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The social construction of sustainable futures: how models and scenarios limit climate mitigation possibilities

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ABSTRACT
This article shines a light on the act of social construction of climate change mitigation as a policy issue at the hands of expert bodies enjoying epistemic power, notably the Intergovernmental Panel on Climate Change (IPCC), using Integrated Assessment Models (IAMs) as key tools. This is crucial to the politics of tackling climate change as IPCC models and scenarios profoundly shape what are seen as viable futures and mitigation policy options. Analysing how technocratic governance bodies broach climate change, its mitigation, and the associated economic costs and implications, reveals contestations within the technocratic politics of climate change. The particular social construction of mitigation as a policy issue through IAMs and IPCC scenarios has important and real socio-ecological consequences. This engagement with the technocratic politics of mitigation problematises five key assumptions that are fed into modelling, and reveals why and how they matter politically. We also highlight ways in which contestable assumptions built into IPCC IAMs undermine their credibility and usefulness for planning mitigation strategies.

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Introduction

Since the aim of limiting global warming to 1.5°C above pre-industrial levels was agreed at the UN Paris Climate Change Conference, climate change mitigation targets have proliferated, across many sites of governance. One hundred and fifty countries, covering 88 per cent of the world's emissions, are now committed to net zero greenhouse gas (GHG) emissions by varying dates (Net Zero Tracker 2023). Whatever one's views on the sufficiency of such targets, increasing numbers of civil servants, policymakers, and corporate executives have the unenviable task of meeting them – not least because in some jurisdictions net zero targets are legally binding. Policymakers must navigate the increasingly extreme uncertainties surrounding climate change, its effects on how humankind will use energy and land for the rest of this century, and the socio-economic contexts within which policy is made (Carbon Brief 2018, Rogelj *et al.* 2018, Low *et al.* 2022). For climate mitigation policymakers, then, scenarios of what future systems might look like are becoming fundamental to their ability to make decisions. Yet these themes have been under-explored in political economy analysis. Indeed, how the climate crisis and its mitigation reshape

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the politics of economic policy and state-market relations has been a 'blind spot' for international political economy (IPE) (Kuzemko *et al.* 2019, Paterson 2021).

When policymakers attempt to tackle large-scale, globally relevant problems, such as meeting net zero targets, technocratic International Organisations (IOs) can play a key role in shaping understandings of appropriate policy. Our focus is on the Intergovernmental Panel on Climate Change (IPCC) as a key technocratic body imbued with epistemic authority to pronounce on tackling climate change and to shape how mitigation gets understood as a policy issue. This article starts from the premise, familiar in constructivist IPE, that the interpretive framework through which technocratic bodies address policy issues is potentially influential in shaping the limits of thinkable policy (Barnett and Finnemore 2004, Best 2010). We zero in on the IPCC's use of Integrated Assessment Models (IAMs), and related scenarios, and their role in constructing and legitimising political visions of pathways towards Net Zero.

Climate change, and its mitigation, are vastly complex issues – in temporal, scalar, and political terms. We engage with emerging critiques of modelling, from socio-technical studies and modelling scholarship, exploring how mitigation is being 'made sense' of by policymakers through heuristic devices, including computer-based models and related adjustment scenarios (van Beek *et al.* 2020, Pye *et al.* 2021, Pielke and Ritchie 2021, Shen 2021, Low *et al.* 2022, Stoddard *et al.* 2021). Some claim that models and scenarios are becoming performative, bringing into being the world they describe (Beck and Mahoney 2018, 2018, van Beek *et al.* 2020 in IPCC 2022, p. 304), treated at times more like predictions (Pielke and Ritchie 2021). Indeed, in 2023 both the UK Prime Minister and the COP28 President used scenario predictions of future oil and gas demand in 1.5°C compliant energy systems to justify continued political support for oil and gas extraction (Carrington and Stockton 2023, Channel 4 2023). IAMs and scenarios are, then, crucial for planning, shaping, and *justifying* policy choices (van Beek *et al.* 2020, Low *et al.* 2022), whilst policy, investment, and infrastructure decisions made today have emissions and socio-ecological implications long into the future.

Models and scenarios necessarily abstract from the inordinate complexities of mitigation realities. Yet understandings of 'how the sausage is made', how mitigation scenarios are arrived at, is limited. It matters that details of their construction are under-appreciated by policymakers and by political economy scholars, as these models and scenarios are powerful policy framing tools. Recalling discussions of the politics of economic ideas, we analyse scenarios, and the IAMs that underpin them, as political artefacts. Perhaps the biggest failing of IAMs identified below is the way they project forward from historical trends to anticipate future outcomes. This 'past as future' presumption makes no logical sense in the context of decarbonisation and green transition – where economic, energy and other systems must of necessity undergo profound transformation. This means that past economic trajectories and energy usage trends will be poor guides to how energy and socio-economic systems evolve towards 'Net Zero'.

We, like Stoddard *et al.*, take IAMs to be grounded in neoclassical economic (NCE) theory (2021). We highlight and interrogate five key assumptions to reveal problematic aspects of their social construction. Our article shines a light on how visions of 1.5°C compatible future systems are built unreflexively on embedded ideas that many consider to be part of the problem. IAMs incorporate highly problematic assumptions, for example, about energy demand growth and technologies deemed compatible with 1.5°C – such that possible futures are constrained by our fossil fuel dependent past. Paradoxically, some assumptions construct scenarios in ways that can be used to excuse delay in mitigation policies precisely when the IPCC argues that urgent action is required – so-called 'mitigation deterrence' (Markusson *et al.* 2022, Price *et al.* 2014). As such, the methodological discussion around IAMs and their construction, although somewhat arcane, is a key site of mitigation contestation. The ways modelling is conducted, how models are constructed, on what assumptive foundations, is ultimately crucial for the politics of climate mitigation.

How to construct scenarios is becoming a contested realm at the margins of IAM modelling communities. Challenges of IAMs' assumptive foundations admit more plurality and deliberation into the way the 'science' of scenario-building is discussed within the IPCC (Lidskog and Sundvist 2018, pp. 13–14). Meanwhile, IOs and technocratic bodies take differentially bold stances on mitigation strategies, and climate change's economic costs (Skovgaard 2021). This opens up possibilities for technocrats to re-construct visions of sustainable futures. This is urgently needed as IAMs' problematic assumptions highlighted here undermine the credibility and usefulness of current 1.5°C scenarios for planning mitigation strategies. Indeed, building assumptions about negative emissions technologies and carbon capture and storage into IAMs renders their viability at scale and efficacy a foregone conclusion. It is anything but (Carton *et al.* 2023).

We deal here with a relatively small part of a much bigger story. Climate change is but one facet of a broader and deeper ecological crisis wrought by global capitalism. There are huge swathes of this crisis, biodiversity loss, ocean acidification, soil depletion, which are not touched upon here. Even within climate change discussions, our focus is confined to greenhouse gas (GHG) emissions, the energy sector, and models and scenarios as policymaking tools. We zero in on this theme to reveal specific limitations of tackling the climate crisis through technocratic institutions, given shortcomings in their current thinking and assumptions. The politics of mitigation is likely to become increasingly fraught as sustainable climate pathways continue to be missed by worryingly wide margins (IPCC 2023).

After setting out the technocratic politics of climate mitigation, we introduce IAMs and their significance within IPCC scenario construction before interrogating and problematising five key assumptions underpinning them. The conclusion then draws out the implications of these assumptive foundations for the politics and political economy of mitigation.

Technocratic politics of climate change mitigation governance

We are interested in the technocratic politics of the imagined 1.5°C compatible futures constructed by official bodies. We define technocracy as a mode of governing where credentialed knowledge and 'expert judgement are applied to the policy process' (Clift 2023, p. 27), in ways that can place 'key socio-economic decisions above and beyond political contestation' (Esmark 2020, pp. 207–11). It is significant for how the politics of mitigation has developed that understandings of climate change are science based. The creation of the United Nations Framework Convention on Climate Change (UNFCCC) negotiation process, and the establishment of mitigation as a policy area at all governance scales, are grounded on insights from scientific research on humankind's impact on nature. Those insights have, since 1988, most often been generated by the IPCC.

From the 1950s onwards modelling emerged as the dominant way of analysing climate change, and of predicting future outcomes, placing mathematics methodologies as central to how science formulates understandings of climate change (Edwards 2011, Pielke and Ritchie 2021). This coincided with the growing influence of NCE ideas over policymaking (Stoddard *et al.* 2021). The earth's system has increasingly been represented in detailed but somewhat simplified fashion, based on physics and chemistry, and put into a numerical box (Dahan 2010, Edwards 2011). Global climate change models have become so complex that they are now run on 'super-computers', and yet their critics point to a wide range of over-simplifications which fail to capture key current and future climate realities and social implications (Trust *et al.* 2023).

This paper engages with those IAMs that are designed to show what *energy* systems should look like to reach a predefined, normative climate target. These are produced by British Petroleum (BP), Shell, Equinor, the International Energy Agency (IEA), as well as by and for the IPCC (Blondeel *et al.* 2024).[1] Our focus is on the IAMs and scenarios that delineate IPCC pathways towards the desired climate target of a 1.5°C limit to global warming from pre-industrial levels (Rogelj *et al.* 2018). They are computer-based, coupled socioeconomic and bio-geophysical models that tend to include reduced form representations of climate-earth systems (Stoddard *et al.* 2021). They provide a quantitative description of key processes in human and earth systems, and their interactions, from which scenarios can be derived (IPCC 2022, p. 305). They are typically constructed by economists and/or engineers, remaining relatively inaccessible to non-expert communities. They tend not to engage political science or sociology (Shen 2021). This latter point is salient given the degree to which policy is responsible for driving emissions reductions and societal change within IAMs.

Climate mitigation necessarily involves projecting policy and other developments many years hence. Tackling climate change has so far involved the global uptake of mitigation commitments, but adopting targets and designing long-term strategies and policy to meet them are two very different political exercises. Targets are usually set well before facing up, within current policy settings or societal norms, to the enormity of the task of achieving them. Instead, near term changes to socio-economic business-as-usual often tend to be minimised to gain/maintain political support for mitigation (Paterson 2021, Stoddard *et al.* 2021, Paterson *et al.* 2022). The imagined futures experts envision in the present day, through modelling and scenarios stretching forward many decades, are the first technocratic vocalisations of the political, societal, and economic restructuring that meeting targets will necessarily entail.

We interpret climate scenario-building as a form of 'anticipatory governance', reflecting the ability to craft visions that justify actions and, just as importantly, non-actions in the present and 'channel the conduct of state and non-state actors' (Kranke 2022, pp. 224–5). These 'present futures' thereby govern today's policymaking through anticipation (Berten and Kranke 2022). We explore the epistemic politics involved when IAMs and scenarios shape how contemporary policymakers view possible low emission futures. Assumptive foundations and analytical choices built into scenarios and models tend to supress alternative understandings and sustainable transformations (Pye *et al.* 2021). Likewise, alternative policy routes to 1.5°C, and the broader, socio-economic outcomes of mitigation policy choices, are rarely considered (Willis 2020, Paterson *et al.* 2022). As such, it is important to analyse technocratic models and scenarios, and the assumptions that underpin them, as constructed artefacts to reveal their politics, which goes mostly unacknowledged.

That politics is shaped by key political compromises made during the establishment of the UNFCCC. Early arguments for *Limits to Growth* (Meadows *et al.* 1972), and for a carbon price established via taxation, were tempered to bring the United States on board, and to engage corporations in driving innovation and sustainable change (Newell and Paterson 2010). The resultant compromise of 'liberal environmentalism' emphasises the benefits of economic growth, the role of markets in driving change, and focuses on GHG emissions at the expense of other issues of environmental degradation and of equity and justice (Bernstein 2001, see also Stoddard *et al.* 2021, Mason and Büchs 2023). This approach to mitigation sees market actors as innovators, and advocates for market-friendly policies, such as emissions trading schemes and carbon offsetting (Bernstein 2001, Newell and Paterson 2010). Such NCE framings of climate change as a policy problem, and how to address it, have been consequential in establishing climate action as a matter of market and/or technical rationality. This has marginalised alternative ideas and voices within policy debates and influenced the choice of IAMs as key analytical and policy tools (Felli 2015, Kuzemko 2016, Machin 2019, Stoddard *et al.* 2021).

Whilst the self-understanding of technocrats presents their work as technical and scientific, the complexities and uncertainties surrounding economic forecasting, and indeed climate scenario-building, means their analysis is always based on contestable assumptions about the social and political world (Clift 2023). Their work, of necessity, entails abstraction – but the question is which simplifying assumptions are chosen. In each case, assumptions are somewhat 'buried' – and our work here is partly to reveal and problematise them. Given the complexities and contingencies of mitigation policy processes, and of constructing IAMs and scenarios to inform them, there are always alternative interpretations, or assumptive foundations, available. Indeed, IAMs and scenarios started to be critiqued within the 2022 round of IPCC assessment reports (IPCC 2022, 2023), revealing that underlying modelling assumptions are not unassailable (Lidskog and Sundvist 2015, pp. 13–14). This creates space for the contingency, contestation and deliberation that is, we argue, central to the politics of mitigation.

The selection of a particular policy approach is a political choice – even when this politics is obscured by technocratic veneer. Updated scientific knowledge has of late been utilised to contest the politics of climate policy by raising questions about the inability of current policies to mitigate sufficiently. The IPCC's 2018 Special Report was a prime example which, after decades of disappointing policy responses, set out the speed and degree of emissions reduction still required in stark terms (IPCC 2018). This report, alongside the growth of global climate movements and slow progress in global emissions reduction, is often credited with inciting the global round of commitments to net zero emissions which represented, at the time, a notable increase in stated targets and commitments (Schenuit 2023). IAMs, however, profoundly undermine the IPCC's ability to contest the status quo.

IAMs as constructed futures

IAMs and associated adjustment scenarios are widely used. They represent but one part of a 'suite' of tools used to answer central questions around mitigation policymaking, but they feed directly into the IPCC assessment reports that, in turn, inform UNFCCC negotiation processes and policy decisions (Shen 2021, Stoddard *et al.* 2021). They can be useful in characterising relevant uncertainties in future development pathways and informing policymakers about options and implications of decisions or indecision, including possible policy trade-offs (Wilson *et al.* 2021, pp. 3–4). Modelling complex interactions also enables the comparison, on a systematic basis, of economic costs and effectiveness of alternative mitigation strategies 'as well as the scope and timing of required emissions reductions' (van Beek *et al.* 2022, p. 193). They show us how enormous current emissions are, and the scale of necessary reductions by 2050. Importantly, whilst IAMs and scenarios explicitly tell us that there is no single pathway to 1.5°C, they do not claim to tell us how to get there or to 'fully account for all constraints that could affect realization of pathways' (Rogelj *et al.* 2018, p. 100).

There is an emerging socio-technical studies and economics literature critical of IAMs. Trutnevyte *et al.* point towards tendencies in IAMs to assume only one speed for sustainable transitions and to not see varied aspects of societal transformation (2019). Others have observed that pathways resulting from IAMs have been constrained by an extreme 'business-as-usual' scenario (Petersen 2023, p. 111), not least because assumptions are laden with embedded, contestable, value judgements (Stoddard *et al.* 2021). Here we explore the political economy of IAMs by analysing and problematising five specific assumptions made (explicitly or implicitly) in their construction. To reveal specific ways in which IAMs construct climate mitigation as a policy issue, we delineate how each assumption narrows down and shapes possible visions of policy in relation to constructed futures.

Economic growth

A key ecological critique of established climate change governance focuses on NCE thinking (Keen 2021), and its attendant problematic concepts and frameworks used to gauge economic performance, notably GDP (Mitchell 2011, Schmelzer 2016, Hickel 2020, pp. 92–100). Here mainstream thinking has essentially abandoned the *Limits to Growth* argument (Meadows *et al.* 1972), in favour of assumptions, built into IAMs, that economies continue to grow at circa 2–3 per cent a year. Transition, then, involves doing this 'sustainably' through 'clean' growth. Many informed commentators, however, raise serious questions about the viability of decoupling economic growth from resource extraction, environmental damage, and ecological collapse (Hickel 2020, Hickel and Kallis 2020, Paterson 2021, Green 2022, Copley 2023). Because the IPCC, like the UNFCCC, is focused narrowly on GHG emissions, they can cite instances where some economies have delinked these emissions from GDP growth (IPCC 2022), suggesting tensions between growth and ecological degradation may be surmountable.

IAM assumptions about *socio-economic* aspects of the global future, like population dynamics, GDP, urbanisation, development, levels of cooperation in society, and policy direction, are represented through reference to Shared Socio-Economic Pathways (IPCC 2022). These pathways were developed in 2014 by teams of climate scientists, economists, and energy systems modellers to 'support integrated climate research across the IPCC Working Groups' (IPCC 2022, p. 305). Importantly, these shared pathways were developed using externally generated data, from the OECD and other established bodies,[2] and are taken up as 'exogenous narratives' that form important inputs into IAMs (Hausfather 2018, Trutnevyte *et al.* 2019, IPCC 2022, p. 304). These externally generated socio-economic assumptions then feed through IAMs into the scientific evidence base for climate change (Pielke and Ritchie 2021, p. 10). Five quantified Shared Socio-Economic Pathways have been used as the basis for most climate modelling since Assessment Report 5 (AR5) (IPCC 2022, p. 305), and most of the scenarios in the Assessment Report 6 (AR6) database are based on the same pathways (IPCC 2022, p. 78).

Shared Socio-Economic Pathways are built upon a range of contestable assumptions. Firstly, they assume low-income countries grow until they converge on high-income country GDP per capita (Beck and Mahony 2018). All five shared pathways, including those that envision low future emissions, assume dramatic economic growth. Global GDP in 2100 is predicted to be between four and ten times larger than in 2010 – an annual growth rate of between 1.8 and 3.4 per cent (Hausfather 2018). Shared Socio-Economic Pathway-5 articulates another related, hotly contested NCE assumption – that faith in competitive markets, innovation and participatory societies can be relied upon to produce rapid technological progress, human capital development, and a path to sustainable development (ibid). Such assumptions represent an orthodox Global North view that ignores questions about how high-income countries developed their economies – relying on a politics of colonisation, relations of extraction, fossil fuel subsidies, and protectionism (see e.g. Hickel 2020, Hickel and Kallis 2020, Brand and Wissen 2021).

Secondly, all shared pathways assume that the energy (fossil fuel) intensive economic activity that supported developed country growth continues (Barrett *et al.* 2022). The pathway that assumes the highest fossil fuel use and natural resource exploitation, and lowest energy efficiency, Shared Socio-Economic Pathway-5, also assumes the *highest* global GDP growth. Access to fossil fuel energy is understood to be a driver of industrialisation and growth (Jones *et al.* 2021). This heavily underplays negative relationships between (fossil fuel) energy based economic growth and environmental sustainability and, just as importantly, the high degrees of fossil fuel subsidy that have historically sustained the relationship.

This ubiquitous acceptance of GDP growth as a *sine qua non* policy prioritisation amongst expert bodies framing sustainable futures, and across the political spectrum, has meant that 'alternative and more ecologically attuned possibilities were concomitantly pushed out of the realm of the politically imaginable' (Craig 2020, p. 2). This growth-addicted, 'productivist' (Green 2022) view, enshrined in IAMs, fits within that broader picture of climate governance and technocratic politics. It reveals how ecologically problematic NCE ideas are imported unreflexively via assumptions baked into the historic data produced by external expert bodies, such as the OECD.

Demand for energy

Many IAMs make generalised assumptions that future growth will be relatively less energy intensive. As a result, in 2.0°C consistent pathways it is assumed that total energy consumption of end-use sectors grows only by about 20 per cent and in 1.5°C consistent scenarios all end-use sectors show energy demand reductions (Rogelj *et al.* 2018). Yet, most IAMs do not include any detailed, considered focus on deep demand reduction policies and technologies or on low energy demand futures.

Energy system IAMs are rooted in an energy supply side logic (Pye *et al.* 2021, Blondeel *et al.* 2024), which further normalises positive connections between economic and energy demand growth. Partly as a result, very limited attention is paid to reducing energy demand as a specific mitigation policy, with still less direct consideration of low energy demand futures (IPCC 2022, p. 535). Indeed, the 2022 AR6 *Climate Mitigation Assessment Report* (WGIII) was the first to include a section on energy demand reduction. There is a huge amount at stake here – at the heart of

UNFCCC agreements sits the argument that low-income countries have the right to grow their economies, that economic growth enables sustainable development (Bernstein 2001), and that GDP growth requires considerable energy demand growth. Without ambitious energy demand reduction policies this, in turn, implies an enormous need for fossil fuels much longer into the future.

Indeed, many IPCC IAMs and scenarios, in line with those of Shell, BP, and Equinor, make the questionable assumption that certain degrees of fossil fuel use are 1.5°C compliant. These are used to justify new fossil fuel investments and extraction (Carrington and Stockton 2023, Channel 4 2023, Blondeel *et al.* 2024). It also excuses policymakers from grappling with the thorniest mitigation political questions – how to phase out oil and gas, whose reserves should stay in the ground, and who, if anyone, should be compensated for stranded assets (Newell 2021). At the same time the IEA and other IPCC cited research claim that new fossil fuel extraction is not compatible with 1.5°C. Others argue that with any long-term continuation of fossil fuel energy, net zero will necessitate heavy reliance on technologies, like negative emissions technologies and carbon capture and storage, that are either unproven or in early development, as well as extreme levels of tree planting (Carbon Brief 2018, McLaren and Markusson 2020, Calverley and Anderson 2022, Blondeel *et al.* 2024). The latter raises yet more tricky political-economy questions, this time over land use.

There are two further issues, which indicate an inability to think pro-actively about energy demand reduction. Firstly, most models, again unreflexively, construct energy systems based on exogenous energy service demand projections (Pye *et al.* 2021). Secondly, changes in energy end-use tend to be captured at the aggregated sectoral level as a function of changing incomes and prices (Wilson *et al.* 2017), but not resulting from strategies, and associated targets and policies, aimed specifically at reducing demand. As a result, important questions about which forms of policy can facilitate demand reduction remain absent from most IAMs by construction. Their inbuilt supply-side logic underestimates the value of acting to reduce energy demand today. New policy ideas, about demand-side-response, demand flexibility and management, and evidence of the higher energy efficiency of electrified versus fossil fuel systems (Barrett *et al.* 2022), are being used to contest IAM energy demand assumptions. Indeed, some of these insights were referred to in the narrative of the 2022 AR6 WGIII report (IPCC 2022), whilst the 2023 AR6 *Synthesis Report* includes a new graphic on the potential of demand-side mitigation policy by 2050 (IPCC 2023). Yet most IAMs have not yet incorporated these incredibly important ideas.

Some recent studies explicitly focus on deep demand reduction as a route to low energy demand futures. One inter-disciplinary study argues that demand-side measures can reduce counterfactual sectoral emissions by 40–80 per cent (Creutzig *et al.* 2022), whilst another predicts that globally energy demand can be 40 per cent lower than today by 2050 whilst maintaining economic development (Gruebler *et al.* 2018). Others argue that Global North countries can reduce energy demand by 50 per cent by 2050 without negatively affecting citizens' quality of life (Barrett *et al.* 2022). By reflecting on what can be achieved by proactively implementing demand-side policy, such studies offer different pathways to the passive practices and incumbent supply-side ideas discussed above.

Low energy demand futures not only contribute towards much lower emissions, but a range of other positive social outcomes. Demand-side solutions imply a substantially reduced need for unproven technologies, and are also associated with socio-economic benefits, including improved well-being and health outcomes, lower energy and transport system costs, reductions in fuel poverty, and enhanced energy security (Bento *et al.* 2024). It is increasingly clear that the pursuit of demand reduction strategies can reduce emissions more equitably (Barrett *et al.* 2022, Creutzig *et al.* 2022). Further, the built-in ignorance of deep demand reduction possibilities deeply complicates the politics of mitigation, not least by denying publics positive social outcomes that can be associated with climate action.

Future as past

Perhaps the most problematic IAM assumption is modellers' unreflexive reliance on *historic data* as they seek to identify baseline trends, develop projections, and construct the future. This reflects so-called 'ergodic' assumptions, made by most economists, which see the future as 'merely a statistical shadow of the past' (Davidson 2009, 328). Presuming that the past is a reliable guide to the future is understandable as an approach for forecasting in the face of radical uncertainty. It is, however, deeply problematic at a time when many relevant systems, not least energy, are undergoing rapid and unprecedented forms of change. Never before have whole energy sectors started a process of decarbonisation, let alone demand reduction.

As is inferred in the previous two sub-sections, this fundamentally flawed 'future as past' construction of IAMs involves past trends drawing boundaries around imaginable futures (Carbon Brief 2018), building in path-dependencies. This helps to explain why so many IAMs under-estimated the rate at which renewable energy costs would decrease and the timescale within which renewables would become economically competitive with fossil fuel electricity (Pye *et al.* 2021). IAMs overstated costs associated with transitioning towards renewable energy systems, thereby favouring fossil fuel and carbon capture and storage alternatives. Since 2014, when the first set of Shared Socio-Economic Pathway data was made available, there has also been a divergence between scenario and historic trends – not least because baseline scenarios over-projected growth and emissions (Burgess *et al.* 2021). The need for updating has recently been recognised by the IPCC (IPCC 2022, p. 305).

Lastly, and most worryingly, most IAMs do not take full account of damage to future economic growth resulting from climate change (Rogelj *et al.* 2018, p. 109, Schultes *et al.* 2018 in IPCC 2022, p. 304). Previous patterns of economic growth and prosperity, it is now widely accepted, entailed massive ecological degradation, and stored up huge social and economic costs. Mitigating for the climate change that results from centuries of industrialisation is a necessary part of any future development path. Therefore, previous economic growth and development trends which did not mitigate for, but rather aggravated climate change, constitute hugely problematic and deeply flawed benchmarks for projecting future sustainable scenarios.

As Keen notes, spurious assumptions about the relationship between climate change and the economy have long caused under-estimations of future economic impacts of climate change (2021). Most IAMs do not include the costs of climate related extreme weather events or even many adaptation costs. Indeed, 'many estimates do not account for catastrophic changes, tipping points, and many other factors' (Arent *et al.* 2014, p. 663 in Keen 2021). Yet worse, IAMs routinely include costs associated with mitigation policies whilst under-estimating the value of avoided damage through near-term mitigation spending. Importantly, the lack of accounting for climate change's adverse economic impacts also explains why the high fossil fuel shared pathway is also dubiously presented as yielding the highest growth.

Arguably, neglecting future economic costs of climate change becomes increasingly untenable given the growing availability of estimates of negative GDP implications of extreme climate-associated events (Carlton and Hsiang 2016, Kahn *et al.* 2019, EEA 2022). This knowledge is not new, the Stern report of 2006 set out very clearly the future economic costs of climate change. At the same time, gauging accurately climate change's future costs is very difficult, and working this into huge and complex models is extremely time-consuming, which may explain the modelling choice. Yet IAMs projections should at the very least be accompanied by strong and prominent caveats about how this key omission significantly distorts the picture, and the cost/benefit analysis, that flows from the models. Crucially for climate politics, this failure of IAMs to account for the massive socio-economic costs associated with unmitigated climate change causes models and scenarios to dramatically underestimate the value of mitigation actions today.

What counts as policy?

A heavy burden of responsibility for driving emissions reduction is placed on mitigation policies in IPCC models and scenarios of how the world can meet normative targets. Thus far, however, although some IAMs include technology policies, such as research and development funding, the main policy emphasis is on carbon pricing (Rogelj *et al.* 2018, p. 98, IPCC 2022, p. 304). It has become increasingly apparent that simply laying out the scientific facts of climate change is not sufficient to engender the systematic and socio-economic changes needed to mitigate the climate crisis. One example of this realisation is the decision taken by the IPCC to add new chapters and insights from political science and sociology in its AR6 WGIII report (IPCC 2022). The report suggests a need to include a greater suite of mitigation measures, whilst an informative table (TS.7) shows just how many measures are *not* included in IAMs (IPCC 2022, p. 115). Implementing these measures would require a sharp up-tick in political commitment and policy activism, neither of which is encouraged by the current construction of IAMs.

Thus far, IAMs have deployed a reductionist understanding of social change, with policy understood very narrowly, and often assessed according to cost–benefit analyses (Stoddard *et al.* 2021). This is, perhaps, understandable given the historic lack of inclusion of political science and sociology insights. As a result, however, many IAMs are essentially about calculating cost-effective trajectories towards given goals (IPCC 2022, p. 173 and 305), whilst the basis for IAM pathways to desired climate targets is often the 'minimization of mitigation expenditures' (Rogelj *et al.* 2018, p. 98). This least-cost paradigm over-estimates costs associated with policy action today without, as noted above, taking sufficient account of future economic costs of unmitigated (or under-mitigated) climate change (Carbon Brief 2018). Further, societal change is seen as exogenous to the models, which poses the risk of 'biasing policy recommendations toward easier quantifiable technical and economic pathways' (Trutnevyte *et al.* 2019, p. 424).

This overly simplistic approach to policy results in a tendency to use an homogenous, global, economy-wide emissions price as proxy for mitigation policy when developing pathways to induce emissions reductions, and associated changes in energy and land use, consistent with the climate target (Carbon Brief 2018, Rogelj *et al.* 2018, p. 100). There are, of course, practical limitations when designing models and scenarios, but an over-reliance on emissions pricing is problematic on many levels. It has proven very difficult to maintain prices at levels sufficient to drive significant emissions reduction, whilst a *global* price remains politically unrealistic with currently only 25 per cent of global emissions covered by GHG pricing (Lackner *et al.* 2021).[3] As countries have varied target dates for reaching net zero, from 2050 to 2070, in reality countries' emissions pricing will vary significantly making an homogenous price also unrealistic. Furthermore, by including emissions pricing policies but neglecting the growing breadth of other, workable policy options, especially on the demand side, too much emphasis is placed on emissions removal *technologies* (Pye *et al* 2021, p. 226). Heavy reliance on emissions pricing policies accentuates the value of negative emissions technologies and carbon capture and storage because high prices increase the 'cost effectiveness' of carbon removal solutions (Pye 2021).

Lastly, IAMs treat climate policy as devoid of politics (Carbon Brief 2018), as opposed to embedded within wider institutional contexts and incumbent power relations (Kuzemko 2019, Newell 2021). Where IAM modellers do invoke policy, they do so in mechanistic terms – assuming that policy is the cog in the machine that will seamlessly deliver the changes mandated by their modelled pathways to 1.5°C. Policy is presented in this reading as a *deus ex machina* – it is like the 'invisible hand' of classical liberal political economy that will seamlessly bring forth optimal societal outcomes. There is also an assumption that through markets, innovation, and technology, 'society will adjust the choices it makes as new information becomes available and technical learning progresses' (Rogelj *et al.* 2018, p. 99).

The complexities, power struggles, difficulties, contestations, unintended consequences, and wrong turns that will characterise public policy shifts on a scale such as this are simply wished away. For example, many deep decarbonisation scenarios make heavy use of negative emissions from unproven bioenergy with carbon capture and storage (Carbon Brief 2018, Low *et al.* 2022). However, widespread bioenergy with carbon capture and storage raises incredibly complex political-economy issues, including potential damage to biodiversity, and land use, human rights, and food security issues as land is taken away from agriculture. IAMs have no way of seeing, and therefore taking account of, potential socio-economic implications, making models' over-reliance on bioenergy with carbon capture and storage 'profoundly misleading' for policymakers (Carbon Brief 2018, p. 12, Calverley and Anderson 2022). Moreover, this unproven technology may not even generate negative emissions as expected (Petersen 2023).

Arguably, it is only by ignoring the difficult politics of environmental policy that climate mitigation can be presented to policymakers as technocratic and do-able. This functionalist vision of linear pathways, delivered by 'policy', towards low emissions futures is at best unrealistic, at worst deeply misleading. A set of assumptions can be developed showing a particular pathway is possible in a model, but 'a trajectory that is feasible in a model can reveal itself to be quite unfeasible in the real world' (Carbon Brief 2018, p. 11).

Long-term technical solutions

IAMs are driven by heroic assumptions about unproven, future technologies, like carbon removal, whilst underplaying the value of investment in more established technologies such as renewables and demand reduction (McLaren and Markusson 2020, Low *et al.* 2022). As already discussed, the tendency to weigh near-term costs more heavily means that today's mitigation policies are seen as costly compared with deploying unproven technologies later in the century. IAMs do, however, reveal the extraordinary degree to which a whole range of low emission technologies will need to be scaled-up globally. Whilst annual adoption rates assumed for renewables, of 20 per cent in the 2020s and 2030s, are broadly in line with recent adoption rates of wind and solar photovoltaics, CCS adoption rates of 15–30 per cent seem incompatible with carbon capture and storage's slow development thus far. In 2021 there were only 27 carbon capture and storage plants operational on the planet, with four more under construction, resulting in carbon capture of less than 0.1 per cent of total fossil-fuel CO2 emissions (Calverley and Anderson 2022, p. 24, see also Rogelj *et al.* 2018). Other forms of carbon removal remain, of course, very nascent. That IAMs reveal the rapid rates at which unproven carbon removal technologies still need to develop seems contradictory with the in-built bias against implementing policy to enable rapid uptake of proven renewables and demand reduction technologies.

Over-reliance on future technologies also reduces the space for climate mitigation today. It is all too tempting for policymakers to put off politically and/or economically difficult decisions on the promise of tomorrow's technological advancements (Pye *et al.* 2021, p. 226), something Markusson *et al* term 'mitigation deterrence effects from NETs' (2022). Building assumptions of negative emissions technologies and carbon capture and storage efficacy at scale into IAMs reinforces this tendency. The real socio-ecological impact of over-reliance on future technologies is that insufficient effort has been put into exploring already available, low-technology, low energy demand solutions.

Deeply contested and/or non-existent technologies – reliant on a Cornucopian belief in human ingenuity and innovation – are the solutions that best align with least cost models that undervalue lower energy demand and renewables technologies. Silences on ecological and food security damage and fossil fuel phase out allow these issues to be brushed under the carpet within IAMs and the scenarios they are used to construct. Over-reliance on future technological advancements makes mitigation action seem simpler, avoiding nearer-term discussions of the very difficult economic and societal transformations that will be necessary to *actually* achieve climate goals on any politically sustainable basis. Only by IAMs making outlandish technological assumptions can largely unaltered capitalism be reconciled to ambitious climate targets.

Conclusions

The assumptive foundations of IAMs and scenario-building *really* matter. The IPCC represents an expert realm with some powers to both legitimise and undermine the status quo (Stoddard *et al.* 2021, Mason and Büchs 2023), whilst the social construction of climate mitigation as a policy issue has important and real-world consequences. IAMs use historical data to construct inaccurate visions of the future, shaped by problematic incumbent ideas about growth, energy demand, and even what counts as policy and solutions. In these ways they encourage policymakers to delay mitigation, and actively limit possible futures by making implicit choices about which policies and technologies are necessary to meet climate targets. Yet worse, relying on scenarios as a basis for policy (in)action gets the relationship between the present, future, and past the wrong way around. Instead of using futures narrowed down by past high emissions structures to inform how to act today, more socially inclusive mitigation policies should be adopted that can *proactively reshape* the future away from incumbent structures. This infers a more reflexive and active relationship between policymaking, evidence bases, and future politics and emissions – a move from using 'expected' to 'desirable' futures to inform policymaking (Hajer and Pelzer 2018).

IAMs, scenarios, and their policy inferences, however, increasingly jar with recent narratives in IPCC reports which highlight the vital necessity of mitigation action today, the value of a wide range of policies already available, and justice and equity in sustainably reducing emissions (IPCC 2018, 2023). There is something deeply ironic about IPCC efforts to stress just how urgent political action is, when IAMs and scenarios undervalue today's actionable mitigation policies leaving us prisoners of our climate polluting past. By highlighting and critiquing specific assumptions and the degree to which they encourage the under-valuation of policy action our paper provides some insight into *why* contradictions between IPCC calls for action and lack of policy response persist. The IPCC's decision to incorporate more insights from political science in AR6, and the recognition that alternative policies and choices exist, indicate some awareness of analytical limitations. This suggests that there are tensions within the IPCC and that there is a politics of modelling and scenario methodologies which needs to come to the fore – whilst we see our paper as one small step in encouraging greater deliberation of this politics. Methodological discussions around IAMs, even though they take place on the margins of technocratic governance, are key sites of contestation of the more consensus IAM assumptions and blind spots.

It will be interesting to see if, and to what extent, IPCC and associated modelling communities can adjust their assumptions to take account of the shortcomings highlighted here – whether alternative approaches can move from the margin towards consensus. IAMs are, after all, constructions and therefore open to contestation and change, whilst some assumptions are assailable both via evidence of inaccurate predications and the emergence of alternative approaches. IAMs can evolve away from the 'least cost' paradigm, to take better account of the range of policy opportunities to reduce emissions that already work, especially on the demand side. Barrett (2022) and Gruebler *et al.* (2018) by doing so demonstrate the many socio-ecological co-benefits of acting today to build towards a low energy demand future. Revised modelling assumptions can also better incorporate the economic costs of unmitigated climate change, as is clear in recent analysis which shows that accelerated action today would result in 7 per cent higher global GDP in 2050 (Mehrhoff 2023).

IAMs and scenarios, however, until such time as they can more consistently and accurately take account of the politics and costs of climate change, should come with much stronger caveats and clearer indications of how problematic some assumptions are in mitigation terms. This too might enable IPCC scenarios to galvanise the more effective political and policy change that they argue is crucial.

Notes

1. For a useful discussion of the variety of IAMs see Stoddard (2021). Each model is, of course, only as reliable as the data it runs on, whilst energy system models run on data gathered mainly by the energy industry. Indeed, IAMs

grew out of scenario-based energy analysis led by oil and gas corporations in the 1960s and 70s. Only a few organisations have the resources to pay for the computer hardware and access to the considerable quantities of data required.

2. For more detail on SSP data sets and projections on population growth, urbanisation and GDP see: https://tntcat.iiasa.ac.at/SspDb/static/download/ssp_suplementary%20text.pdf. GDP and per capital income forecasts are based on data from the OECD, the International Institute for Applied Systems Analysis (IIASA), and the Potsdam Institute for Climate Impact Research (PIK).
3. For updated information on global carbon pricing see the World Bank's 'carbon pricing dashboard': https://carbonpricingdashboard.worldbank.org/.

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References

Arent, D., *et al.*, 2014. Key economic sectors and services – supplementary material. In: C.B. Field, *et al.* eds.*Climate change 2014: impacts, adaptation, and vulnerability*. New York: Cambridge University Press, 659–688. Contribution of working group A to the fifth assessment report of the IPCC.

Barnett, M., and Finnemore, M., 2004. *Rules for the world: international organizations in global politics*. New York: Cornell University Press.

Barrett, J., *et al.*, 2022. Energy demand reduction options for meeting national zero-emission targets in the United Kingdom. *Nature energy*, 7 (8), 726–735.

Beck, S., and Mahony, M., 2018. The politics of anticipation: the IPCC and the negative emissions technologies experience. *Global sustainability*, 1 (e8), 1–8.

Bento, N., *et al.*, 2024. Leverage demand-side policies for energy security. *Science*, 383 (6686), 946–949. doi:10.1126/science.adj6150.

Bernstein, S., 2001. *The compromise of liberal environmentalism*. New York: Columbia University Press.

Berten, J., and Kranke, M., 2022. Anticipatory global governance: international organisations and the politics of the future. *Global society*, 36 (2), 155–169.

Best, J., 2010. Bringing power back In: IMF's constructivist strategy in critical Perspective. In: R. Abdelal, M. Blyth, and C. Parsons, eds. *Constructing the international economy*. New York: Cornell University Press, 194–210.

Blondeel, M., *et al.*, 2024. Global energy scenarios: a geopolitical reality check. *Global environmental change*, 84 (2024), 102781.

Brand, U., and Wissen, M., 2021. *The imperial mode of living: everyday life and the ecological crisis of capitalism*. London: Verso Books.

Burgess, M.G., *et al.*, 2021. IPCC baseline scenarios have over-projected CO2 emissions and economic growth. *Environmental research letters*, 16 (1), 014016.

Calverley, D., and Anderson, K., 2022. *Phaseout pathways for Fossil fuel production within Paris-compliant carbon budgets*. Tyndall Centre for Climate Change Research. Available from: https://pure.manchester.ac.uk/ws/portalfiles/portal/213256008/Tyndall_Production_Phaseout_Report_final_text_3_.pdf.

Carbon Brief, 2018. Q&A: how 'integrated assessment models' are used to study climate change. *Carbon Brief Explainers*, 2 October. Available from: https://www.carbonbrief.org/qa-how-integrated-assessment-models-are-used-to-study-climate-change/.

Carlton, T., and Hsiang, S., 2016. Social and economic impacts of climate, a University of California Research Review Summary, September 2016. Available from: https://escholarship.org/content/qt2vz2d2zz/qt2vz2d2zz.pdf.

Carrington, B., and Stockton, B., 2023. Cop28 president says there is 'no science' behind demands for phase-out of fossil fuels. *The Guardian*, 3 December. Available from: Cop28 president says there is 'no science' behind demands for phase-out of fossil fuels | Cop28 | The Guardian.

Carton, W., *et al.*, 2023. Is carbon removal delaying emissions reductions? *Wires climate change*, 14, e826.

Channel 4, 2023. Rishi Sunak defends expansion of North Sea oil and gas drilling. *Channel 4 News*, 31 July. Available from: https://www.youtube.com/watch?v=dVB3B5bmynl&t=38s.

Clift, B., 2023. *The office for budget responsibility and the politics of technocratic economic governance*. Oxford: Oxford University Press.

Copley, J., 2023. Decarbonizing the downturn: addressing climate change in an Age of stagnation. *Competition & change*, 27 (3-4), 429–448.

Craig, M.P.A., 2020. Greening the state for a sustainable political economy. *New political economy*, 25 (1), 1–4.

Creutzig, F., *et al.*, 2022. Demand-side solutions to climate change mitigation consistent with high levels of well-being. *Nature climate change*, 12 (1), 36–46.

Dahan, A., 2010. Putting the earth system in a numerical box? The evolution from climate modeling toward global change. *Studies in history and philosophy of science part B*, 41 (3), 282–292.

Davidson, P., 2009. Can Future Systemic Financial Risks Be Quantified? Ergodic vs Nonergodic Stochastic Processes. *Brazilian Journal of Political Economy*, 29 (116), 324–340.

Edwards, P., 2011. History of climate modeling. *Wires climate change*, 2 (1), 128–139.

EEA (European Environment Agency), 2022. *Economic losses from climate-related extremes in Europe*. European Environment Agency, 3 February. Available from: https://www.eea.europa.eu/ims/economic-losses-from-climate-related.

Esmark, A., 2020. *The new technocracy*. Bristol: Policy Press.

Felli, R., 2015. Environment, not planning: the neoliberal depoliticisation of environmental policy by means of emissions trading. *Environmental politics*, 24 (5), 641–660.

Green, J., 2022. Greening Keynes? Productivist lineages of the green new deal. *The anthropocene review*, 9 (3), 324–343.

Gruebler, A., *et al.*, 2018. A low energy demand scenario for meeting the 1.5°C target and sustainable development goals without negative emission technologies. *Nature energy*, 3 (6), 515–527.

Hajer, M., and Pelzer, P., 2018. 2050—An energetic odyssey: understanding 'techniques of futuring' in the transition towards renewable energy. *Energy research & social science*, 44, 222–231.

Hausfather, Z., 2018. Explainer: how 'shared socioeconomic pathways' explore future climate change. *A Carbon Brief Online Explainer*, 19 April.

Hickel, J., 2020. *Less is more: how degrowth will save the world*. London: Random House.

Hickel, J., and Kallis, G., 2020. Is green growth possible? *New political economy*, 25 (4), 469–486.

IPCC, 2018. *Global warming of 1.5°C: special report*. Geneva: IPCC.

IPCC, 2022. *IPCC sixth assessment report: working group III: mitigation of climate change*. Geneva: IPCC.

IPCC, 2023. *Sixth assessment report: synthesis report: climate change 2023*. Geneva: IPCC.

Jones, A., *et al.*, 2021. Finance for a future of sustainable prosperity. *Area*, 53 (1), 21–29.

Kahn, M., *et al.*, 2019. *Long-term macroeconomic effects of climate change: a cross-country analysis*. IMF Working Paper WP/19/215.

Keen, S., 2021. The appallingly bad neoclassical economics of climate change. *Globalizations*, 18, 1149–1177.

Kranke, M., 2022. Tomorrow's debt, today's duty: debt sustainability as anticipatory global governance. *Global society*, 36 (2), 223–239.

Kuzemko, C., 2016. Energy depoliticisation in the UK: destroying political capacity. *The British journal of politics and international relations*, 18 (1), 107–124.
Kuzemko, C, 2019. Re-scaling IPE: local government, sustainable energy and change. *Review of International Political Economy*, 26 (1), 80–103.
Kuzemko, C., Lawrence, A., and Watson, M., 2019. Rethinking the international political economy of Energy. *Review of International Political Economy*.
Lackner, M., *et al.*, 2021. *Pricing methane emissions from oil and gas production how new methane measurement data and pricing designs can complement direct regulation and enable additional emissions reductions*.
Lidskog, R; and Sundqvist, G, 2018. Environmental expertise as group belonging: Environmental sociology meets science and technology studies. *Nature and Culture*, 13, 309–331.
Low, S., Baum, C., and Sovacool, B., 2022. Undone science in climate interventions: contrasting and contesting anticipatory assessments by expert networks. *Environmental science & policy*, 137, 249–270.
Machin, A., 2019. Changing the story? The discourse of ecological modernisation in the European Union. *Environmental politics*, 28 (2), 208–227.
Markusson, N, et al., 2022. Life in the hole: practices and emotions in the cultural political economy of mitigation deterrence. *European Journal of Futures Research*, 10 (2), 1–14.
Mason, N., and Büchs, M., 2023. Barriers to adopting wellbeing-economy narratives: comparing the wellbeing economy alliance and wellbeing economy governments. *Sustainability: science, practice and policy*, 19 (1), 1–15.
McLaren, D., and Markusson, N., 2020. The co-evolution of technological promises, modelling, policies and climate change targets. *Nature climate change*, 10, 392.
Meadows, D.H., *et al.*, 1972. *The limits to growth: a report for the club of Rome's project on the predicament of mankind*. Washington: Potomac Associates.
Mehrhoff, J., 2023. Benefits of accelerating the climate transition outweigh the costs. *IMF Blog*, 5 December 2023. Available from: Benefits of Accelerating the Climate Transition Outweigh the Costs (imf.org).
Mitchell, T., 2011. *Carbon democracy: political power in the age of oil*. London: Verso.
Net Zero Tracker, 2023. *Global net zero coverage*. Net Zero Tracker website. Available from: https://zerotracker.net.
Newell, P., 2021. *Power Shift.* Cambridge University Press.
Newell, P. and Paterson, M., 2010. *Climate Capitalism.* Cambridge University Press.
Paterson, M., 2021. Climate change and international political economy: between collapse and transformation. *Review of international political economy*, 28 (2), 394–405.
Paterson, M., Tobin, P., and VanDeveer, S., 2022. Climate governance antagonisms: policy stability and repoliticization. *Global environmental politics*, 22 (2), 1–11.
Petersen, A., 2023. Disciplines. In: K. DePryck, and M. Hulme, eds. *A critical assessment of the intergovernmental panel on climate change*. Cambridge: Cambridge University Press, 107–115.
Pielke, R., and Ritchie, J., 2021. Distorting the view of our climate future: the misuse and abuse of climate pathways and scenarios. *Energy research & social science*, 72, 101890.
Price, C, Morris, J and Morris, C, 2014. Biochar carbon markets: A mitigation deterrence threat. *Environmental Science and Policy*, 154 (2024), 103704.
Pye, S., *et al.*, 2021. Modelling net-zero emissions energy systems requires a change in approach. *Climate policy*, 21 (2), 222–231.
Rogelj, J., *et al.*, 2018. Mitigation pathways compatible with 1.5°C in the context of sustainable development. In: V Masson-Delmotte, *et al.* eds. *Global warming of 1.5°C: an IPCC special report*. Geneva: World Meteorological Organization, 93–174.
Schenuit, F., 2023. Staging science: dramaturgical politics of the IPCC's special report on 1.5°C. *Environmental science & policy*, 139, 166–176.
Schmelzer, M., 2016. *The hegemony of growth: the OECD and the making of the economic growth paradigm*. Cambridge: Cambridge University Press.
Schultes, A., *et al.*, 2018. Optimal international technology cooperation for the low-carbon transformation. *Climate policy*, 18 (9), 1165–1176.
Shen, S., 2021. Integrating political science into climate modelling: an example of internalizing the costs of climate-induced violence in the optimal management of the climate. *Sustainability 2-21*, 13 (19), 10587.
Skovgaard, J., 2021. *The economisation of climate change.* Cambridge University Press.
Stoddard, I., *et al.*, 2021. Three decades of climate mitigation: why haven't we bent the global emissions curve? *Annual review of environment and resources*, 46, 653–89.
Trust, S., *et al.*, 2023. *The emperor's new climate scenarios. Limitations and assumptions of commonly used climate-change scenarios in financial services*. Institute and Faculty of Actuaries. Available from: the-emperor-s-new-climate-scenarios.pdf (actuaries.org.uk).
Trutnevyte, E., *et al.*, 2019. Societal transformations in models for energy and climate policy: the ambitious next step. *One earth*, 1 (4), 423–433.
van Beek, L., *et al.*, 2020. Anticipating futures through models: the rise of integrated assessment modelling in the climate science-policy interface since 1970. *Global environmental change*, 65, 102191.

van Beek, L., *et al*., 2022. Navigating the political: an analysis of political calibration of integrated assessment modelling in the light of the 1.5°C goal. *Environmental science & policy*, 133, 193–202.
Willis, B., 2020. *Too hot to handle? The democratic challenge of climate change*. Bristol: Bristol University Press.
Wilson, C., *et al*., 2017. Evaluating process-based integrated assessment models of climate change mitigation. *An International Institute for Applied Systems Analysis (IIASA)* Working paper, WP-17-007, May 2017.
Wilson, C., *et al*., 2021. Evaluating process-based integrated assessment models of climate change mitigation. *Climatic change*, 166, 3.