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Imagining the corridor of climate mitigation – What is at stake in IPCC's politics of anticipation?

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ABSTRACT

The article examines how the Intergovernmental Panel on Climate Change (IPCC) performs its self-proclaimed role as 'mapmaker. We seek to contribute to the emerging literature on global environmental assessments (GEA) and climate politics by reconstructing how the IPCC imagines the corridor for climate mitigation. Our particular focus is on the emergence of Integrated Assessment Models (IAMs) as the preferred scientific approach to projecting mitigation pathways consistent with average global temperature target. Taking our lead from current research in science and technology studies (STS) and sociology of futures, we reconstruct the emergence of a science policy tradition of modeling in the field of climate change as a particular mode of anticipation. We summarize the main findings of this literature in order to illustrate the historical and socio-political context in which this mode of anticipation is embedded. Based on this genealogy, we demonstrate how, in its role as mapmaker, the IPCC has also functioned as a corridor maker. We highlight how the IPCC has achieved consensus on a limited set of mitigation pathways, thus effectively narrowing down the discursive space for imagining potential futures to pathways that are deemed technically feasible and cost-efficient. We conclude by discussing the political consequences of this mode of anticipation in order to give us a more comprehensive understanding of what is at stake in the politics of anticipation. We elucidate why the techno-economic framing of current mitigation pathways is highly restrictive, especially when it omits many cultural, political, and other dimensions involved in deploying CDR at scale in their 'real-world' context of application.

1. Introduction

The main aim of international climate policy, as codified in the 2015 Paris Agreement, is to strengthen the global response to climate change by restricting the average global temperature rise this century to 'well below' 2 °C above pre-industrial levels and to pursue efforts to limit it even further to 1.5 °C. These ambitious temperature targets are to be achieved by balancing sources and sinks of greenhouse gas emissions. 'Sinks' or 'negative emissions' are becoming a significant part of the imagined portfolio of climate responses (Beck and Mahony, 2018; Geden and Schenuit, 2020). According to the Intergovernmental Panel on Climate Change (IPCC), approaches for removing carbon dioxide from the atmosphere and sequestering it in geological, terrestrial, or ocean reservoirs, or in products – typically referred to as CDR technologies – are a necessary strategy for keeping the average rise in global temperature well below 2 °C and are vital in achieving the more stringent 1.5 °C target (Intergovernmental Panel on Climate Change (IPCC, 2018a, b). IPCC defines CDR as the anthropogenic process of removing carbon from the atmosphere and storing it, generating negative emissions. Accordingly, Negative Emissions Technologies (NETs) are technologies or approaches used as means to achieve negative emissions as goal. It is important to note that removal of carbon that occurs naturally - without anthropogenic intervention - does not count as CDR, and that there are a number of approaches/technologies that remove carbon as one step of the process, but do not generate long-term negative emissions (e.g. fossil CCS) (see IPCC, 2018c, Annex 1, p. 544; Intergovernmental Panel on Climate Change (IPCC, 2018a, p. 394). In line with the IPCC, we use CDR approaches as umbrella term, which covers specific technologies such as bioenergy with carbon capture and storage (BECCS).

In this article, we explore the origins of particular mitigation pathways, which introduce CDR as a feasible mitigation option, and examine how they shape imaginations regarding possible ways to achieve the ambitious temperature targets, codified in the Paris Agreement. Specifically, the paper takes as its starting point a 'co-productionist'

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approach (Jasanoff, 2004). Using this lens, several STS works have shown how model premises frame the model conclusions and thus influence the political measures taken in the name of it (Beck et al., 2016). During its 5th assessment cycle, the IPCC Working Group III (WG III) developed a mapmaker strategy (Edenhofer and Kowarsch, 2015; Intergovernmental Panel on Climate Change (IPCC, 2014). It used the image of the scientist as mapmaker and the policy-maker as navigator to illustrate the division of responsibilities between science and policymaking (Edenhofer and Minx, 2014). Based on a co-productionist approach, we illustrate why mapmaking is not, as intended, a neutral but a performative practice. We reconstruct how the IPCC actively acts as a 'corridor maker' by narrowing the space of possibilities (Groves, 2017) to a 'corridor', that is a limited set of paths all directing to the same endpoint. We deliver a fine-grained perspective on the respective roles and practices of different actors and organizations to better understand how exactly imagining and discursive narrowing down takes place.

We contribute to the emerging literature on global environmental assessments (GEA) and climate policy on two levels, one conceptual, one empirical.

Conceptually, we draw on ideas from STS and the sociology of the future to understand the performativity, temporality and political nature of anticipation adopted in recent mitigation pathways. Often based on ethnographic study of the social life of scientific modeling, STS scholars have performed analyses of the emergence of predominant approaches of modeling. Specifically, we draw on and contribute to literature on anticipation in the climate regime by exploring the social environments which enable and constrain the politics of anticipation (Beck and Mahony, 2017; Granjou et al., 2017; Kearnes and Rickards, 2017) to give us a more comprehensive understanding of what is at stake in the politics of anticipation. In the course of exploring these themes, we develop two main lines of empirical argument based on two different but complementary strands of evidence.

First, on the basis of a literature review we reconstruct the genealogy of our argument and situate it within the existing body of research (section 2). Summarizing the empirical findings of previous studies, we also reconstruct the historical context in order to explore how the IPCC's mode of anticipation both shapes and is embedded in the socio-political contexts and organizations of climate research and assessment. We illustrate how the socio-material organization of climate knowledge by the IPCC – its rules of procedure and modes of orchestration towards consensus – enables a particular mode of anticipation in such a way that political contestation is pre-empted (Groves, 2017).

Second, in order to provide empirical evidence to support our argument, we include a case study on how the IPCC performs its role as mapmaker (section 3). Based on analysis of IPCC reports and its reception in the scientific literature, we illustrate how the IPCC imagines the corridor for future climate mitigation; we do so by looking critically at the implicit, rarely explicated assumptions and promises made about the feasibility of CDR technologies that guide projections of the future and justify policy and model choices in the present. In the conclusion, we summarize the lessons from our findings and outline what is at stake in the politics of anticipation and how it is constitutive of emerging conflicts in international climate politics.

2. Emergence context of climate modeling and assessment practices

The use of modeling in international climate policy has been subject to critical observation for several decades. STS scholars in particular have shown that current modeling practices originated in a vast array of strategic foresight techniques that emerged after the Second World War (see Edwards, 1996; Heymann and Dahan Dalmedico, 2019). In the following, we focus on a particular type of model that was developed in order to translate scientific findings into the policy-relevant knowledge base for international climate policymaking. Section 2 explores how the IPCC's mode of anticipation both shapes and is embedded in the socio-political contexts and organizations of climate research and assessment, including the emerging infrastructure of the IPCC.

2.1. Janus-headed status of scientific models for policy

In the 1970s the Club of Rome established a science-for-policy tradition of modeling. This is the historical context within which the emergence of the IPCC is embedded (Edwards, 1996; Andersson, 2018).

Early on, Richard Ashley (1983) demonstrated how a new genre of scientific study, namely, 'world modeling', came into being. These models functioned as epistemologically and ethically complex, strictly indeterminate *heuristics.* Likewise, Paul Edwards (1996) illustrates how early world models provided the heuristic for the evolving 'limits of growth' narrative. This role of scientific models can be elucidated by applying the notion of interactional co-production to the making of expertise (Jasanoff, 2004): scientific devices are both a *description* of the world and a series of tacit *prescriptions* about how that world could best be managed. According to this co-productionist approach, knowledge-making has a 'world-making' function in that it provides policy makers with the categories, objects and devices (such as emission and mitigation pathways) they seek to govern (Jasanoff and Simmet, 2017). This framework shows how scientific ideas and their associated technological artefacts, such as models, evolve together with the *representations*, *identities*, *discourses* and *institutions* that give practical effect and meaning to ideas and objects. In this view, expert bodies do not provide a neutral, factual basis for policy, but rather a set of performative and reiterative assessment practices that shape the policies they seek to evaluate (Beck and Mahony, 2018). By explicitly addressing the political and normative dimensions of the relationship between science and political power, the co-productionist approach helps us to understand the underlying (normative) but rarely explicated justifications for policy choices – and to uncover taken-for-granted assumptions that shut down alternative imaginations. Following this line of argument, sociologists Taylor and Buttel (1992; see also Vieille Blanchard, 2010) criticized the famous *Limits to Growth* report on the grounds that this conclusion could only be reached if one assumed that human societies acted in common and undifferentiated ways—and in particular in a rational-choice way characterized by individualism, economic competition as well as maximization of resource use. As such, the projection of the report and the vision of society linked to it upheld each other. However, the act of world-making contained in the report was largely ignored. For Taylor and Buttel, this form of analysis was problematic because these assumptions were woven into the Limits to Growth model without discussion, amid insufficient evidence to justify viewing societies in this way. Accordingly, they argued that the Limits model pre-ordained its results because: "catastrophe is thus inevitable unless 'everyone'—all people, all decision makers, all nations—can be convinced to act in concert to change the basic structure of population and production growth" (Taylor and Buttel, 1992, p. 408). The Limits to Growth narrative became a *vanguard vision* (Hilgartner, 2015) for the environmentalism of the 1970s, around which a broader coalition of groups with varying motivations and social, ethical and political concerns emerged. Following this line of argument, Brian Wynne (1984) illustrated the Janus-headed status of global energy models: whereas they were developed as neutral and objective descriptions of the world, they functioned in effect as tools of political persuasion and community building. Designed as tools of scientific discovery to produce objective, technical instructions on how to make 'the environment safe, and manageable', they were used simultaneously as symbolic vehicles to justify policy decisions (ibid.).

2.2. Emerging object of representation: framing climate change as an ontologically unitary whole

Edwards (2010) and Andersson and Westholm (2019) have shown how scientific practices contribute in specific ways to the imagining of environmental futures. According to Edwards (2010), it was its *simplicity* that lent global modeling its rhetorical force. The idea was to offer policymakers an effective way to learn a set of heuristics – a quasi-intuitive ‘feel’ or rule of thumb based upon, yet not fully determined by, data-driven analysis – for evaluating policy options (Edwards, 1996). Some IAMs have decade long history evolving from models covering energy systems (Wynne, 1984). Many of the researchers building IAMs hope their models will be simple, transparent and portable enough to explore the links between socio-economic development, mitigation and climate outcomes (Weyant, 2017; van Beek et al., 2020).

The simplicity of models is generally sought by using *a one-size-fits-all approach* to assess anthropogenic climate change. In order to aggregate local trends into a global picture, global models have been used as a technique to link together relatively simple dynamic models of natural resources, population, pollution, capital and agriculture. A key feature of such a one-world, globalist approach is its emphasis on the *universality* of climate risk – anthropogenic climate change is represented as an *ontologically unitary whole* (Ashley, 1983; Jasanoff, 2004; Miller, 2004). Social scientists have emphasized the effects of this totalizing, unifying approach (coined the *global gaze*) introduced by global models since the 1970s (Carton et al., 2020). These scientific practices have turned climate change into a very specific ‘object of representation’ (Groves, 2017, p. 37). The hugely complex challenges posed by anthropogenic climate change are boiled down to a single indicator for risk, namely, rising concentrations of a single gas: CO_2 (Hulme, 2010). The unitary framing ‘homogenizes the climate, disavowing multiple and complex relationships between humans and their environments’ (Oomen, 2019, p. 8). According to Ashley (1983), this global gaze also paved the way for a particular mode of scientific modeling and *technocratic authoritarianism*, which he calls the ‘eye of power’.

Ashley’s critique sharpens Taylor and Buttel’s point: the global gaze reinforced expectation of a singular authority of science to secure the predominance of collective expectations as to the singularity and objectivity of the given order. World modeling lends “ideological reinforcement to the dominance of technical reason” and “negates reflective interaction as a legitimate basis for the questioning and possible transformation of the given order” (Ashley, 1983: 529). This tradition of critical thinking illustrates how global models are built upon taken-for-granted assumptions that necessarily shut down alternative imaginations of environmental futures and thus pre-empt political consideration of alternative futures.

2.3. World-making implications: the search for a silver bullet solution

Modeling climate change as one, singular entity helped to imagine it as manageable (Hulme, 2010). A narrow framing of climate change focused on risk, measured by a single indicator set the stage for defining and enabling monolithic understanding of climate policy. The unitary framing of climate change resonated strongly with the idea of a globally orchestrated, centralized pathway for international climate policy, characterized as *cockpit* governance (Hajer et al., 2015). As a result, the response to climate change was predominantly imagined as global collective action in a multilateral setting (Fig. 1). In the 1980s and 1990s scientists and policymakers concluded that accumulating CO_2 in the atmosphere would be best addressed via a single international treaty that focused on incremental reductions in emissions, based on negotiations between countries (Rayner, 2016). According to Rayner (2016), this approach borrowed assumptions from other international governance regimes addressing stratospheric ozone and nuclear weapons (see also Pielke, 2018). This unitary approach culminated in the 1992 United Nations Framework Convention on Climate Change (UNFCCC), which later came to include the Kyoto Protocol of 1997 and the Paris Agreement of 2015. A result of the political focus on CO_2 concentration is that the spectrum of policy options has been reduced to a single *silver bullet* solution in the shape of the carbon market, introduced by the Kyoto Protocol. This idea of a single, global market has prevailed as the principle that guides choices about policy options. It rests on the assumption that carbon should be mitigated where it is least expensive and that it can be traded everywhere to everyone’s benefit (Bäckstrand and Lövbrand, 2019). Until the Paris negotiations (2015), the Kyoto Protocol was accepted as ‘the only game in town’ (Hulme, 2010). As a result, a broad range of legitimate policy alternatives have been neglected (Carton et al., 2020; Markusson et al., 2020). It is important to note that COP21 (2015) represents a major change in the climate regime. The Paris agreement adopts a voluntary, decentralized policy approach, which has important implications for how we think about the relationship between science and politics. In the years since COP21, the IPCC has had to adapt to the emerging poly-centricity in political architecture and to become more responsive to the needs of state and non-state actors at different levels of decision-making (Beck and Mahony, 2018).

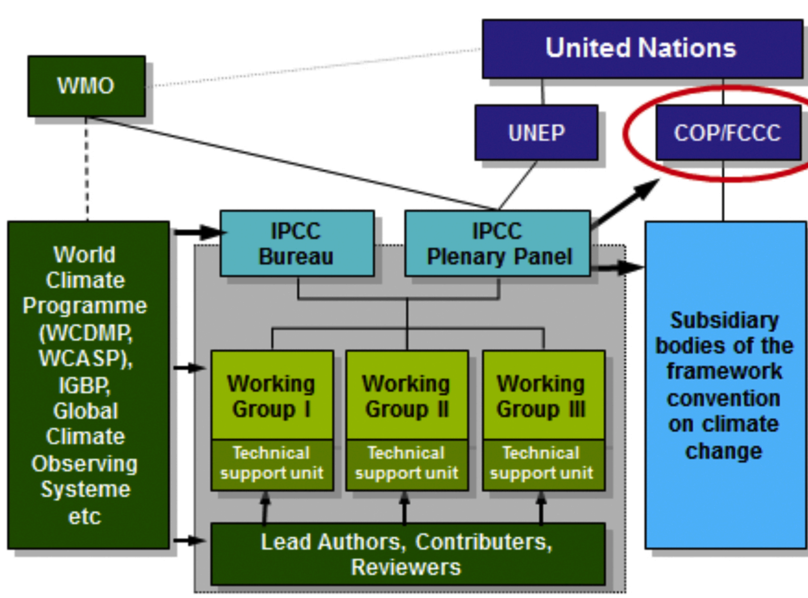

Fig. 1. The embeddedness of the IPCC in the international policy landscape.

2.4. The emergence of IPCC as socio-political context of anticipation

The creation of the IPCC was a constitutional moment in the institutionalization of science policy interactions at the global level (Beck et al., 2016). The IPCC was set up jointly by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988. The IPCC is mandated to provide regular assessments of the state of knowledge on the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. IPCC is a hybrid science-policy body whose reports are both scientific documents and the agreed outcome of an intergovernmental process. Its reports are formally accepted by member governments and the 'summaries for policymakers' are approved line-by-line. It does not conduct or publish its own research.

When the IPCC was formed in 1988, it fit neatly into the UN's multilateral order – a centralized governance regime based on national representation and the search for an internationally negotiated solution.

Accordingly, its first Chairman announced that the IPCC would speak with one voice on behalf of science, adopting its assessment reports by consensus and delivering univocal statements to the governments funding it. In order to achieve this ambitious aim and create a monopoly on climate expertise, the IPCC sought to restrict the input of expertise into the international policy process. This was a deliberate effort to maintain its epistemic authority over the interpretation of scientific results for policymaking (Beck et al., 2016). In order to speak with one voice, it adopted consensus as the organizing principle of assessments and used assessment practices to make researchers with differing views 'walk together' towards shared expectations (see Andersson and Westholm, 2019). It helped shape the mode of anticipation in a way that served to 'empty the future' and pre-empt political contestation. According to Groves (2017), 'emptying the future' means that the future is not simply constructed as a totality of possible events - it is anticipating choices which are oriented towards a particular direction. In the case of the IPCC, it is the expectation to 'walk together' to a shared understanding of climate change which serves the trajectory for assessing the state of climate knowledge. Under the guise of consensus, disagreements in IPCC assessments are addressed through expression of degrees of uncertainties and as such rendered invisible (Beck and Krueger, 2016). The IPCC has established a particular way of organizing the assessment of climate knowledge which enables the homogenization and standardization of assessment practices along with its distinctive ways of creating claims of legitimacy. As a result, it exercises a considerable amount of political influence: it has indeed spoken with one voice on behalf of international science, and plays a key role in providing the epistemological foundations for climate policies and for raising political and public awareness of climate change. The IPCC has provided sound scientific evidence that climate change is real and that it can be attributed to human activities—and is the widely accepted authority to make these claims. As such, the IPCC plays a crucial role in climate politics.

2.5. IPCC's mapmaker strategy

Since 1992, the IPCC has served to support the formulation and implementation of climate policies established by and pursued under the UNFCCC (Pielke, 2018). It provides key guidance on the details of implementation and makes scientific projections, such as those relating to CO_2 concentrations, politically actionable. During its 5th assessment cycle, the IPCC Working Group III (WG III) developed a mapmaker strategy to provide guidance to navigate through the largely unknown territory of climate policy (Edenhofer and Kowarsch, 2015; Intergovernmental Panel on Climate Change (IPCC, 2014). It used the image of the scientist as mapmaker and the policymaker as navigator to illustrate the division of responsibilities between science and policymaking. It is a constellation where 'the scientist explores different paths to certain goals and characterizes these paths in a map; but it is the policymaker who makes the decision on which path to follow' (Intergovernmental Panel on Climate Change (IPCC, 2014). The mapmaker metaphor is used by the IPCC WG III to can act as an 'honest broker' (identifying a broad range of action rather than closing it down to one single option) and thus defend its mantra of being 'neutral' and 'not prescriptive' (Intergovernmental Panel on Climate Change (IPCC, 2014; Edenhofer and Minx, 2014). Following the mapmaker metaphor, the IPCC WG III Summary for Policy Maker (SPM) provides a comprehensive assessment of mitigation pathways to climate goals (Edenhofer and Minx, 2014). With this turn to a 'mapmaker strategy', the relationship between climate science and policy can be seen as undergoing a fundamental transformation.

In response to the mapmaker strategy, the relationship between the IPCC and the IAM community was rearranged. After its 5th Assessment Report, the IPCC decided that new scenarios and pathways how to achieve temperature targets should not be produced by the IPCC itself, as was the case for previous reports, but that it would commission the IAM community to produce them according to particular requirements (Beck and Mahony, 2018). In the successive IPCC assessment reports, there has been an expanding coverage of IAM modeling (van Beek et al., 2020). Scenarios were developed by the IPCC itself for the early assessment reports but with production of the 6th Assessment Report scenario production was left to the scientific community with IPCC playing a facilitating role. This change was considered important to maintain the distinction between scenario and pathway development on the one hand and assessment on the other. In short, it was important to maintain the IPCC's independence as an assessor, rather than a producer, of knowledge. It ultimately served to maintain the IPCC's mandate of being *policy-relevant but not prescriptive*. As a consequence, the development and use of pathways at the science-policy interface also changed significantly. Originally, integrated assessment modellers had generated scenarios that described how emissions would evolve in the future based on plausible (internally consistent) economic and technological developments. These scenarios showed how a future world might look with and without (particular) climate policies under the UNFCCC, helping policy makers to understand the costs and benefits of proposed actions (Pielke, 2018). In response to a growing political demand for solutions, the focus of IAMs shifted from the modeling of emissions under a range of plausible assumptions ('emission pathways' in short) to the construction of pathways that projected *how* to achieve specific long-term climate goals ('mitigation pathways' in short, see Anderson and Jewell, 2019; van Beek et al., 2020). The novel generation of pathways is developed to describe the range of pathways consistent with global temperature targets. Both generations of IAM differ in their directionality and temporality: while the first IAM generation (of emission pathways) assesses future impacts of climate policies and looks from the present into the future, the second generation of mitigation pathways looks from the future to the present and takes politically adopted temperature targets as endpoints and develops pathways how to achieve them. The development of mitigation pathways by the IAM community can been seen as major attempt to provide the scientific base for IPCC's mapmaker strategy.

3. Imaging the corridor for climate mitigation

3.1. Temperature targets as 'endpoints' and 'guardrails'

This section illustrates how in its role of mapmaker, the IPCC has also functioned as a corridor maker. Investigating the IPCC's mapmaker role, we reconstruct how the IPCC defines the scope and time horizon of future political intervention, thereby opening up or closing down particular options for future action that serve to coordinate the actions of political actors. In the mapmaker metaphor, the Conference of the Parties (COP) operates as navigator, navigating a terrain charted by the IPCC. The COP represents 197 nation states as members and is the supreme decision-making body of the United Nations Framework Convention on Climate Change (UNFCCC) (Fig. 1). As a hybrid organization, the IPCC mediates between political information requests from

COP and synthesizes the state of research in response to these information demands. According to the internal division of labor, IPCC WG III is targeted with assessing pathways coherent with these temperature targets adopted by the COP. The temperature targets fulfill the function to regulate action towards goal achievement (Geden and Löschel, 2017). In its function as mapmaker, the IPCC WG III translates temperatures targets into guardrails for assessing the coherence of pathways with temperature targets.

In its 5th assessment report (AR5), the IPCC WG III provided an overview of pathways for achieving the 2 °C target (see Fig. 2; Beck and Mahony, 2018).

At this stage, the IPCC expanded the range of pathways aimed at keeping warming below 2 °C by including CDR based pathways into the spectrum of mitigation pathways. IAM pathways explicitly put forth the production of BECCs, along with afforestation, as an important mitigation option (Fuss et al., 2014). The IPCC integrated these CDR based pathways in the spectrum of feasible mitigation options. It also highlighted that many 2 °C scenarios entail large-scale deployment of NETs after 2050 to compensate for residual CO_2 emissions from sectors that are difficult to decarbonize, such as industry and aviation (Fuss et al., 2014). Performing its role as mapmaker, the IPCC opened the corridor of mitigation action by including a novel generation of CDR based pathways.

At its 21st meeting in Paris 2015, the COP explicitly requested a special report on the 1.5 °C target. The IPCC accepted the UNFCCC's request, translating it into a task for the Special report to meet this information demand (Livingston and Rummukainen, 2020). By accepting this request, the IPCC accepted the temperature targets as given. As a result, the IPCC's special report 'Global Warming of 1.5 °C' focused on which pathways are feasible if the political targets are to be achieved (Intergovernmental Panel on Climate Change (IPCC, 2018a, p. 17). The IPCC uses temperature targets as endpoints towards with all pathways are directed. By translating the politically adopted targets into guardrails and using them for the selection of mitigation pathways, the IPCC operates as a corridor maker: it only includes pathways coherent with temperatures targets (Livingston and Rummukainen, 2020) and it narrows down the range of possible climate policy futures to a more limited range consistent with the relevant temperature targets. In doing so, the

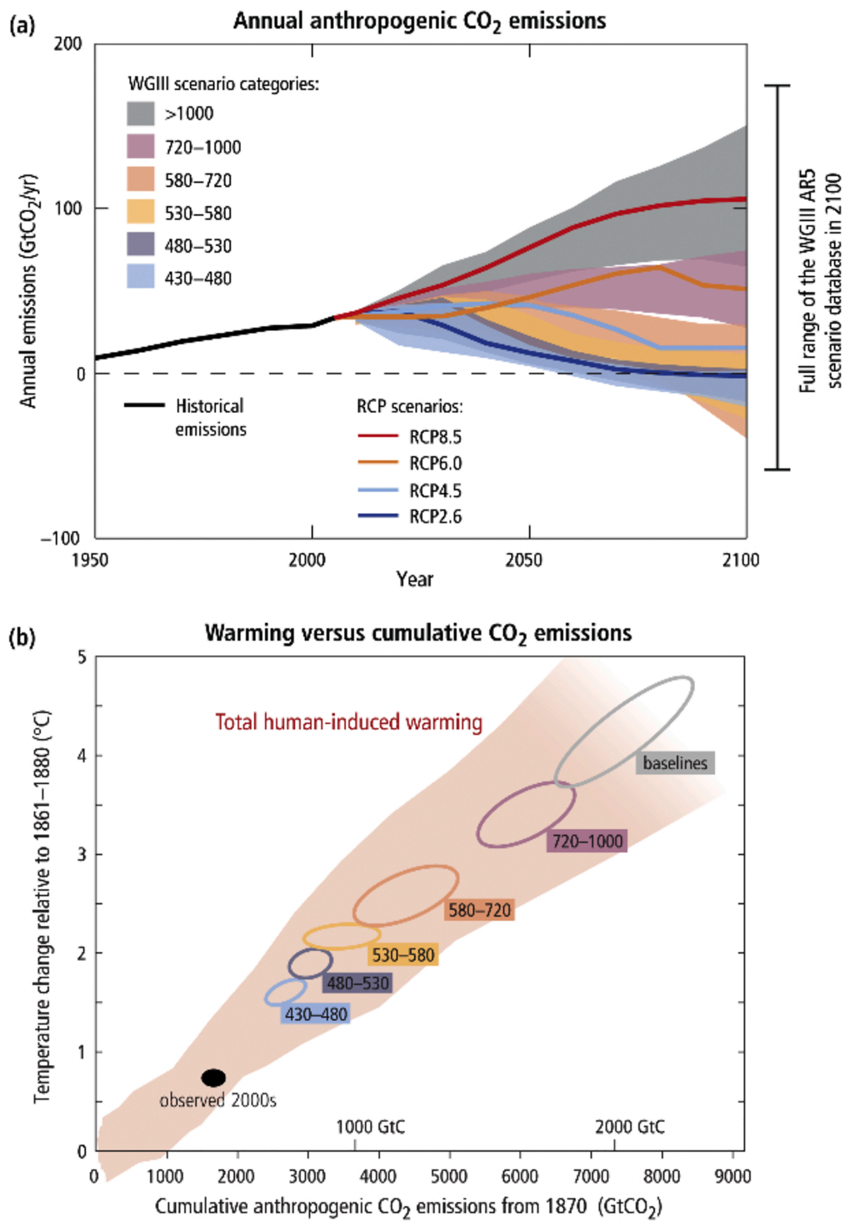

Fig. 2. Range of possible future emissions (Intergovernmental Panel on Climate Change (IPCC, 2014, p. 9).

IPCC performs the function of a filter: it assesses which pathways are consistent with climate targets and demarcates these from the ones that are not consistent with them. In this stage, the IPCC excludes potential pathways from the corridor of future mitigation which are not coherent with temperature targets.

As shown in Fig. 3, the possible pathways for a 1.5 °C future almost unilaterally assume *significant* net-negative emissions by the end of the century. This reliance on negative emissions means that by the middle of this century, the CO_2 emitted by human activities needs to be matched by the CO_2 deliberately taken out of the atmosphere through CDR technologies.

The ostensibly descriptive nature of the use of IAMs for exploratory purposes becomes prescriptive by assessing mitigation pathways as (technically) feasible and cost-efficient. Vaughan and Gough (2016) highlight the risk of IAMs creating a *lock-in* effect when NETs are relied on, turning CDR based pathways as an explanatory tool into a prescriptive one that might become the 'default mitigation strategy' (p. 2). All 1.5 °C pathways share certain features, including CO_2 emissions falling to net-zero. By plotting the future as a space of a narrow predictable trajectory towards an endpoint- (see Fig. 3), the IPCC performs as corridor maker by narrowing the range of mitigation pathways to pathways consistent with the temperature target which all include CDR technologies.

3.2. *Defining plausible futures*

This section reconstructs how and why CDR technologies were included in the projections of limiting global warming to 1.5 or even 2. °C. As Anderson and Jewell observe, the IAM approach 'follows the convention, originating in military and corporate planning, of systematically asking 'what if' questions to envisage future consequences of decisions or developments' (Anderson and Jewell, 2019, p. 349). In doing so, IAMs attempt to construct mitigation pathways that are plausible or feasible. This 'what if' approach relies heavily on the types of change and continuity that such models can assume – on the types of what-ifs that are possible in the model's structural design. Originally, mitigation pathways were developed to explore the effects of different climate policies and emissions trajectories. In this projection of future impacts, negative emissions were added to fill the gap between emissions reduction commitments and the pledged levels of ambition required for emissions pathways consistent with staying below a 2 °C temperature increase. Like nuclear power in the earlier models, CDR technologies act as backstops for achieving temperature targets (Low and Schäfer, 2020).

A useful way to illustrate how IAMs contribute towards shaping the politics of anticipation is to compare IAM projections to a heuristic often used in scenario planning called the 'futures' cone'. (Fig. 4) The futures cone visualizes a present that projects outward temporally towards a future that becomes progressively more open and uncertain the further away it is. Different parts of the cone represent different aspects of the future: the outermost boundary depicts the broadest range of possible futures – no matter how unlikely they may be – given the socio-material conditions of the present as a starting point. The range of 'plausible futures' is narrower. Plausible futures are those that one might reasonably expect on the basis of current socio-material, environmental, technological and cultural conditions. Narrower still is the range of probable and preferable futures. 'Probable' futures are those that are thought most likely to come about. The preferable, finally, describes futures that are deemed to be desirable. It might overlap with probable or plausible futures, but it could also be wildly implausible, albeit not impossible. What counts as a desirable future, of course, is always also a deeply normative issue. Put simply, the futures' cone is a visual

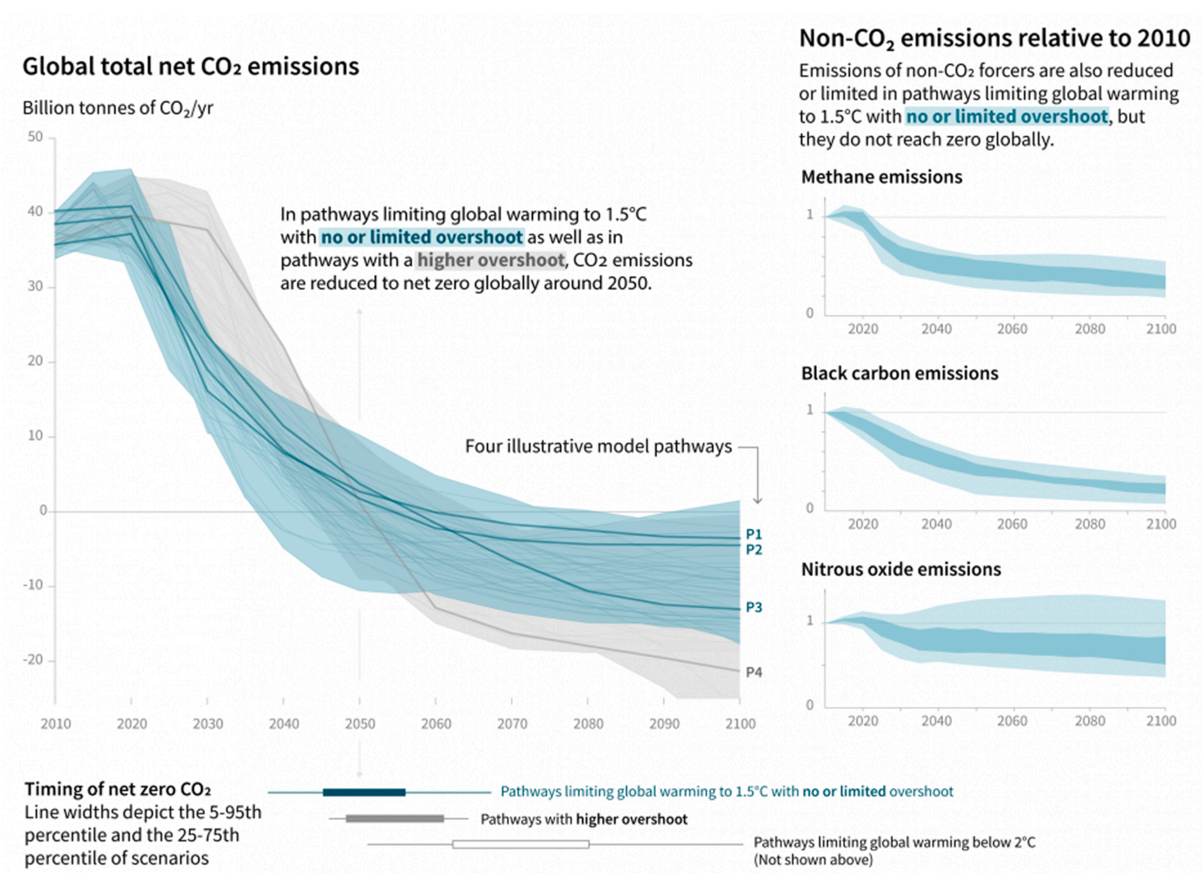

Fig. 3. Imagined Emissions Pathways (Intergovernmental Panel on Climate Change (IPCC, 2018a; Figure SPM.3a, p. 13).

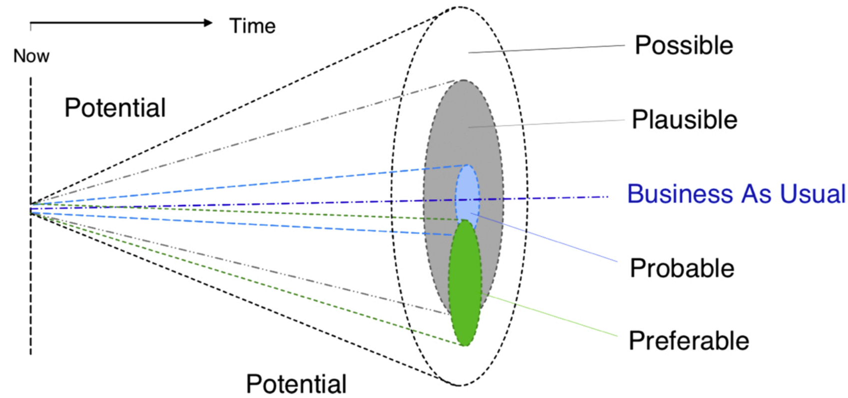

Fig. 4. The 'Futures Cone', see Voros, 2003, p. 13.

representation of the range of possibilities for the future, some more plausible, probable and/or preferable than others.

3.3. Assessing the feasibility of CDR technologies

This section explores a set of promises made about the feasibility of CDR technologies (Beckert, 2016; Beckert and Bronk, 2018; Konrad et al., 2016; van Lente and Rip, 1998) by reconstructing the metrics used to assess their plausibility and probability (Borup et al., 2006, p. 285–286). Based on a co-productionist approach, we illustrate how the choice of metrics and criteria turns out to be an important part of mapping the corridor for future climate mitigation. IAMs assess mitigation pathways by a *set of criteria* consisting largely of technical feasibility. Feasibility is a function of model solvability (Low and Schäfer, 2020). As part of their basic logic, IAMs can integrate certain forms of technological change into their projections because they can be easily scaled up and aggregated in the IAMs to the level required to meet the temperature targets. This is one of the reasons why IAMs tend to 'emphasize technological rather than social change' (Anderson and Jewell, 2019, p. 3). Models are epistemologically limited in their ability to include non-linear complex social and political parameters. As a consequence, they selectively reduce social and policy complexity to metrics manageable within their epistemological parameters, thereby privileging a continuity in trends and underestimating the potential for social, political and policy ruptures, that is, for radical, non-linear changes associated with social uncertainties. Relying on economic metrics that assume technological progress, IAMs draw an assumed continuity between past, present and future by extrapolating past trends into the future. IAMs thus project the future as resembling the past by continuing observed trends in the value of a given variable (such as aggregated technological advances, driven by carbon prices).

The choices of model priorities and parameters have been relied on and shaped by fairly techno-optimistic, optimization-based assumptions, with a carbon price as the main driver. In considering economic criteria, IAMs also play a significant role in defining what *desirable* futures are: they are, among other things, cost-efficient. This is one of the reasons why CDR technologies play a major role in IAMs. These choices of model priorities and parameters, however, rely on and are shaped by free-market axioms, on a techno-economic, optimistic view of the world in which rising carbon prices (De Coninck AR6, WG III as cited in Young, 2018) and technological advances continue to drive the *economic* costs of CDR technologies down. Almost all IAMs foresee gradually rising carbon prices (costs applied to CO_2 emissions). If carbon prices rise gradually, the 'market' will eventually reward mitigation in the most cost-efficient way. This means that IAMs work on the assumption that there is a cost-optimizing way of achieving climate mitigation. The decision to make the price of carbon a key driver in the pathways of IAMs has major implications: many economic models tend to underestimate climate damages (Stoerk et al., 2018) and to accept ecological and societal risk if it is *economically* optimal to do so.

One of the most critical decisions in designing mitigation pathways is the use of the 'discount rate' (Rosen, 2015, 2016; Emmerling et al., 2019). Effectively, discounting converts future economic impacts into present-day economic value in order to assess the trade-off between making deep cuts in carbon emissions in the present and negative emissions deployed later this century (Rosen, 2018). The choice of the discount rate matters when translating policy targets – such as 1.5 °C and 2 °C – into emission reduction strategies with the possibility of overshoot. Discounting affects the time when net global emissions reach zero and the amount of carbon budget overshoot. Overshoot, that is, an exceedance of the threshold before bringing global mean temperature back below the intended level (for example, for 50 years by up to 0.3 °C) (Geden and Löschel, 2017). By applying a comparatively high discount rate (5% annual discount rate in the IPCC 5th Assessment Report) to reduce the predicted costs of future technologies, IAM modelers have shown that, in the decades to come, CDR technologies, despite the uncertainty about the feasibility of future deployment (see e.g. IPCC, 2018b) will be much cheaper than immediate and substantial mitigation today.

In a co-productionist perspective, these technical criteria for assessing pathways also shape underlying (normative) but rarely explicated rationales of policy choices. They justify the prioritization of technological solutions, such as switching the source of energy supply or adding carbon capture and storage (CCS). To sum up, by using technical criteria and parameters, IAMs and their underlying assumptions shape how climate mitigation is projected and assessed.

3.4. Framing negative emissions as a matter of necessity

The technological promises made about the feasibility of carbon removal have not been subjected to rigorous scientific scrutiny; they have been framed as a matter of necessity and thus rolled out and standardized across IAM studies, as attested by modelers involved in the construction of these models (Anderson and Jewell, 2019; Kearnes and Rickards, 2017). This section explores the implicit assumptions that shape and justify the choice of pathways consistent with 1.5–2 °C.

Mitigation pathways are based on the techno-optimistic assumptions that there will always be a cheaper technological solution if the price of carbon rises high enough. The inherent optimization logic of economic change and technological innovation also suggests that necessary emissions reductions can be achieved through an incremental decarbonizing of the free-market economy (Anderson and Jewell, 2019; Pielke, 2018; Beck and Mahony, 2018).

These technologies are speculative, however, in the sense that carbon storage and capture at scale only exists in IAM projections. Although pilot projects exist, it is highly uncertain whether these CDR technologies could be implemented on the scale proposed (Lawrence et al., 2018; van Vuuren et al., 2017). For modelers themselves 'the question still remains as to whether any of these mitigation pathways are feasible' (Anderson and Jewell, 2019, p. 349). The IPCC also acknowledges that the feasibility of CDR technologies 'deployed at scale is unproven, and reliance on such technology is a major risk in the ability to limit warming to 1.5 °C' (Intergovernmental Panel on Climate Change (IPCC, 2018a, p. 96).

Even if there are significant uncertainties regarding their technical feasibility, there is a striking reliance on CDR technologies in IAM projections and IPCC assessments. All pathways consistent with 1.5 °C or 2 °C levels rely on negative emissions to some degree: they 'project the use of carbon dioxide removal (CDR) in the order of 100–1000 Gt CO_2 over the 21 st century' (Intergovernmental Panel on Climate Change (IPCC, 2018a, p. 17). Despite addressing uncertainties about the feasibility of CDR technologies at scale (see Ch. 4 of the same report), the summary for policymakers treats them as a critical component of mitigation pathways and renders them politically actionable.

These implicit, rarely explicated assumptions made about the feasibility of CDR technologies have considerable governance implications but have not been included systematically in the assessment of mitigation pathways yet (Buck, 2016; McLaren, 2018; Fridahl, 2017). Trade-offs between CDR technologies, other demands on land use and societal risks are not taken into account in the models, even though these social uncertainties may undermine their feasibility and economic optimization to a considerable extent (Markusson et al., 2020; Carton et al., 2020).

Moreover, the decision to incorporate a high discount rate into mitigation pathways displaces the burden of climate mitigation from the present into the future, while reliance on negative emissions (Fuss et al., 2014) risks distracting policymakers and others from mitigation requirements in the present (Vaughan and Gough, 2016). Overshooting is compared to borrowing emissions from the future to defer mitigation in the present by promising to pay off later through large-scale CDR; thereby buying time for mitigation (Asayama and Hulme, 2019). These concerns have led the European Academies' Science Advisory Council (EASAC) to conclude that 'relying on NETs to compensate for failures to adequately mitigate emissions may have serious implications' (European Academies Science Advisory Council (EASAC, 2018, p. iv) if it turns out that CDR technologies cannot be deployed at scale or if they fail to sequester carbon to the required degree and switch from being a carbon sink to becoming a carbon source (Dooley, 2018; Kon Kam King et al., 2018; Lawrence et al., 2018). Ultimately, a reliance on negative emission technologies could undermine efforts to achieve political temperature targets altogether (Markusson et al., 2020).

The co-productionist approach puts attentions to the way how apparently apolitical, technical concepts such as NETs also serve justificatory purposes (Lövbrand and Stripple, 2011; Hajer and Versteeg, 2011). In this lens, mitigation pathways provide scientific evidence that the temperature targets can be achieved through an incremental decarbonizing of the free-market economy (Anderson and Jewell, 2019; Pielke, 2018) and thus legitimize the status-quo. As some critics have observed, CDR mitigation pathways contribute to delaying political action to tackle climate change (Pielke, 2018). They distract from the mitigation challenge made clear in the Paris agreement – the need for immediate and radical change across all facets of society (Anderson and Jewell, 2019) and the urgency with which CDR technologies would need to be scaled up (Laude, 2020; Carton et al., 2020; Markusson et al., 2020).

4. Conclusion: opening the horizon of climate mitigation

In sum, the findings presented above highlight the need to pay more attention to the political consequences of particular ways of anticipating the future. In the following, we conclude by outlining these future challenges, tasks, and open questions at stake in the politics of anticipation:

First, we illustrated how the IPCC mode of anticipation is deeply embedded in its socio-political context and we reconstructed how assumptions in current IAMs regarding volume, feasibility and cost-efficiency of CDR technologies constitute a bold bet on the future (Geden and Löschel, 2017; Asayama and Hulme, 2019; McLaren and Markusson, 2020). We drew attention to how this mode of anticipation narrows the corridor of action to a range of policy options available to a deeply entrenched technical trajectory, thus potentially displacing present mitigation commitments with speculative future technologies. Thus, the political impacts and implications of the IPCC's role as mapmaker call for rethinking the role and mandate of the IPCC in the post-Paris regime (Beck and Mahony, 2018).

Second, the article has illustrated how the implicit techno-economic assumptions limit the corridor of future action, thus effectively narrowing the discursive space to technically feasible pathways. Criticism of the approach to scenarios and models is not new, but there has been an increasing number of published critiques since the 5th Assessment Report (Intergovernmental Panel on Climate Change (IPCC, 2014). The prominence of climate change in public debate, and the influential role IAM modeling with respect to policy processes, have drawn attention and scrutiny to the practices of the IAM-modeling community. As a response to these debates, the research community and the IPCC have taken steps to open the black box of IAMs and to make more transparent what the assumptions are that drive mitigation pathways (Young, 2018). The emergence of the IPCC mode of anticipation, however, indicates a remarkable lack of institutional reflexivity and raises questions related to public transparency and accountability (Robertson, 2020). This lack has remained a constant feature from early energy models through to the most recent generation of IAMs (Wynne, 1984). The problem acquires an added urgency given the widening gap between current CO_2 emissions and political commitments. This could become apparent when policymakers - such as during the current UNFCCC Structured Expert Dialogue (UNFCCC, 2020) - interrogate researchers about the implications of key methodological choices addressing key issues such as greenhouse gas emission pathway characteristics, temperature overshoot, the balance of mitigation action in the near-and long-term, remaining carbon budgets and the role of CO_2 removal. The paper did not address the question how the IPCC pathways resonate and are received by policymakers, international negotiations, and civil society. As such, the political performance of pathways is a question that warrants considerable further research.

Third, we conclude that this particular mode of anticipation will be constitutive of emerging conflicts in international climate politics when CDR approaches will be deployed at scale or negative emissions will be integrated into national climate strategies at different times, in different places and in different ways. By providing political legitimacy for particular (but not all possible) mitigation pathways, the IPCC mode of anticipation becomes a contested and politicized terrain of configuration for essentially conflicting interests concerning long-term developments (Hajer and Pelzer, 2018). As shown in section 3.4, particular styles of anticipation, such as discounting, also have distributional consequences in terms of international and intergenerational justice, making mitigation pathways a legitimate object of political challenge, debate and choice. Anticipation does not just have rhetorical or performative effects, it also raises questions of representational and material capacities to project and influence climate futures (Groves, 2017; Kearnes and Rickards, 2017). The capabilities required to project mitigation pathways by IAMs are distributed unevenly and unequally. Mitigation pathways are emerging from small informal networks and expert cycles, based on large infrastructure of modeling communities in a few Western countries (Markusson et al., 2020; Hughes and Paterson, 2017; Cointe et al., 2019). The questions 'who gets to imagine the future?' and 'whose vision counts?' are and should be a key focus of public debates in order to broaden the corridor for future climate action and bring in alternatives to techno-economic optimization pathways.

Author contributions

Silke Beck: Conceptualization; writing-original draft; writing-review and editing. Jeroen Oomen: Conceptualization; writing-review and editing.

Declaration of Competing Interest

The authors report no declarations of interest.

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