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The politics of anticipation: the IPCC and the negative emissions technologies experience

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Research Article

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Non-technical summary. In the post-Paris political landscape, the relationship between science and politics is changing. We discuss what this means for the Intergovernmental Panel on Climate Change (IPCC), using recent controversies over negative emissions technologies (NETs) as a window into the fraught politics of producing policy-relevant pathways and scenarios. We suggest that pathways and scenarios have a 'world-making' power, potentially shaping the world in their own image and creating new political realities. Assessment bodies like the IPCC need to reflect on this power, and the implications of changing political contexts, in new ways.

Technical summary. Following the adoption of the Paris Agreement of December 2015, the Intergovernmental Panel on Climate Change (IPCC) has begun to reconsider its role in the climate regime. Based on work in Science and Technology Studies (STS), we reconstruct how the IPCC has historically positioned itself between climate science and policy-making. We then discuss particular challenges raised if the IPCC is shifting along the spectrum from attributing causes and detecting impacts of global warming towards projecting policy solutions, including emerging technologies, by examining recent controversies over negative emissions technologies (NETs). We conclude that the IPCC exercises a 'world-making' power by providing new, politically powerful visions of actionable futures, for example, based on speculative technologies of bioenergy with carbon capture and storage (BECCS). The task of providing future pathways poses great challenges to conventional ideals of scientific neutrality. We argue that the growing political demand for pathways, and their political significance, requires rethinking modes of assessment that go beyond expert-driven neutral input. Assessment processes must take into account their political contexts and implications in a systematic way.

1. Introduction

Following the adoption of the Paris Agreement of December 2015, all parties are obliged to offer proposals of concrete contributions to the climate change mitigation challenge. There have been concerted calls for the Intergovernmental Panel on Climate Change (IPCC) to reconsider its role in a new global climate policy regime shaped around the national implementation – and international monitoring – of highly heterogeneous, domestically-determined mitigation policies. The IPCC's new leadership has called for a focus on climate solutions to support the Paris Agreement, including an anticipated Special Report on the impacts of 1.5 °C of warming (IPCC Special Report [SR]1.5) (p.xi [1]).

We are arguably on the cusp of a fundamental re-alignment of the relationship between international climate science and policy, crystallizing the move from climate science as a herald of societal problems and an advocate of political action, to a 'solution- and future-oriented', regulatory science. This paper, based on a meta-assessment of the scientific literature on the IPCC as a boundary organization operating at the interface between climate science and international decision-making, considers some of the implications of this move [1–3].

We examine some of the challenges that may arise from what we call the politics of anticipation. This is when science is asked to project and evaluate the performance of policies in the future. We discuss particular challenges raised if the IPCC is now shifting along the spectrum from cause and impacts into future solutions by examining recent controversies over the inclusion of negative emissions technologies (NETs) in posited pathways of climate change. The NETs case exemplifies some of the challenges that may emerge from the politics of anticipation, including the assessment of emerging technologies. In particular, we focus on why, how and with what consequences the IPCC will perform this novel task, particularly concerning questions of the IPCC's mandate of providing 'policy relevant but not-prescriptive' assessments. Our analysis is informed by perspectives from Science and Technology Studies (STS), which encourage consideration of responsibility for institutions' own role in the wider politics of global environmental change.

2. Approach: a co-productionist framework

In the section that follows we elaborate on these perspectives [1–3] before looking more closely at the IPCC's own role in the global politics of climate change.

The challenges the IPCC faces after the Paris agreement are neither novel nor unique, but have already been discussed under categories such as 'regulatory science' [4], 'anticipatory governance' [5] or 'responsible research and innovation' [6]. Scientific claims about the future are political interventions, defining political choices about future options for action and thus influencing the often irreversible path of societal developments.

The ideal of political neutrality in scientific advisory and assessment processes has a particular history and serves as an important principle, shaping the public performance of scientific communities. Scientific neutrality is not just about protecting the 'republic of science' from the corrupting forces of outside influences [7]. It is an ideal built into the constitution of liberal democracies, serving both science and politics. Science offers a "politically attractive strategy for defining, observing and evaluating the effectiveness or the instrumental adequacy of actions independently of the subjective traits of actors" (p. 33 [8]).

However, historians and sociologists of science have shown how this powerful ideal of scientific neutrality has to be constantly renegotiated in practice as the political roles of science and cultures of scientific knowledge making continuously change. The concept of 'boundary work' was introduced [9] to describe the social practices by which distinctions are drawn between legitimate and illegitimate knowledges, and by which certain actors are admitted into expert collectives [3,10,11]. In 'boundary organizations' like the IPCC, the constant negotiation of the science–politics boundary is a crucial feature, performed through practices of boundary work including choices about rules of membership for an expert organization, its lines of accountability to scientific and political communities, the standards by which it defines evidence, and its procedures for review and approval [2,4].

STS scholarship has developed the concept of co-production as an analytic concept to understand the political power and implications of knowledge production (p. 37 [12]). It is based on the assumption that there are intrinsic links between ways of representing a phenomenon on the one hand, and ways of acting upon it, so as to transform it, on the other [12]. Assessments deliver both a description of the world, and a set of tacit prescriptions for how that world should be rationally managed. In this way, the definition of a problem – the causes and impacts of global warming – and the search for appropriate ways to respond – are reiterative and mutually reinforcing. STS scholarship has helped to show how forms of knowledge-making do not only offer policy-makers useful information, but perform a 'world-making' function of furnishing policy-makers with the objects, variables and relations upon which they seek to exert influence [4]. With this lens, authoritative science may not just be a neutral input into policy, instrumentally informing policy decisions, but a set of performative and reiterative practices that frame and transform the social relationships, political norms and cultural values they seek to represent [2,5,12].

What is of interest here is the performativity of scientific assessment – that is, the ability of particular descriptions of the world to act upon, transform or bring into being the objects they describe, not just through the direct informing of policy decisions, but through the wider conditioning of the world according to authoritative scientific descriptions of it. Here we draw on lessons learned from the literature on imaginaries [13] and the sociology of the future [14,15] to explain why any knowledge about the future, especially knowledge that emanates from authoritative institutions such as the IPCC, can be performative.

In order to account for the politics of anticipation, we take into account particular challenges raised by the assessment of emerging technologies such as bioenergy with carbon capture and storage (BECCS). The pathways that keep global warming within Paris Agreement limits rely on the application of NETs to remove CO_2 from the air on a large scale. NETs fill the gap between emissions reduction commitments and the level of ambition required for an emissions pathway consistent with staying below a 2 °C, let alone a 1.5 °C, temperature increase. NETs, however, are speculative in the sense that most of their proposals only emerge from artificial renderings and exist within the parameters of Integrated Assessment Models (IAM). IAMs use BECCS because of 'hoteling' and 'backstops'. This basically means that if the carbon price becomes high enough, there will always be a cheaper technological solution [16]. At the same time, NETs are not yet available at the extent and scale calculated by these models [17,18]. The IAMs now routinely integrate the (highly speculative) assumptions that NETs will be available by the latter part of the 21st century and that they are able to remove more CO_2 from the atmosphere than that added [19,20]. Attempts to deploy NETs at large scales, however, involve significant uncertainties regarding the extent of the CO_2 removal which could be achieved, economic costs and likely major impacts on terrestrial or marine ecosystems [21]. The dominant role assigned in IAMs to NETs (in particular BECCS) faces serious challenges in taking fully into account the magnitude and duration of possible temporary exceedance of temperature targets, interactions between NETs (such as BECCS, afforestation and reforestation) and their competition for scarce resource such as land, as well as allowing for factors that potentially may reduce or even reverse CO_2 removal (CDR) capacity. This adds further uncertainties to the calculation of the cumulative potential in integrated assessment [21,22].

In light of the approaches described above, we explore why scientific projections such as the IPCC pathways not only project visions about technological and economic capabilities into the future, but also (and often implicitly) expectations and images of social order; they constitute 'sociotechnical imaginaries' [13] that shape society independently of whether the promises of the technologies at their core are actually fulfilled [18,23]. We apply this lens to demonstrate that the IPCC is one key institutional site where the expert imagining(s) of climate futures is communally adopted and thus transformed into a collectively held (canonical) vision of our collective future. The way the IPCC generates and adopts particular expert imagining(s) of futures indicates their performative power – their transformation from purely speculative visions into politically powerful visions of actionable futures [24].

It is the recognition of this performative power of science, and particularly of scientific projections of the future, that has led many to rethink the role and responsibilities of scientific institutions not in spite of their scientific neutrality, but because of science's political impacts and implications [1,2,5,15,17,18].

3. IPCC strategies for performing the neutral arbiter

The IPCC is widely considered to be the most significant environmental boundary organization [25]. In this section we illustrate how the IPCC's role as a key boundary organization is guided by the principle of performing the role of neutral arbiter, made clear in part through its attempt to maintain a clear separation between science and politics.

3.1. Setting the boundary: policy relevant but not-prescriptive

During its first assessment cycle (1988–1990), the IPCC already operated in a 'solution-oriented' mode. Alongside what became its regular scientific assessment tasks, it also performed the role, in the nascent Working Group III, of assessing existing legal instruments and additional elements of an international framework convention in the run-up to the Rio Earth Summit [26]. In doing so it laid out the bare bones of the United Nations Framework Convention on Climate Change (UNFCCC), which was adopted at Rio in 1992. The IPCC was serving as the main forum in which early political negotiations were taking place at this time [27]. The political task – in addition to the intergovernmental status – was seen as a threat for the scientific credibility of the entire organization, while developing countries expressed concerns that the close coupling of science and politics would leave them, with their lower scientific capacities, with less political influence [25,27]. As a response, the IPCC decided in 1990: "The work of the organization is […] policy-relevant and yet policy-neutral, never policy-prescriptive" [28], and the task of deliberating over policy instruments was delegated to a new Intergovernmental Negotiating Committee. Most notably, IPCC representatives contended that the strategy to provide a politically neutral assessment based on scientific rigor and consensus was the only way the body could preserve its scientific credibility [28,29]. When the IPCC withdrew from providing policy recommendations in 1990, the division of tasks between the IPCC and governments was reorganized in order to maintain a strict demarcation between scientific assessment and political negotiation. This move was the first of many by which the IPCC has re-ordered its internal boundaries in order to maintain a firm external distinction between science and politics, and to reconcile policy relevance with political neutrality. In an STS perspective, these strategies can be understood as forms of boundary work that – whether intentional or not – serve to maintain the stability of the boundary between science and policy-making. Scientific assessment is supposed to be independent of political values and interests and thus able to serve as a neutral arbiter or harmonizing force in politics (see [30,31]).

4. Making futures

Against this background we turn to a more recent case, which we believe to be instructive in thinking, in an anticipatory mode, about the likely complexities of solution-oriented assessment.

4.1. From emissions scenarios to representative pathways

Prior to 2007, the IPCC's Special Report on Emissions Scenarios (SRES) presented the main scenarios underpinning assessments of future climate trajectories. They were "plausible alternative futures"; storylines of future socio-economic and demographic changes and associated changes in greenhouse gas (GHG) emissions (p. 24 [32]). Crucially, they did not include 'climate policy' as such, but rather were representations of possible social trends, such as accelerating industrialization or economic localization. Towards the end of the production of IPCC Fourth Assessment Report: Climate Change 2007 (AR4) it was agreed that a new set of climate change scenarios should be produced to inform subsequent assessments. However, it was decided that the scenarios should not be produced by the IPCC itself, as with the SRES (IPCC 2000), but rather that the IPCC should commission the IAM community to produce scenarios along certain lines (25th Session, April 2006). This was thought important in maintaining a distinction between scenario development and assessment, and thus to maintaining the IPCC's independence as an assessor, rather than a producer, of knowledge.

An expert meeting in September 2007 fleshed out plans for a new methodology of scenario production. The new aim was to expedite the production of socio-economic scenarios and climate projections by identifying a set of pathways describing the evolution of atmospheric GHG concentrations and radiative forcing levels over time. Such pathways could then be given to the IAM and general circulation model (GCM) communities for the subsequent production of socio-economic scenarios and climate projections. In the past, scenarios were produced by the IPCC and the IAM community, before being fed into GCMs to produce projections of climate change and its impacts.

The Representative Concentration Pathways (RCP) essentially switched round this order of input and output, removing the primary focus on social change and replacing it with a focus on a physical variable – radiative forcing – and on the end point of climatic change (radiative forcing levels in 2100), rather than plotting a path forwards from the present [33]. The RCPs would provide a set of end points against which climate policy options could be assessed for their effects on the likelihood of reaching certain end points. The pathways selected would be representative of the literature from the burgeoning field of integrated assessment modelling, but would make no "judgment as to their desirability" (p. 43 [34]).

The boundary between description and prescription was however immediately difficult to negotiate, and particular controversy emerged over the selection of a low radiative forcing pathway. Participants of the expert meeting reported demand from both the scientific and policy community for a low-emission pathway [35], but the decision to select either a 2.9 or 2.6 W/m^2 pathway proved controversial (p. xix [36]). In 2007, a 2.6 pathway had only been produced by one modelling group [37], so perhaps couldn't be considered 'representative' of the literature. However, an intervention by Malte Meinshausen, Bill Hare and others at the meeting argued that it would be 'policy prescriptive' to exclude the 2.6 pathway from the set, as that would essentially exclude that future, and its associated policy options, from scientific assessment and political consideration. An IPCC meeting agreed that the Panel's decision to produce scenarios representative of the 'full range' of the literature meant that 2.6 had to be considered, but serious doubts abounded, including from the pathway's originators, about the technical feasibility of what was seen as an essentially 'exploratory' piece of modelling [34].

A special committee was therefore formed to investigate the technical feasibility and replicability of the 2.6 scenario. The committee scrutinized the "technical soundness" of the 2.6 pathway, checking it for "sound assumptions, logic, and associated calculations" (p. xi [34]).

Meanwhile, the modelling team responsible for the 2.6 scenarios also went away to further scrutinize their assumptions and results, particularly those pertaining to the differences between the 2.9 and 2.6 pathways, in particular, BECCS.[i] Both pathways

[i]There is an important distinction between the capacity of outside actors to scrutinize a scenario, and to scrutinize the underlying model, which has recently been subject to some debate (e.g. [38,39]).

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assumed demanding levels of emissions reductions over the next few decades. The 2.6 pathway followed this with a massive roll-out of BECCS to pull the radiative forcing level down even further by giving large expanses of land over to growing fuel crops, which would draw down carbon, and then capturing and burying this carbon when burned [21,40]. The requisite technologies to remove carbon from the atmosphere were then, and largely still are, untested at the scale and rate of deployment envisaged by the IPCC scenarios [21] but the pathways met the committee's criteria of internal logic and calculative robustness, despite the pathways making a large number of (quite openly acknowledged) critical assumptions about technical innovation, institutional change, and political acceptability (see [41]).

Reproducibility was a further desired trait, and while the panel was considering the technical soundness of the 2.6 pathway, an EU-funded project saw the two main European IAM teams invited to produce 2.6 pathways "with which they were comfortable" (p. 5 [42]). This they did, as did two other IAM groups. Together, all four replication scenarios included, as the committee put it, "critical assumptions about energy technology and institutional requirements that will be very challenging to achieve" (p. 5 [42]), particularly regarding BECCS, which was central in all the model runs achieving the 2.6 W/m^2 end point. Nonetheless, the criteria of internal logic, technical soundness and reproducibility had been met, and the 2.6 pathway was recommended as a member of the new RCP family.

The episode provides further illustration of how the IPCC has maintained the external-facing boundaries between relevance, neutrality and prescription through a series of internal re-organizations and boundary work; in this case, at the level of institutional design, the effort to separate scenario development from assessment, and arguably to position a physical variable (radiative forcing) as the starting point of scenario development, rather than social variables and futures. At the level of practice, the decision to include such a low stabilization pathway was influenced by policy-maker interest, not least from the EU which was actively asking new questions of the IAM community [35], but the decision in favour of 2.6 rather than 2.9 was arguably not just about avoiding prescriptiveness ('do this'), but about policy performativity – that is, concerns about the role of scientific assessments in defining the possibility space within which political actors can deliberate and make decisions (see also [43]). The SRES-RCP shift arguably created the space for more speculative technological futures to find their way into officially authorized scenarios – a technology like BECCS perhaps would not have been included in the SRES scenarios (had it been imagined at that time) given the SRES emphasis on social plausibility. The move to the RCP methodology, which was partly a strategy of further distancing the IPCC from the messy business of socio-economic scenario building, arguably and paradoxically facilitated the construction of futures that were both more speculative and politically charged than the SRES scenarios. Technical feasibility and experimental reproducibility replaced social plausibility as the key criteria for formally sanctioning certain constructions of the future. The idea of negative emissions and technologically afforded overshoot and respite is beginning to affect policy discussions in concrete terms, even if these technologies are still highly speculative. The politically adopted 2 °C target likely already assumes overshoot in atmospheric carbon followed by a drawdown (p. xix [35]). The implicit – but scientifically contested – assumption of the availability of huge negative emissions technologies has led to renewed questioning of the processes by which political demands and funding can drive scientific expertise toward speculative assumptions (p. 68 [15]).

In the next section, we examine what happened to this particular future construction as it began to circulate around and exert agency in the policy world.

4.2. From a matter of fact to a fact that matters: the political impacts of RCP2.6

The RCP2.6 pathway held huge political significance, as it appeared to demonstrate the continuing feasibility of the world meeting the 2 °C target as a 'matter of fact.' RCP2.6 therefore quickly became a 'fact that matters'. By providing evidence that the world might manage to limit warming to 2 °C, RCP2.6 had a significant impact on political negotiations. The IPCC's identification of a possible pathway to 2 °C can be considered performative in itself, in the sense that it has enabled transactions that it claims only to describe. The 2015 Paris Agreement to hold global temperate rise to "well below 2 °C" [44] was informed by scientific evidence for the continued technical feasibility of 2 °C, even as analyses continued to show that meeting the target would be extremely difficult [41,45]. This created an interesting slippage between a 'possible' pathway and a political reality – the pathway has informed and justified political aspirations to a certain end, while also becoming a policy option in terms of both ends and means, thereby bringing new topics, such as BECCS, into political debate as future political options to achieve the Paris ambition. The IPCC's RCP2.6 created new political facts, such that ambitious mitigation targets cannot seemingly be achieved without NETs. IAMs in general and RCPs in particular have served to make the pathway politically legible and actionable.

The heavy reliance of RCP2.6 on BECCS has nonetheless been a source of great controversy since the Paris Agreement was signed. The BECCS element of the pathway depends on a rapid deployment on a truly massive scale of a technology currently in its early deployment stage, while the construction of areas of the tropics as simple sinks for global carbon has caused controversy in the past [2] and is already doing so again [46]. Even if it is possible in purely technical terms to grow huge quantities of biomass or capture and store huge amounts of carbon, then biophysical, biogeochemical (i.e. nutrients), ecological, energy, water and economic resource implications of large-scale implementation of NETs differ significantly. Such factors need to be taken fully into account in any realistic assessment of the potential of NETs; a point well recognized by other authors [21,19,41]. This has led to criticisms that integrated assessors/modellers have been insufficiently open about the assumptions contained in the RCP2.6 scenarios, or that details have been lost in translation [20,45,47]. The reliance on NETs in the scientific foundation of policy-making has been questioned, because NETs' future contributions to CO_2 removal, and thus to meeting Paris targets, appear 'optimistic' on the basis of current knowledge (p.19 [21]). The European Academies' Science Advisory Council (EASAC) concludes: NETs should not "form the basis of developing, analyzing, and comparing scenarios of longer-term energy pathways for the EU" [21].

We might say that the IPCC performed an important legitimating function for the speculative technology of BECCS, pulling it into the political world, making previously unthinkable notions – such as overshoot and negative emissions – more mainstream and acceptable, as well as perhaps pushing it ahead of policy options (such as radical mitigation) in political calculations, and thus raising new questions about the neutrality of climate science.

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The NETs example indicates that the IPCC will increasingly face difficult questions over how to handle the assessment of such speculative and controversial 'solutions' to climate change.

5. From neutral to responsible assessment

In the concluding sections, we argue that a turn towards solution-oriented assessment may necessitate a reconsideration of the principles that have heretofore guided scientific assessments of climate change.

The preceding discussion has emphasized how the development of the IPCC's design choices and assessment practices can be read as a history of efforts to maintain the IPCC's policy-neutrality and policy-relevance. Maintaining the stability of the external boundary between international climate science and policy-making has been achieved through a series of internal readjustments and reorganizations, for example, through the early withdrawal from political functions and the emergence of new scenario methodologies. The latter has given rise to a controversial situation in which questions of technical feasibility of certain pathways have been given primary consideration over questions of their societal or political desirability in the construction of actionable futures. This is instructive for thinking about the politics of neutral assessment, as it demonstrates how a narrow scientific focus can be instrumental in controlling potential futures. The narrow focus and IPCC's reluctance to openly address the political implications of its findings were criticized when it came to approval of the WG III Summary for Policy-makers during AR5: as Victor suggests, it contributed to masking major political implications in terms of costs, as well as winners and losers [48]. In the same spirit, Anderson argues that climate scientists have been unwilling to address and communicate "the revolutionary implications" of their scientific results [20].

STS research shows that knowledge-making about future pathways is never neutral, but is instead inescapably political. We have argued that IPCC pathways exercise a world-making power by providing new, politically powerful visions of actionable futures. With this world-making power in mind, we would suggest that the IPCC understands its political role not just in terms of policy-relevance and policy-neutrality, but in terms of policy-performativity. Our discussion above illustrates how scientific assessment does not just linearly deliver facts into the political world, but rather shapes what kinds of futures are thinkable and therefore actionable. The link between the development of future pathways and political choices in the present is rarely understood and requires further exploration [49].

The heated debates about the RCP2.6 scenario are not solely a consequence of the IPCC's work.[ii] However, we would suggest that the controversy provides an opportunity for reflecting about the practices of scientific assessment in terms of its neutrality and its role in, and implications for, climate politics.

We situate this argument within work on responsible research and innovation, especially in wider academic calls to 'open up' debates about emerging technologies [51], negative emissions [52] and options such as BECCS [53]. Responsible research and innovation (RRI) has become a popular topic within and beyond STS of late, with scholars engaging in debates over new technologies, such as nanotechnology, emphasizing the need for modes of research and innovation that anticipate and take account, at an early stage, of social, ethical and political challenges and questions; which involve deliberation among and responsiveness to diverse experts and stakeholders; and which are accountable to concerned publics (e.g. [6,54]). We summarize which lessons can be learned from experiments in applying an RRI framework to climate engineering for the future work of the IPCC. For this, we use the similarities between STS and RRI approaches, which are both based on a constructivist, 'co-productionist' approach. Similar to work on RRI, we would draw attention to the importance of framing effects and what RRI scholars call 'governance implications' [55,56] and 'cognitive lock-in' to particular options and future pathways [57].

[ii]On the much longer history of BECCS in climate science [50].

Based on this body of emerging literature on RRI, we delineate three implications for future IPCC assessments and the directions that these should take.

Firstly, our case study indicates how RCP2.6 helped reinforce the idea that the 2 °C target was still possible. RCP2.6 provided scientific evidence for the feasibility of the 2 °C target and set the stage for more ambitious goals to be included in the Paris agreement (cf. Article 2.1.a). The 2 °C target seems hardly achievable without BECCS according to many recent scenarios:

> "it may no longer be possible to reach a goal of 450 ppm CO_2eq by the end of the century without large-scale deployment of carbon dioxide removal technologies. […] carbon dioxide removal technologies could become necessary in such a scenario" (p. 490 [58]) [51,59].

In the aftermath of Paris, the idea of an overshoot and the deployment of CDR are widely agreed to be preconditions for achieving the 2 °C target (p. xix [35]). At the same time, the Paris agreement (cf. Article 2.1.a) has also been used to push proposals for large-scale use of technologies, ranging from BECCS to nuclear power [60].

Secondly, we have demonstrated with the RCP2.6 example in AR5 that pathways are political interventions that shape the spectrum of choices in the future. The IPCC expanded the range of scenarios and included NETs as a future mitigation option [49,55] to staying within 2.6 W/m^2. If the goal is set to 2 °C or 1.5 °C stabilization, flexibility in mitigation choices is reduced. Virtually all of the trajectories to 2 °C or 1.5 °C stabilization include the assumption of an overshoot. There are only a few examples of scenarios with zero or very low levels of negative emissions that are consistent with the 2 °C goal. All of these are, however, substantially more costly than scenarios that include negative emissions [53]. The SR 1.5 °C also set the research agenda for modelling a 1.5 °C limit [61]. For the 1.5 °C goal, almost all models predict that limiting the use of BECCS would require applying other CO_2-removal technologies or applying potentially risky solar radiation geoengineering technologies [53]. The consequences of these technical choices for policy-making are great [53].

According to some critics, the "mathematically nebulous green-growth and win–win rhetoric" has set the parameters for climate scenario building [41,20]. The idea of overshoot introduced by AR5 represents a techno-economic, optimistic view of the world that is based on the assumption that the economy is optimizing on abatement (or GHG reduction) costs [62]. These pre-existing commitments constrained the choice of priorities: by setting a carbon price as a main driver of pathways, societal priorities such as behavioural change and societal transformation have been excluded or marginalized [49,55]. As a result, developing countries have not been given an option that is a viable alternative to a transition to a high-carbon society [61].

In their assessment of the potential of NETs, the European Academies' Science Advisory Council (EASAC) comes to the conclusion: "Relying on NETs to compensate for failures to adequately mitigate emissions may have serious implications for future generations" (iv [21]). Emerging research on ethical and political aspects demonstrates how and why the overshoot vision is not neutral but has major distributional consequences:

> "The models point out how this overshoot strategy shifts the burden for mitigation from present to future generations" (p. xix [36]).

The overshoot vision also has major political implications in terms of historical and future responsibilities and burdens:

> "the assumption of the availability of huge negative emissions later tends to also favor the high emitting countries in the current generation since they are required to do less in the near term" (p. xix–xx [36]).

Others have argued that 'betting' on BECCS as a future mitigation option [19] risks distracting from mitigation requirements and difficult policy choices in the present [50]. Nordmann warns that "an imagined future overwhelms the present" (p. 32 [63]), in noting the inherent impossibility of anticipation as a way to know the future in anything more than a superficial sense which, inadvertently, serves to reify certain futures (for a more detailed discussion and defence of this view, see pp. 39–41 [54]; for a critique, see [14]).

The EASAC warns:

> "Placing an unrealistic expectation on such technologies could thus have irreversibly damaging consequences on future generations in the event of them failing to deliver. This would be a moral hazard which would be the antithesis of sustainable development" (iv [21]).

Thirdly, if BECCS remains a key part of low stabilization pathways and scenarios then the IPCC, if it is to retain its political relevance, will need to be prepared to 'get its hands dirty' in the politics of BECCS as a speculative mitigation solution that is not yet available at the scale assumed in IAMs.

Since the implementation of NETs is also likely to be location-, technology- and circumstance-specific, alternative, place-based forms of information are relevant for policy-making on the ground. The context-specific, socio-political preconditions for BECCS deployment at different scales are poorly captured in climate scenarios [53]. Research into the consequences for climate policy-making communities as well as for the possibilities of reaching various temperature goals will be greatly needed [50].

Accounting for what we call the IPCC's policy-performativity – the broader, more intangible political effects of IPCC assessment – may be aided by a mode of 'responsible assessment'.[iii]

'Responsible assessment' of BECCS as a potential mitigation solution would include a full exploration of its social and political aspects, as called for by the early assessors of the would-be RCP2.6 scenario [40]. This includes a systematic inclusion of the political implications of RCP2.6, or of a widespread deployment of BECCS to meet the 2 °C or 1.5 °C target. Impacts on land use, food security, human rights and investment costs, and the wider politics of developing new plantations and infrastructures, have to be openly communicated to policy-makers. A future solution-oriented IPCC may well be asked to address these gaps in a more explicit way. Findings from RRI indicate that research on ethical and social aspects may not necessarily undermine the scientific credibility of assessments – rather it can contribute to building trust and anticipating objections [17].

In line with RRI scholars, we suggest that the IPCC open up and integrate a broader range of approaches when it comes to framing and assessing the future impacts of emerging technologies – including but going beyond IAMs. The challenge is not only about broadening the scope and scale of global assessment [48] but also about opening up to a broader and more diverse set of metrics, criteria and frameworks including qualitative research on behavioural change, innovation and societal transformation [64,65] to assess the policy implications of the large-scale use of technologies such as BECCS on the ground. This is particularly important for the assessment of potential solutions, not least CDR or solar radiation management, which imply important and perhaps unintended side effects.

Ex-ante assessments, based on global and top-down approaches, tend to address simply the symptoms (such as global radiative forcing) rather than context-specific societal drivers that include land-use changes and their various societal implications, impacts and risks. Bottom-up and ex-post analysis of the policy performance of and compliance with the climate regime may also contribute to re-evaluating and readapting policy targets. The controversy around the use of BECCS by IAMs indicates that there are major methodological and epistemological uncertainties as well as a lack of transparency about the basic assumptions and feedback loops [38,39].

An uncritical use of IAMs may undermine the scientific and political credibility of the IPCC in the long term, especially after the publication of SR1.5. In line with RRI approaches, we call for opening up basic assumptions on which IAMs are based and presenting them in a transparent manner rather than treating them as a 'black box', along with a critique drawing on the most recent, available literature [66–68]. IPCC representatives such Masson-Delmotte (AR6, WG I) have reflected that negative emissions were included in pathways assessed in the IPCC AR5 WG III report "not in a fully transparent way" [62]. In response to this critique, the IPCC is trying to make more transparent the assumptions guiding the pathways, taking into account new and emerging literature, and to make scenario data more accessible [62]. For the SR1.5, the IPCC seeks to include two key elements: a feasibility assessment of some of the technologies favoured by the models, and an assessment of the enabling conditions such as governance, finance, innovation and behaviour, as compared with the rate and scale of emission decreases for 2 °C pathways [61,62].

While model-builders are very aware of the shortcomings of their models and attempt to communicate them clearly, this often gets lost in the chain of translation from model developer to model (or results) user [57,69]. As such, the responsibility to 'open up' the models does not lie simply with the modellers, but with the institutions and structures through which their knowledge circulates and is put to work – such as the IPCC.

These dimensions are gaining in importance in the scientific literature and thus are also taken up by the IPCC. Furthermore, there are a variety of well-established, scientifically sound methodologies applied in the field of innovation and technology assessment, including RRI, which the IPCC might learn from. For example, deliberative and multi-criteria mapping methods [70] have been developed specifically to broaden out and open up

[iii]We use the term 'responsible' in the RRI sense, not to suggest that assessments in the past have been 'irresponsible'.

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the assessment of negative emissions in order to defuse exactly the sorts of problems highlighted above. They also represent proactive approaches for engaging incoming stakeholders, and mapping the concerns and agendas that underpin their conceptions of the future under conditions of deep uncertainty [15].

6. Conclusion

We have suggested that the politics of anticipation poses new challenges to scientific assessments, thus necessitating new consideration of the IPCC's own role in climate politics. Accounting for the IPCC's policy-performativity, and engaging more directly with putative solutions, including future, speculative and contested technologies, while retaining scientific credibility and relevance among various communities, may be aided by what we call a mode of 'responsible assessment'. Such a turn to responsible assessment, according to RRI principles, would also contribute to opening up the spectrum of actors, framings and options included in the assessment, and it can contribute to making the IPCC more responsive, accountable and credible to diverse political communities and publics across the world.

Technologies such as BECCS would, if realizable at the scale projected by IAMs, have major and unintended ramifications for ambitious pathways to future climate mitigation efforts. Taking the principle of RRI seriously, such large-scale interventions need alerting to prior questions emerging from public concern and democratic scrutiny, including not only the technical, but also the political, ethical, socio-economic and distributional implications over the course of the coming century [6]. Debates about future mitigation pathways that will affect citizens around the world in differentiated ways raise urgent ethical and political questions of democratic accountability and legitimacy. A responsible IPCC will need to experiment with new means of shaping the contours and inventing the vocabularies of such debates.

The IPCC is one of the most significant acts of collective experimentation ever undertaken in the history of science, and its innovations and practices have shaped climate politics in profound ways and have sparked other institutional attempts to solve other global problems. That shaping has often been quite intentional, in executing its mission to inform global policy-making. At other times, we've suggested, it can be more tacit. By embracing the full spectrum of ways in which the IPCC shapes climate politics, the organization can continue to experiment and innovate with new modes of knowledge-making, which will ensure its continued relevance and importance to our collective experiment with the climate system.

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