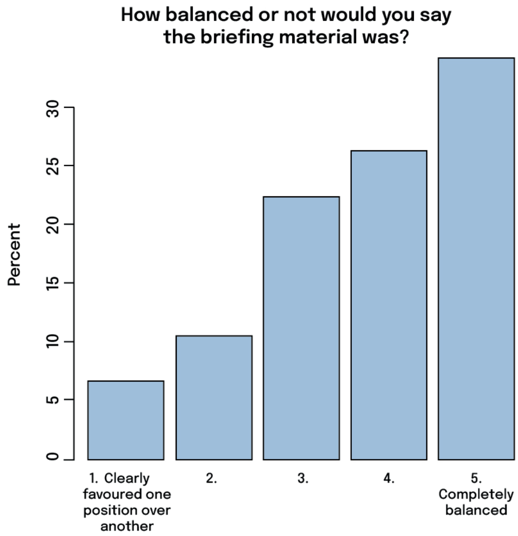
Survey results obtained from Farrell et al. (2017)

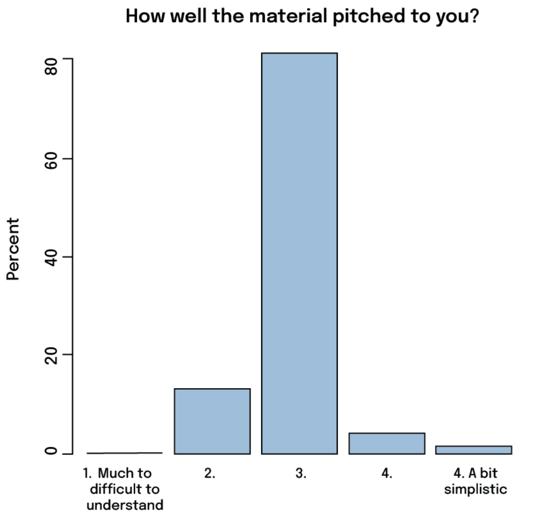
These feedback reports below were developed by a research team that investigated the ICA, including surveys among Assembly Members (Farrell et al., 2017). The feedback reports were sent to author 1 and included in this Supplementary Information with permission of this research team.

Feedback report on Weekend 8 (30 September-1 October, 2017)

The first set of questions were about the briefing materials. Compared to the previous weekends, there was a further reduction in the numbers of members who said they had read most or all of the briefing material; on this occasion, less than half the members had. However, as in previous weekends, the views about the quality of the briefing material were again positive: the greater majority of members felt that the briefing material was balanced, and four-fifths said it was 'pitched about right'.

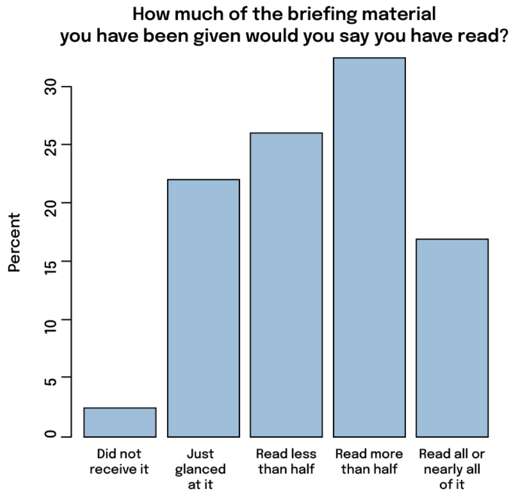

How much of the briefing material
you have been given would you say you have read?
Percent
0
5
10
15
20
25
30
35
Did not receive it
Just glanced at it
Read less than half
Read more than half
Read all or nearly all of it

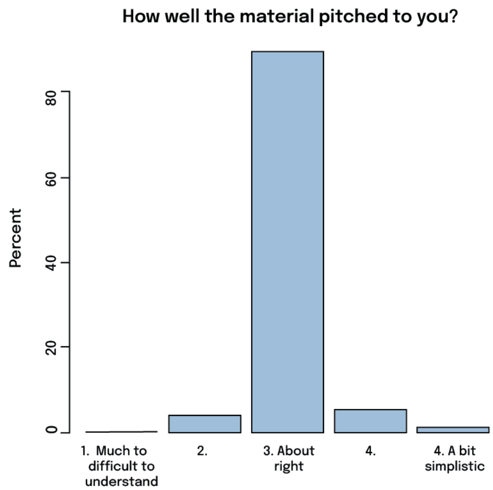

How balanced or not would you say
the briefing material was?
Percent
0
5
10
15
20
25
30
1. Clearly favoured one position over another
2.
3.
4.
5. Completely balanced

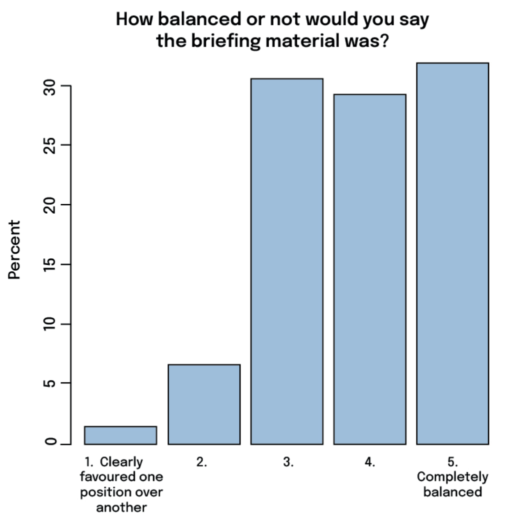

How well the material pitched to you?
Percent
0
20
40
60
80
1. Much to difficult to understand
2.
3.
4.
4. A bit simplistic

Feedback report on Weekend 9 (4-5 November 2017)

The first set of questions were about the briefing materials. Compared to the previous weekend, there was a slight improvement in the numbers of members who said they had read most or all of the briefing material; on this occasion, just over half the members had. As in previous weekends, the views about the quality of the briefing material were again positive: the greater majority of members felt that the briefing material was balanced (though there were a significant number who were undecided), and four-fifths said it was 'pitched about right'.







D2. Overview of policy options and level of consensus

List of citizens' recommended policy options and level of consensus

Sector	ICA		PVE		
	Policy option	Percentage in favour	Policy option	Percentage in favour	
				Open	Sample
General	Climate change at centre of policy-making	97%			
	State should take leadership role in climate mitigation and adaptation	100%			
	Willingness to pay higher taxes on carbon intensive activities	80%			
	Comprehensive assessment of vulnerability of critical infrastructure across sectors	96%			
Energy	Enabling citizens to sell back energy from micro-generation at wholesale price	99%	Investment in off-shore wind energy	85%	84%
	Support community ownership of future renewable energy projects	100%	Investment in on-shore wind and solar energy	45%	60%
	End all subsidies for peat extraction and invest in peat bog restoration	97%			
Transport	Increase and give priority to infrastructure for bus and cycling lanes and park and ride facilities	93%	Introduction road pricing for car users	85%	60%
	Support transition to electric vehicles	96%	Increase subsidies on electric vehicles	68%	
	Support land use diversification to encourage afforestation and organic farming	92%			73%

Sector	ICA		PVE		
	Policy option	Percentage in favour	Policy option	Percentage in favour	
				Open	Sample
Agriculture	Tax on GHG emissions from agriculture and rewards for carbon sequestration by farmers	89%	Reduce livestock through buy out or allowances	83%	62%
	Mandatory measurement and reporting of food waste across whole supply chain	93%	Introduction of a tax on meat consumption	80%	48%
	Support land use diversification to encourage afforestation and organic farming	99%			
Industry			Carbon tax in industry		
			Subsidies to reduce emissions in industry		
Built environment			Stimulate insulation of residential buildings		

Comparison of ICA recommendations by citizens and experts

Sector	Citizens' recommendations		
	Policy option	Percentage in favour	Number of experts who mentioned policy option
General	Climate change at centre of policy-making	97%	n.a.*
	State should take leadership role in climate mitigation and adaptation	100%	n.a.*
	Willingness to pay higher taxes on carbon intensive activities	80%	4
	Comprehensive assessment of vulnerability of critical infrastructure across sectors	96%	0

Sector	Citizens' recommendations		
	Policy option	Percentage in favour	Number of experts who mentioned policy option
Energy	Enabling citizens to sell back energy from micro-generation at wholesale price	99%	2
	Support community ownership of future renewable energy projects	100%	5
	End all subsidies for peat extraction and invest in peat bog restoration	97%	3
Transport	Increase and give priority to infrastructure for bus and cycling lanes and park and ride facilities	93%	1
	Support transition to electric vehicles	96%	6
	Prioritise expansion of public transport over road infrastructure with no less than 2:1	92%	4
Agriculture	Tax on GHG emissions from agriculture and rewards for carbon sequestration by farmers	89%	1
	Mandatory measurement and reporting of food waste across whole supply chain	93%	3
	Support land use diversification to encourage afforestation and organic farming	99%	6*

* these policy proposals were considered lacking specify in order to determine whether experts suggested these

** experts that only mentioned part of the recommendation (e.g. afforestation or organic farming were) were all counted

Comparison ICA recommendations and Irish climate policy

Sector	Citizens' recommendations	Climate Action Plan 2019	Climate Action Plan 2021
General	Climate change at centre of policy-making	"Reflecting the central priority that climate change will have … this Plan sets out a series of new governance arrangements"	"strengthening the governance structure" … "legally binding target to be climate neutral no later than 2050 and to reduce emissions by 51% by 2030"
	State should take leadership role in climate mitigation and adaptation		"Ireland has already been demonstrating leadership in a just transition by explicitly recognising and aligning it with our climate policy framework"

Sector	Citizens' recommendations	Climate Action Plan 2019	Climate Action Plan 2021
General	Willingness to pay higher taxes on carbon intensive activities	"Implement a carbon tax rate of at least €80 per tonne by 2030"	"carbon tax receipts amounting to €9.5 billion out to 2030"
	Comprehensive assessment of vulnerability of critical infrastructure across sectors		Several assessment schemes of vulnerability of risks of infrastructure in National Adaptation Framework
Energy	Enabling citizens to sell back energy from micro-generation at wholesale price	Providing grant for ca. 30% of installation cost of PV	"Microgeneration Support Scheme (MSS) …, including an export payment for all micro – and small-scale generators that reflects the market value of their electricity to the grid"
	Support community ownership of future renewable energy projects	Renewable Electricity Support Scheme (RESS): "community investment and ownership"	"further strengthen the community energy framework, including consideration of community-benefit funds and community ownership provisions in the RESS"
	End all subsidies for peat extraction and invest in peat bog restoration	Assess mitigation options on rewetting and post-production, implement peatland conservation measures, improve land-use mapping	Peatland restoration through funding various programmes, incl. Mona Peatlands Climate Action Scheme and supporting research and innovation
Transport	Increase and give priority to infrastructure for bus and cycling lanes and park and ride facilities	Expand infrastructure for bus, cycling and walking through 'BusConnect'	Several measures incl. 1000 km additional walking and cycling infrastructure, bus infrastructure through BusConnect
	Support transition to electric vehicles	Develop EV charging network and infrastructure	New Scheme to deliver 200 charge points for EVs, Electric Vehicle Policy Pathway published
	Prioritise expansion of public transport over road infrastructure with no less than 2:1		
Agriculture	Tax on GHG emissions from agriculture and rewards for carbon sequestration by farmers		
	Mandatory measurement and reporting of food waste across whole supply chain	Identify opportunities to strengthen regulatory and enforcement frameworks and structures for waste collection and management	Develop Food Waste Prevention Roadmap, enhance food waste segregation, develop Regional Waste Management Plan, introducing Circular Economy Bill

Sector	Citizens' recommendations	Climate Action Plan 2019	Climate Action Plan 2021
	Support land use diversification to encourage afforestation and organic farming	New Common Agricultural Policy which encourages diversification and afforestation	Several afforestation projects incl. Project Woodland and new Forestry Programme, pilot project for supporting environmentally friendly farming practices, organic farming scheme, Land Use Review including reviews for income for farmers inc. diversification and agro-forestry

D3. Types of experts and expertise in both cases

	ICA		**PVE**	
	Experts	**Forms of expertise***	**Experts**	**Forms of expertise**
Experts involved in design	*Expert Advisory Group*	*Process expertise* on deliberative democracy	*PVE researchers*	*Process expertise* on designing and analysing the PVE
		Scientific, technical and policy expertise on climate policy, international relations, sustainability, environmental law and environmental science.		*Scientific, technical and policy expertise* on climate policy; economics; political/social science; philosophy;
External experts	*Expert witnesses (knowledge experts)*	*Scientific, technical and policy expertise* on climate science; current EU and Irish policy frameworks, technical knowledge in environmental science, energy and engineering; economics; innovation	*Externally consulted experts*	*Scientific, technical and policy expertise* on environmental science; existing Dutch policy frameworks; energy science; political science; philosophy; psychology;
	Expert witnesses (advocates)	*Experiential and policy expertise* on how to initiate on-the-ground initiatives (e.g. farmer, fire fighter, social entrepreneur) and expertise on climate policy in other countries		

*these were derived from descriptions of expert witnesses and the EAG as described in the Assembly's report (The Citizens' Assembly, 2018)

D.4 Detailed overview of the design process of both cases

The PVE

Phase	Date	Activity
Phase 1: Reaching agreement to apply PVE	**July-August 2020**	PVE researchers reach out to policy advisors of Negotiations on National Climate Agreement to apply PVE
	Sept 2020	Meeting with policy advisors to present PVE method
	Oct 2020	Meeting with policy advisors and representatives of the Ministry of Economic Affairs and Climate to propose PVE method
		Motion filed in Houses of the Representatives to engage citizens in climate policy and assess possibility to apply citizens assemblies
	Nov 2020	Official accord by Ministry representatives agree to apply PVE to National Climate Agreement
Phase 2: Design of the PVE	**Dec 2020**	Meeting with policy advisors and representatives of the Ministry of Economic Affairs and Climate. Decisions: → Reporting results prior to elections for agenda-setting → Maximum of 13 policy options to ensure feasibility for citizens → New 55% emissions reductions as primary basis → Use of government report on 55% measures
	Jan 2021	Expert meeting with researchers from UU and PBL. Decisions: → Concrete policy options rather than abstract scenarios → Policy options across all sectors → Use of images and personal benefits to make it tangible
		Expert meeting with National Think Tank. Decisions: → Layered information to make PVE relevant to varying knowledge levels → Include question on perceptions on ambitious climate policy to ensure inclusiveness
		Meeting with policy advisors and representatives of the Ministry of Economic Affairs and Climate. Decisions: → Ability to adjust levels of policy options instead of ‘yes/no’ → Explicitly explain absence of nuclear energy and hydrogen → Provide ability to propose alternative policy options
		Expert meeting NWO Consortium. Decisions: → Reduce amount of policy options to 10 → Explicitly explain absence of flying tax → Use of factual information to ensure credibility

Phase	Date	Activity
		Meeting with policy advisors and representatives of the Ministry of Economic Affairs and Climate → Include nuclear energy, hydrogen and flying tax in second part of PVE → Final set of 10 policy options, 2 per sector → Use of budget constraint of +20%
		Policy report on policy measures to reach 55% emissions target
	Feb 2021	PVE researchers develop content of PVE: introduction text and film, information of policy options and questionnaire in iterative process with external experts on climate mitigation.
		Pilot sessions with citizens to test relevance, comprehensiveness and feasibility of PVE
Phase 3: PVE online	**March 2021**	PVE link online between 5 and 31 March and press release by TU Delft, UU and Dutch Climate Agreement Media echo announcement PVE (radio, TV, news articles: → RTL: news article → Twitter: message by Director General of Ministry of Economic Affairs and Climate → Radio 1: interview with PVE researchers → NOS: news article → Trouw: newspaper article → GeenStijl: article → Gaslicht.nl
Phase 4: Reporting of results	**June 2021**	Publishing report and handing over to Ed Nijpels
		Official letter to Ministry of Economic Affairs and Climate
		Media echo of findings → Trouw → NOS → Tweet Jesse Klaver
	October 2021	Ed Nijpels reiterates four key principles in political debates on climate mitigation

The ICA

2016	**Feb**	Fine Gael manifesto promising to establish a Citizens' Assembly to consider 1) the Eighth Amendment of the Constitution; 2) Seanad Reform; 3) climate change; 4) the way in which referenda are held; 5) ageing population
	Mar	RED C polling revealed 55% of citizens agreed expanding access to abortion should be one of the priority issues

	Jul	**13**	Parliamentary debates on establishment Citizens Assembly: Green Party emphasizes need to include climate change as one of the five topics for Assembly to discuss
		16	Approval of establishment Citizens' Assembly by a Resolution of both Houses of the Oireachtas to discuss five topics: Eighth Amendment of the Constitution (abortion), ageing population, fixed term parliaments, manner in which referenda are held, climate change
	Aug		Participant selection by market research company RED C
	Oct	**15**	Inaugural meeting Citizens Assembly
	Nov	**26**	Assembly meetings on Eighth Amendment of the Constitution (abortion)
2017	**Jan**		Assembly meeting: decision to move climate change from fifth to third topic and to dedicate two weekends instead of one
	Apr		Successful referendum on abortion (87% in favour of not retaining Eight Amendment of the Constitution and 64% in favour of "terminations without restrictions")
			Establishment National Dialogue Climate Action
			National Mitigation Plan published by Department of Communications, Climate Action and Environment
	Jun 9 – Aug 11		Public submissions: 1,205 online/written submissions by advocacy groups, experts and citizens
	Sep		Developing work program by Secretariat, Assembly Members and Expert Advisory Group
	Oct	**1**	First Assembly meeting on climate change → 12 expert presentations on climate science and impacts, current status of climate and policy in Ireland and energy → 3 rounds of Roundtable discussions and Q&A → Suggestions for issues to become included in Ballot Paper
		19	→ Steering Group meeting a number of Assembly Members provide feedback on the first draft of the Ballot Paper
	Nov	**4**	9 expert presentations on transport, agriculture and international perspectives on leadership 3 rounds of Roundtable discussions and Q&A Ballot Voting
2018	**Apr**	**18**	Final report with 13 recommendations on putting climate change at centre of policymaking (1-4), energy (5-7), transport (8-10) and agriculture (11-13)
			Establishment Special Joint committee on Climate Action (JOCCA): all-party parliamentary committee to 'consider' the Assembly's report and how it may inform Ireland's National Mitigation Plan and National Energy and Climate Plan
2019	**Mar**		Final report JOCCA, largely endorsing Assembly's recommendations
	Jun		Climate Action Plan 2019 published by government, shaped by JOCCA recommendations and reflecting part of the Assembly's recommendations

2020	**Dec**		Climate Action and Low-carbon Development Bill 2020
2021	**Mar**		Climate Action and Low-carbon Development Bill 2021
	May		Climate Action Plan 2021 published by Government introducing additional and more ambitious climate policies
	July		Climate Action and Low Carbon Development Act 2021
	Dec		New National Investment Framework for Transport reflecting Assembly's recommendation of the 2:1 ratio of expenditure between new public transport infrastructure and new roads

Summary

As the planet becomes an ever more hostile place, the need for a radical societal transformation intensifies. In response, countries globally have set ambitious climate targets, such as the 1.5 and 2°C degrees temperature goals in the Paris Agreement in 2015 and mid-century emissions targets. Both scientifically and politically, these goals strongly rely on a specific type of computer model: Integrated Assessment Models (IAMs). IAMs are global models that represent the complex interactions between human activities and changes in the climate system. By simulating multiple mitigation scenarios, they provide insights into the trade-offs between mitigation options and the long-term effects. The roots of IAMs can be traced back to the 'World 3' model that provided the calculations for the Club of Rome's 1972 (in) famous *Limits to Growth* report. *Limits to Growth* set in motion a worldwide environmental movement. Simultaneously, its underlying model introduced what would become the primary source of knowledge about environmental futures; it marked the age of global modelling in environmental politics.

Fifty years on, times are changing. Climate change has moved from the confines of science and UN climate negotiations to a primary issue of public debate. National governments, cities, and organisations across the globe are implementing climate strategies. Citizens and activists demand climate justice. Such developments bring the prominence of IAMs into question. IAMs typically focus on cost-effectiveness, technological innovation, and linear change. They may not be suited to project radical transformations and struggle to account for questions of justice. Because their scenarios are tailored to policymakers, it is also unclear if and how they can cater to the knowledge needs of the diverse actors in climate politics.

While IAMs over time attained a clearly defined and prominent role in the science-policy interface, their role in the societal debate is far less self-evident. In this thesis, I aim to explore this tension by investigating the role of IAMs in climate policy (**Part I**) and exploring alternative future roles of IAMs in policy and society (**Part II**). The central question I answer is: *How do IAMs shape the possibility space of low-carbon futures in climate politics, and how could this possibility space be pluralised and democratised?*

Part I first focuses on *how* and *why* IAMs have acquired and retained such remarkable influence by reconstructing the historic interactions between IAMs and climate policy. In **chapter 2**, I illuminate how, between 1970 and 2015, IAMs played leading roles in environmental policy despite changing knowledge demands. The analytical qualities of IAMs and the advances in data availability or computer technology were important, yet not sufficient to explain their political and scientific traction. By looking at IAMs as part of a broader 'technique of futuring', as a practice through which futures are imagined and become collectively shared, I reveal that their authority derives from both the structural legitimacy of quantitative knowledge as well as modellers' deliberate efforts to establish and maintain their policy-relevance. Subsequently, **chapter 3** examines how interactions between modelling and policymaking around the 1.5°C goal shaped climate policy. In the chapter, I observe how modellers calibrate their scenarios politically to fit the demands of the policy community. This political calibration facilitates policy relevance, but navigating between political sensitivities also gives rise to several dilemmas. Through this navigation, certain possible futures are rendered more persuasive than others. Such pathways can become influential drivers of climate policy, as is evidenced in the rapid normalisation of carbon dioxide removal. In short, the close interaction between modelling and policymaking creates a 'possibility space' for low-carbon futures that risks overlooking less prominent possibilities. This is problematic because of the growing plurality of actors in climate politics, their diverse views on desirable futures, and the increasing attention for just climate futures.

Addressing this need to pluralise and democratise this imagined possibility space is the focus of **Part II** of thesis. In this section, I experiment with transdisciplinary exchanges. In **chapters 4 and 5**, I explore interactions between the IAM practice and artistic practices. This is motivated by the observation that artists can imagine radically different societies and engage audiences in alternative futures. I argue that climate fiction might be a particularly fruitful practice to seek such encounters, given that both IAMs and literary fiction involves storytelling (**chapter 4**). By bringing modellers and fiction writers into conversation, a key finding is that modellers and writers rely on different mechanisms to build plausibility. For IAM modellers expert judgment, rationality and abstraction are key, while writers focus on the readers' life world, recognisable protagonists, and emotionally meaningful details. Interactions with climate fiction could help challenge and expand modellers' explorations and establish more reciprocal dialogues with lay publics. For **chapter 5**, I collaborated with two artists-in-residence to engage an IAM team through interviews, group discussions, workshops. These engagements led to the Future Models Manual, a speculative manual in the form of an interactive website that takes modellers on a journey through different steps to reflect on and reconsider their practice. In the chapter, I describe how the artists stimulated reflection by asking unfamiliar questions, identifying generative metaphors and developing visual artefacts. Importantly, however, neither the encounters with visual artists nor with writers *guarantee* more radical imagination, as artists must comply with their own discourses, ethics, and genres. This potential depends on the role of the artist in the collaboration: whether the artist is solely viewed as science communicator or enabled to challenge and transform scientists' assumptions. Pluralising the possibility space presumably requires the latter. In **chapter 6** I take the next step in exploring climate policymaking on the national level. Here, policymaking also strongly relies on model-based approaches including national IAMs. At the same time, citizen engagement practices are on the rise. I compare two contrasting cases of citizen engagement: the Participatory Value Evaluation, an online tool that bears remarkable similarities with IAMs as citizens evaluate a set of climate policy-options to meet a quantified target, and a climate assembly in which experts and citizens engage in live dialogues. In both cases, experts strongly influenced the outcomes. This finding underscores that engaging citizens does *not guarantee* an opening-up of policy options and viewpoints either. Rather, it depends on the roles that experts and citizens have, how expertise is staged and the setting in which interactions take place. In the search for an alternative role of modelling, these are crucial considerations to take into account.

I conclude this thesis by reflecting on the future of IAMs against the backdrop of the growing call for climate justice. Existing perspectives on the future of IAMs tend to analyse IAMs as a technical 'tool'. Yet what this thesis finds is that the models themselves are not necessarily the problem but rather their role in climate politics. To me, the answer therefore lies not in improving the models, but in a *reconfiguration* of modelling in climate politics. Climate politics requires new relationships between IAMs, policy and society, in which the relative importance of modellers and policymakers is decreased. This is no easy task. Still, this thesis demonstrates that the prominence of IAMs is not set in stone. As such, it *can* be reconfigured. I view such a fundamental reconfiguration as a critical step in moving towards a low-carbon and socially just future.

Samenvatting

Nu onze planeet steeds minder leefbaar wordt, is de noodzaak van een grootschalige transformatie van de samenleving onomstotelijk. Wereldwijd hebben landen ambitieuze doelen gesteld, zoals de 1.5 en 2°C graden in het Parijsakkoord en emissiedoelen voor 2050. Zowel wetenschappelijk als politiek zijn deze doelen sterk afhankelijk van een specifiek soort computer model: Integrated Assessment Modellen (IAM's). IAM's zijn mondiale modellen die complexe interacties weergeven tussen het klimaat en de samenleving. Door verschillende beleidsscenario's te simuleren geven de modellen inzicht in de afwegingen tussen beleidsopties en de langetermijneffecten. De oorsprong van IAM's is te herleiden naar het 'World 3'-model, waarmee de berekeningen werden gemaakt voor het *Grenzen aan de Groei* rapport in 1972. Dit wereldberoemde rapport, geïnitieerd door de Club van Rome, leidde tot een mondiale milieubeweging. Tegelijkertijd introduceerde het rapport ook wat later de primaire kennisbron voor milieutoekomsten zou worden; het tijdperk van mondiale modellen in de milieupolitiek was aangebroken.

Vijftig jaar later zijn de tijden veranderd. Klimaatverandering is niet langer alleen een onderwerp in de wetenschap en internationale onderhandelingen, maar een kernonderwerp in het publieke debat. Wereldwijd implementeren nationale overheden, steden en bedrijven klimaatstrategieën. Burgers en activisten gaan massaal de straat op voor radicalere verandering en klimaatrechtvaardigheid. Deze ontwikkelingen stellen de prominentie van IAM's ter discussie. De modellen leggen de focus voornamelijk op kosteneffectiviteit, technologische innovatie en lineaire verandering. Deze eigenschappen maken het twijfelachtig of ze radicale transformaties goed kunnen voorzien en of ze voldoende rekening houden met rechtvaardigheid. Omdat de scenario's zijn gericht op beleidsmakers, is het ook onzeker of ze in de kennisbehoefte van andere actoren in de klimaatpolitiek kunnen voorzien.

Terwijl IAM's groot zijn geworden in wetenschap en beleid, is hun rol in het maatschappelijke debat veel minder vanzelfsprekend. In dit proefschrift verken ik deze spanning door eerst de historische en huidige rol van de modellen in klimaatbeleid te onderzoeken (**Deel I**), om vervolgens mogelijke nieuwe rollen in beleid en samenleving te verkennen (**Deel II**). De centrale vraag die ik beantwoord is: *hoe beïnvloeden IAM's de mogelijkheidsruimte over klimaatmitigatie in de klimaatpolitiek en hoe kan deze mogelijkheidsruimte worden verbreed en gedemocratiseerd?*

Deel I begint met de vraag waarom en hoe IAM's zo'n opvallend grote rol spelen door middel van een historische reconstructie van IAM's en klimaatbeleid (**hoofdstuk 2**). Ik observeer hoe IAM's belangrijke rollen speelden in milieubeleid tussen 1970 en 2015 ondanks de voortdurend veranderende kennisbehoefte. De analytische kwaliteiten en vooruitgang in data en computertechnologie waren belangrijk, maar zeker niet voldoende om deze prominente rol te verklaren. Door IAM's te zien als 'technique of futuring', als een bredere praktijk waarin collectieve verbeeldingen van de toekomst ontstaan, observeer ik dat hun autoriteit sterk afhankelijk is van de structurele legitimiteit van getallen en de toewijding van modelleurs om beleidsrelevant te worden en blijven. Vervolgens onderzoek ik in **hoofdstuk 3** de interacties tussen modellen en beleid rondom het 1.5°C doel. Ik observeer hoe modelleurs hun scenario's 'politiek kalibreren': de oriëntatie van modellen wordt voortdurend aangepast aan de ontwikkelingen in klimaatbeleid. Terwijl deze politieke kalibratie zorgt voor beleidsrelevantie, levert het voortdurende navigeren tussen politieke spanningen ook dilemma's op voor modelleurs. Daarnaast worden door deze navigatie bepaalde toekomstpaden overtuigender dan andere. Deze paden worden invloedrijk in klimaatbeleid, zoals blijkt uit de normalisatie van koolstofverwijderingstechnieken. Kortom, door de nauwe interactie tussen modellen en beleid wordt een 'mogelijkheidsruimte' van klimaatmitigatie geconstrueerd. Zo worden andere toekomsten en standpunten over het hoofd gezien, wat problematisch is gezien de toenemende diversiteit van actoren en standpunten in de klimaatpolitiek en de toenemende aandacht voor klimaatrechtvaardigheid.

Het verbreden en democratiseren van deze mogelijkheidsruimte is de focus van **Deel II** van dit proefschrift. In **hoofdstuk 4 en 5** verken ik interacties tussen modelleurs en kunstenaars. Hierin veronderstel ik dat kunstenaars op een radicalere manier over de toekomst kunnen nadenken en andere publieken kunnen betrekken. Ik zie klimaatfictie als een potentiële praktijk om uitwisselingen mee te verkennen, omdat verhalen in zowel fictie als modellen een centrale rol spelen (hoofdstuk 4). Door modelleurs in gesprek te laten gaan met klimaatfictieschrijvers, blijkt dat schrijvers en modelleurs op een andere manier plausibiliteit geven aan hun verhalen. Voor modelleurs zijn expertoordelen, rationaliteit en abstractie belangrijk, terwijl fictieschrijvers zich richten op de leefwereld van lezers, herkenbare karakters en emotioneel betekenisvolle details. Interacties tussen modelleurs en klimaatschrijvers kunnen daarom mogelijk helpen om een wederkerige dialoog met de samenleving te bewerkstelligen en radicalere toekomsten te verkennen. In **hoofdstuk 5** reflecteer ik op een kunstenaarsresidentie, waarbij kunstenaars in interactie gaan met een IAM team door interviews, groepsdiscussies en workshops. Dit leidde tot een artistieke interventie: de Future Models Manual: een speculatief handboek in de vorm van een interactieve website waarin modelleurs stap voor stap worden gevraagd om te reflecteren op hun praktijk en alternatieven te overwegen. De kunstenaars brachten reflectie teweeg door het stellen van ongebruikelijke vragen, generatieve metaforen en visuele artefacten. Echter, een belangrijke geleerde les van beide hoofdstukken is dat zulke uitwisselingen tussen wetenschappers en kunstenaars niet *gegarandeerd* leidt tot de verbeelding van radicalere toekomsten. Kunstenaars verhouden zich tot hun eigen discoursen, ethische normen en genres. Deze potentie hangt ook af van de rol die de kunstenaar krijgt: of deze alleen wordt ingeroepen voor het communiceren van de wetenschap of ook aannames van wetenschappers ter discussie kan stellen. Het verbreden van de mogelijke toekomsten vraagt wellicht om het laatste. In **hoofdstuk 6** verken ik klimaatbeleid op het nationale niveau. Hier zijn modelbenaderingen, waaronder IAM's, ook zeer invloedrijk. Tegelijkertijd wordt burgerbetrokkenheid als steeds belangrijker beschouwd. Ik vergelijk twee contrasterende casussen van burgerbetrokkenheid: een online tool die lijkt op IAM's waarin burgers mitigatie-opties beoordelen om een gekwantificeerd doel te halen, en een klimaatburgerberaad waarin experts in gesprek gaan met burgers. In beide gevallen hadden experts een grote invloed op de uitkomsten. Het betrekken van burgers leidt dus niet *gegarandeerd* tot de overweging van andere beleidsopties en standpunten. Daarnaast hangt de invloed van experts af van de rol die experts en burgers krijgen, de presentatie van expertise en de setting waarin de interacties plaatsvinden. In de zoektocht naar een alternatieve rol voor modellen zijn dit dus cruciale overwegingen.

In de conclusie verken ik de toekomstige rol van IAM's, waarbij ik bijzondere aandacht schenk aan rechtvaardigheid. Bestaande perspectieven op die toekomstige rol zien modellen vaak als technische 'tools'. Echter, dit proefschrift maakt duidelijk dat de modellen niet noodzakelijk het probleem zijn. In mijn optiek ligt de sleutel daarom ook niet in het verbeteren van de modellen, maar in een *herconfiguratie* van modellen in de klimaatpolitiek: nieuwe interacties tussen modellen, beleid en samenleving waarin modelleurs en beleidsmakers minder centraal staan. Dit is geen eenvoudige taak. Toch laat dit proefschrift zien dat de prominentie van modellen niet in beton is gegoten. Herconfiguratie is daarom goed mogelijk. Ik zie dit dan ook als een cruciale stap in de weg naar een koolstofarme en rechtvaardige toekomst.

Curriculum vitae

Lisette van Beek holds an MSc in Sustainable Development from Utrecht University, graduating from Environmental Governance. Prior to that she graduated from the MSc program in Applied Cognitive Psychology at Utrecht and the BSc program in Psychology. This shift was motivated by an interest in and deep concern about the climate crisis. The combination of these programs helped to develop an interdisciplinary perspective on social change in relation to transformations. Her interests and diverse programs first came together in her master thesis on a serious game on climate tipping points as well as a project on environmental visualisations in the following year.

Pursuing a PhD followed logically from these steps. In this PhD thesis she studied and explored ways to rethink the practice of modelling in climate politics. The thesis was part of the European *CLIMAGINARIES* project that ran from 2018 to 2022, which focused on better understanding and exploring new ways of envisioning climate futures. She presented her research at a number of conferences including the Earth System Governance Conference (2018 and 2021), the Annual Meeting of the Integrated Assessment Modelling Consortium (2019) and the Science and Democracy Network at Harvard University (2022). She organised workshops for researchers at the PBL Dutch Environmental Assessment Agency (2018; 2022) and at the Nordic Environmental Social Science Conference (2022). She also taught in several courses, including the Futuring for Sustainability course (BSc) and the UFS Summer School (PhD), and initiated the Copernicus PhD book club.

Lisette spoke at a number of public events where academics, citizens, practitioners and artists come together, including the Art for Climate Festival 'Nimma aan Zee' (2021), the sustainability festival 'Springtij' (2022) and the 'Urgency Intensive' of the Jan van Eyck Academie (2022). She also co-developed the 'Klimaatraadpleging', an application of the Participatory Value Evaluation method developed by Niek Mouter, of which the results were presented to the Ministry of Economic Affairs and Climate. This work was awarded with the Pathways to Sustainability Award in 2021. She also wrote two opinion pieces for the newspaper NRC with colleagues from the Urban Futures Studio on respectively social movements and the IPCC.

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Non-scholarly publications

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Van Beek, L., & Oomen, J. (2022). Blind varen op de oplossingen van het IPCC ondermijnt echte verandering. *NRC Handelsblad*. 05-10-2022

Mouter, N., Van Beek, L., et al. (2021). Brede steun voor ambitious klimaatbeleid als aan vier voorwaarden is voldaan. Report available at: https://www.rijksoverheid.nl/documenten/rapporten/2021/06/17/brede-steun-voor-ambitieus-klimaatbeleid-als-aan-vier-voorwaarden-is-volda

Acknowledgements

It was only a few months before the start of this PhD that Greta Thunberg sat in front of the Swedish parliament building, which culminated into a global climate movement. The IPCC had also just published its ground-breaking Special Report on 1.5C, causing wide-spread awareness and newspapers to declare a 'climate crisis'. Studying climate politics in such 'hot' times - both climatically and politically - has made this PhD trajectory an incredible adventure. But it was the people around me who supported me that made this adventure an enjoyable and successful one.

I was lucky to be supervised by an unlikely combination of brilliant minds. Maarten Hajer, your passion for doing things differently is contagious. You inspired me to always seek bold new directions and gave me the freedom and opportunities to put these in practice. The references to sociologists that were somehow always ready in your mind – as well as the huge pile of books you handed to me on my first day - truly changed my perspective on the world. Detlef van Vuuren, our countless discussions on IAMs have not only helped me to develop my own position but also enriched me as an academic. Although we may never fully agree, I am grateful for your open-mindedness, sense of humor and – not to forget – Strava kudos. Peter Pelzer, you guided me through every step along the way with an endless amount of enthusiasm. You were always truly there, whether it was brainstorming on a white-board in the VM office, writing feedback on a train to Sweden or preparing a work-shop at a festival on Terschelling. The 'so what' question you always kept reminding me of is now forever on the back of my mind.

I am also thankful for my inspiring, innovative and dedicated colleagues at the Urban Futures Studio. A special thanks to Jeroen Oomen with whom I shared many thoughts and beers, some mildly successful public engagements and an occasional escalated party. Working with you felt like having a fourth supervisor and friend at the same time. Wytske Versteeg, I have always been amazed about how you juggle your dual career as novelist and academic. Thank you for opening my eyes to the literary world and all the hours you put in the countless revisions of our paper. Astrid Mangnus, thank you for our many talks over coffee about the future, both intellectually and personally. Irene Bronsvoort, Kelly Streekstra and Cara Flores, thank you for sharing your struggles and enjoyment of PhD life. Hilde Segond von Banchet, your excellent communication skills truly brought this PhD beyond academia. Chantal Campman, thank you for working your magic to plan PhD meetings despite impossibly busy agendas.

I also owe a big thanks to other Copernicus colleagues. My roomies at 7.30, your continuous joking around made the first years of PhD life so much more fun. A special thanks to Joost Vervoort for giving me a head start in this PhD through the gaming project. Your positive energy keeps reminding me that real change is possible. Abe Hendriks, I really appreciate our intellectual conversations and spontaneous meet-ups at the coffee machine. I am also grateful for the IMAGE modelling team for helping me understand the modelling world and being open to my weird and uncomfortable projects. A special thanks to Mariesse van Sluisveld, your perspective on the modelling world truly helped to develop my own views. Vassilis Daioglou, Shridhar Kulkarni, Kyra Orbons, Nicole van den Bergh and Oreane Edelenbosch, thank you for your time and valuable insights into the artist-in-residence project.

Niek Mouter, collaborating with you on the Klimaatraadpleging has opened my eyes to the policymaking world. Thank you for this exceptional opportunity to put my expertise into practice and for trusting me with great responsibilities from the start.

It has been a privilege to be part of the *CLIMAGINARIES* team, which drastically changed my perspective on what academics do (in a positive way). Johannes Stripple, thank you for initiating this project and always keeping a critical eye. Alexandra Nikoleris, it is thanks to you that the endless creative ideas of this extraordinary group of academics actually got somewhere. You also really made me feel at home in Sweden (admittedly, the cinnamon buns also helped). Roger Hildingsson, Graeme Macdonald and Paul Graham Raven, talking with you always ended up in new ideas. Paul, thank you for help with the artist-in-residence project and making me view modelling from a completely different angle.

I am also incredibly grateful for those involved in the artist-in-residence project. Julien Thomas and Ekaterina Volkova, working with you has been the most exhilarating time of my PhD. Thank you for taking me for a ride in the art world and teaching me the artists' way of doing research. Julien, your crude honesty and boldness has been truly inspirational for me. Ekaterina, I deeply admire your perseverance despite challenging times. The three of us owe a big thanks to Bruno Alves de Almeida, who has guided us through the project and gave us opportunities to test our ideas. A special thanks also to Hachim Khalidi who always made us feel welcome at the Jan van Eyck Akademie.

Last but not least, finishing this PhD would have been impossible without the love and support of my family and friends. A special thanks to Tamarinde Haven, who has always been an example for me from the day we met in the halls of academia. I admire your stubbornness and inexhaustible drive to push your own boundaries. You motivated me to make the most out of my PhD. Mom, you always reminded me to trust my instincts. Dad, you were the first to suggest doing a PhD (to which I answered 'no way'). Thank you both for always believing in me. Maarten, I love how we both ended up working on a sustainable future in our own ways despite our different personalities. Thank you for teaching me how to stand up for myself. Evi, you helped me getting out of bed early and taking me out for fresh air. Rik, you are my tower of strength. Thank you for always making difficult situations seem hilariously simple and celebrating every achievement with me, no matter how small. A big hug to you all!