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The role of the IPCC in assessing actionable evidence for climate policymaking

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Climate policymakers across the world seek inputs from the research community to determine appropriate policies to reduce greenhouse gas emissions. However, the reports of the Intergovernmental Panel on Climate Change (IPCC), which perform the largest available analytical exercise in this area, offer scarce analytics on climate policy design. Here, we explore how, despite its 'neutral, policy-relevant but not policy-prescriptive' principle, the IPCC's analytical scenario process in Working Group III on Mitigation has adopted an implicitly prescriptive policy position in favour of carbon pricing. Drawing on the example of alternative climate-economic modelling using the E3ME-FTT framework, we explore a pathway for the IPCC process that could cater for diverse ranges of more realistic granular policies. We conclude that, to become truly policy-relevant, the IPCC's climate mitigation work is in urgent need of reform to provide more effective support for policy design.

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INTRODUCTION

Following the Paris and Glasgow Agreements, policymakers around the world are now in a critical position. Whether global emissions targets are met could be determined within the current decade, if policymakers can implement effective climate policy and draw in businesses and society in the collective effort to do so. The IPCC has a long history in informing policymakers about the importance of the climate change threat. It covers the latest agreed-upon earth system science, issues concerning adaptation and adaptive capacity to climate change, and concepts revolving around the mitigation of climate change. Given the criticality of the next decade for climate policy, IPCC activities that are focused on mitigation could, in principle, become the most relevant.

This appears not currently to be the case. A quick google trends search reveals that the contribution of Working Group I (WGI) to the IPCC's Sixth Assessment Report (AR6), on the science of climate change, has received the most media attention of any IPCC report, followed by the 2018 special report on 1.5 °C[1]. In comparison, the contribution of Working Group III (WGIII) on mitigation has received less coverage in mainstream media and is the subject of fewer online searches.

More puzzling still is how little WGIII's contribution is used in policy documents. Key results, such as carbon budgets from WGI are referenced (e.g. see ref. [2–7]). The IPCC appears largely to be seen by policymakers as a general source of information on climate change, rather than on solutions to mitigate climate change. These policymakers appear to use the IPCC's reports to justify climate action, but not to formulate climate policy frameworks.

In this paper, we explore the reasons for the lower relative impact of WGIII. We consider the relevance of the WGIII contribution to policy action. We assess whether the WGIII report offers actionable insights for policymakers, assuming that the intention of the report is, at least in part, explaining how to justify, structure and achieve policy action.

The problem of providing evidence for climate policymaking through the IPCC process is closely tied to the IPCC's stated strategy of seeking to remain policy-relevant but not policy-prescriptive[1]. Embedded in this process is the scenario generation activity, where scenarios from Integrated Assessment Modelling teams are submitted to, and collated in, an IPCC scenarios database. For AR6, more than 2,000 scenarios were submitted, out of which 1,202 included sufficient information for assessing the associated warming consistent with WGI[8]. From these scenarios, five Illustrative Mitigation Pathways (IMPs) were defined, representing five different mitigation archetypes. The pathways are important because the modelling scenarios receive an outsized share of attention (including through the IPCC's own summaries for policymakers), offering modelling evidence concerning pathways that achieve climate targets.

However, the IPCC does not specify sets of policy instruments or concrete actionable policy measures that could reliably lead to achieving the respective pathways, neither for the scenarios submitted to the database nor for the IMPs. AR6 Chapters 3-4 and Annex III do not state the exact policy assumptions upon which the scenarios were developed. To quote AR6 text, "In practice, models implement climate constraints by either iterating carbon-price assumptions or by adopting an associated carbon budget." (AR6 Section 3.2.1.2). Furthermore, "A no-climate policy scenario assumes that no future climate policies are implemented, beyond what is in the model calibration, effectively implying that the carbon price is zero." (AR6 Section 3.2.1.1). Lastly, "Cost-effective mitigation scenarios assume that climate policies are globally uniform. There is a substantial literature contrasting these benchmark cases with pathways derived under the assumption of regionally fragmented and heterogeneous mitigation policy regimes." (AR6 Section A.III.II.1.4). The IMPs were selected from the scenario lot and, as shown in Figure 3.31, the carbon price is the only policy instrument reported. Policy instruments in AR6 are discussed in chapters in which scenario analysis with models is not used (e.g. Chapter 13 on policies and institutions) and, therefore,

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quantitative assessments of the effectiveness of policy instruments is not available to the reader.

A key factor used in generating the scenarios is 'the shadow carbon price'[9–12], which is a metric used as a simplified representation of all climate change mitigation policies with the purpose of aligning different models upon common assumptions. The shadow carbon price in the models is a lever that controls socio-technical change, relative costs and prices and, by assumption, energy use and greenhouse gas emissions. Thus, the scenario generation process assumes that there is a relationship between this pricing metric and emissions levels, and that all policy measures can be contained within the boundaries of the shadow carbon price[9]. In other words, the modelling scenarios are deliberately mostly agnostic to policy instruments, for the sake of simplicity and comparability.

In this paper, we suggest that seeking to remain 'not policy prescriptive' has itself drifted toward becoming a policy prescription. While not stated explicitly, the current implicit prescription suggests, to the undiscerning eye, that a single global carbon price set at some appropriate level is sufficient to achieve decarbonization, a transition that causes some economic cost. In that perspective, policy design is not really needed. Moreover, nearly all the models used in the scenario analysis assume that any deviation from this prescription leads to inefficiency and loss of welfare (AR6 Figure 3.33; see also ref. [10–12]), something that is the subject of controversies in the broader modelling and economics community[13,14]. The question of policy relevance in the IPCC is thus closely tied to the types of modelling tools used, and any choice of models is inevitably political. The power of the IPCC to create narratives and political realities from its modelled scenarios is well known[15–17]. Whether intentional or not, the IPCC's received message risks being one of global carbon prices and inevitable economic costs in addressing climate change in first-best scenarios, with the option of adding 'inefficient' non-pricing instruments to address political economy concerns in 'more realistic' second-best scenarios.

Experience shows that implementing climate policy at global level is not feasible[18]. Discussing climate action solely in terms of a uniform global or regional carbon price furthermore creates little incentive for economists and modellers to develop tools that can assess other policy instruments. The result is a self-reinforcing mechanism of demand and supply for models that assess only carbon prices, in contrast to what policymakers may require. And, notably, it is increasingly established that carbon taxes or markets have played little role in scaling-up the capacity and bringing down the costs of key technologies such as solar and wind energy, and electric vehicles. Instead, long-term contracts that help de-risk investments, such as 'contracts for differences', 'power purchase agreements' or 'feed-in tariffs' have been generally used[19–21]. Therefore, policymakers may legitimately wish to investigate the impacts of those instruments using models. Lastly, salient issues for policy design such as impacts on trade, competitiveness, inequality, financial risk and debt sustainability are not considered in the IPCC's modelling analysis. The relevance of the IPCC for policymakers is thus less than it could be.

Following the Paris Agreement since 2015, the IPCC has sought to re-orient its focus toward providing solutions to climate change[15]. We suggest that this endeavour has not been entirely successful, and explore whether the IPCC could move beyond the question of 'why' governments should take action to reduce emissions, to address 'how' governments could do so, without compromising its political neutrality.

The next section reviews the historical context to the IPCC's present position. The following section discusses the role of modelling in policymaking. "Discussion" presents alternative approaches and results that could be used to enrich the evidence base supporting policymaking. Section "Methods" concludes.

RESULTS

Review of the IPCC's historical context

The IPCC was set up in 1988 to provide scientific evidence and advice to governments, given the far-reaching complexities of the climate problem, as an international equivalent to national committees, chaired by Chief Scientists. The institution of the IPCC, its organization and reports is a triumph of international cooperation between governments, scientists and administrators, building consensus and evolving in response to the evidence of climate change and its effects.

The IPCC's first Assessment Report (AR1) was published in 1990[22]. After the Rio conference in 1992, and based on AR1's recommendations, international climate policy was agreed to be coordinated under the United Nations Framework Convention on Climate Change (UNFCCC)[23] with its annual Conferences of the Parties (COPs). The convention, ratified by all UN member states, aims at "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"[23].

A global problem was seen as requiring a global solution, with mandatory targets agreed by an international treaty ratified by member states (achieved in the Kyoto Protocol in 1997). However, the Copenhagen conference, 2009, failed to reach such an agreement and the solution became decentralized with policies coordinated through the COPs and subsidiary bodies. Three 'emission gaps' between (1) global targets and national aspirations, (2) global targets and national outcomes, and (3) national aspirations (emission reductions pledged by countries) and national outcomes (emission reductions achieved from domestic policies) or the so-called 'implementation gap', (e.g. see ref. [24,25]) have become crucial in assessing past successes and needs for more ambition.

Although the IPCC has no competence in putting forward legislative proposals (except in the Technical Support for GHG measurements), national governments rely on the IPCC to assess and consolidate the latest scientific literature. The IPCC's findings thus feed directly into the policymaking process.

The economics literature on climate change, upon which most of the models of the IPCC scenario exercise have been built, derives mainly from the worldview, principles, and axioms derived from one single branch of scholarship, standard neoclassical theory. The basic theoretical axiom is grounded in whole-economy utility maximisation, which can be imagined as a social planner, *organising* [optimally] *the economy, according to rational expectations of future events* (e.g. ref. [26]). In more transparent language, optimisation models assume that all agents in the economy behave cooperatively to achieve the modeller's chosen subjective *objective*. But the models *do not* determine whether agents are usually observed to behave this way. *In that sense, such models are prescriptive rather than descriptive*.

Obviously, it is unverifiable that any particular individual or group optimises an objective function chosen by a modeller[27–29]. The individual would need to be aware of all the options and their consequences made available by the modeller, if they are to select the optimal one. These assumptions work for prescriptive modelling (what should we aspire to?) but not for descriptive modelling (what can we expect to see happen?)[30–36]. Thus, the IPCC scenario work in effect has historically focused on prescriptive messaging, which is part of the conversation but not necessarily actionable.

Greenhouse gas emissions from human activities have generally been framed as 'externalities' in the theory underlying most of the models used in IPCC reports; undesired barriers for the efficient allocation of resources in the economy. Where more than one externality is identified, the Tinbergen Rule[37] suggests that policymakers should choose one policy instrument for each externality. The traditionally assumed efficiency of markets and focus on price mechanisms used in the ARs make the carbon price the optimal instrument for reducing emissions, in theory, but not from empirical evidence[19,20,38].

The tension between this framing and policymakers' concerns has led to an evolution of IPCC procedures by (1) giving more attention to uncertainty and risk, (2) increasing the transparency and inclusivity of author selection, review and agreement processes and (3) including new chapters in the reports outside of the modelling effort, notably on finance and innovation.

The evolution can be seen in changes to the contents of the WGIII reports from 1990 to 2022. AR1 in 1990 had "no detailed assessments [..] of the economic costs and benefits, technological feasibility or market potential of the underlying policy assumptions."[22]. In contrast, AR2 in 1995 was oriented towards whole-economy cost-benefit analysis (CBA) of climate change, an approach later questioned for application in long-term global problems[39] and existential risks[40]. In 2001, AR3 provided cost estimates in the form of scenarios and sectoral analyses for the first time. AR4 in 2007 developed chapters for each key sector of emissions. AR5 in 2014 introduced risk and uncertainty, ethics, equity and sustainable development, infrastructure and planning. AR6 in 2022 in turn consolidated the risk, ethics and equity issues into a single framing chapter and introduced new chapters on institutional change, short-term mitigation, innovation, finance, technology and accelerating the transition to net zero, following SR15 on the 1.5°C target.

Climate policy modelling and the quest for actionable policy insights

Climate policy begins with setting a climate change agenda, based on the country's level of ambition (Fig. 1). Following the failure to introduce globally coordinated policies in 2009, individual countries have instead pledged emissions reductions through Nationally Determined Contributions (NDCs). NDCs are usually decided by what is believed by policymakers to be achievable for their country within current development plans (sometimes economic models are used to inform the choice). However, NDCs rarely specify the exact policy and legal mechanisms through which emissions reductions will be achieved and, in many countries, the strategy for action remains largely undefined.

Policy design and assessment (ex ante and ex post) is where economic and political economy evidence is particularly needed, before decision-making can occur. Where climate policies to reduce greenhouse gas emissions have been implemented, substantial variation has emerged around the world. Policies include targeted support, regulations, taxes, mandates, R&D subsidies, long-term contracts helping to de-risk low-carbon

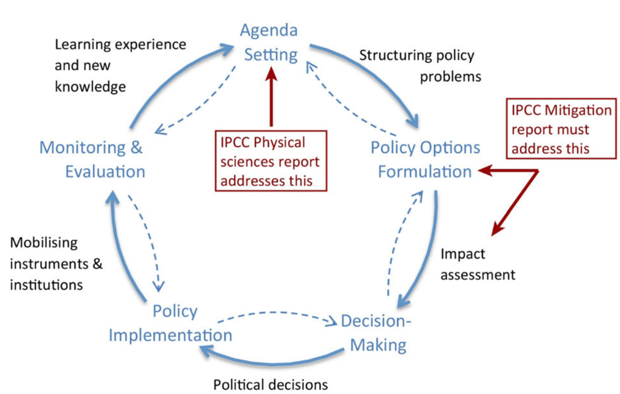

Fig. 1 The IPCC reports within the policy cycle. The policy cycle includes five distinct stages. The IPCC mitigation report must address the formulation of policy options and the impact assessment of these options.

investments (e.g. contracts for difference mechanisms), market creation and demand aggregation mechanisms[19,20,41]. The ex post empirical evidence on the impacts of various policy initiatives is rich with insights on what has worked well and less well[41]. Within this literature, carbon taxes and markets have a mixed record[41–43]. Emission Trading Schemes (ETSs) also suffer from the 'waterbed' effect, where complementary policy initiatives such as energy efficiency improvement measures undermine carbon price signals and may not incentivise further climate action[44,45]. Carbon taxes have been effective at making some high-carbon activities unprofitable (and even causing positive tipping cascades[46]), but are less suitable for incentivising green innovation and technological change. The evidence instead shows that targeted technology support through long-term contracts has been most successful in deploying at scale key low-carbon technologies[19–21,47].

This finding suggests that 'taxing the bads' is not equivalent to 'rewarding the goods' and that, moreover, doing both at the same time may generate substantial synergies. The carbon tax seems good at preventing backsliding on climate, and therefore is a necessary component in any climate policy framework. However, new technologies to replace the old *do not magically materialise* as a result of implementing carbon pricing, and targeted policy support for technology, innovation and market creation is often critical.

Lastly, an exclusive focus on carbon pricing may give undue focus on particular low-carbon technological developments that may not necessarily become reality. Notably, in SR15 it has led to a substantial debate on the feasibility and desirability of geoengineering and negative emissions technologies, solutions that have yet to see any notable deployment[48].

The pricing approach is considered 'efficient', but this is not necessarily the same as 'effective'. Establishing an efficient carbon price looks backwards at how, under a normative frame, goods and services ought to be priced to reflect the external costs associated with emitting carbon, including economic externalities such as air pollution and health burdens[10,49]. This approach is defensible on moral grounds and is the basis for policy action in IPCC scenarios. But this approach does not guarantee emissions reductions, since the calculation has little to do with assembling evidence on the mechanisms driving future technological change and other actions that mitigate climate change. Furthermore, to be comprehensive, the approach should also include the externalities of policy-induced innovation, technology diffusion and the systemic risks caused by a rapid transition, but this is considered out of scope[50].

In contrast, an effective climate policy strategy focuses on evidence over the real expected outcomes of climate policy instruments and related uncertainty. This looks at predicting the future evolution of the economy under certain policy contexts, or looking back at past experiences. This approach is not necessarily 'efficient' and may or may not involve pricing, but it does offer some confidence in the outcome.

In reality, policies explored by governments remain largely defined by previous experience (i.e. looking at effectiveness) and are tested using policy appraisal frameworks[20,51,52]. This explains, to some degree, why policymakers have used IPCC reports mainly to justify action rather than choosing what type of action. It therefore also raises critical questions about the intended purpose of the WGIII reports: they are not used to justify climate action, given this is effectively done by WGI, and they are also not used to design policy.

The IPCC's modelling community has thus trained large numbers of 'agenda-setters' for the first stage of climate action, but has failed to train sufficient numbers of experts in climate policy assessment for the next stage[53]. The 'not policy prescriptive' prescription of the IPCC may in practice have become a barrier for the community to provide actionable modelling policy insights, by generating a narrative under which assessing diverse and emergent policy needs is not incentivised in the modelling community[54].

In 2015, the then governor of the Bank of England, in a single speech created a whole new domain of analytical need in relation to climate change. The Bank of England released a landmark report enumerating the risks imposed by climate change and climate action on the insurance sector and wider financial system[50]. The Task Force on Climate-Related Disclosures[55] was created soon after, and reports by the Dutch central bank[56] and the Banque de France[57] followed. The actions implied an urgent analytical requirement for quantifying the newly named *physical* and *transition* risks to the financial system, which was duly followed by substantial research[58–63], the creation of the Network for Greening the Financial System (NGFS) and the addition of Chapter 15 on finance in AR6.

The NGFS makes use of climate and socio-economic scenarios; a space that was quickly filled by the IPCC's modelling community. However, the community uses models that are inadequate, because they were not updated with capabilities to assess systemic financial risk. Many, if not most, financial questions thus remain unanswered[64]. More broadly, the IPCC's scenario process has not embraced the movement on transition risk assessment. Meanwhile, the chapter on finance remains relatively silent on the drivers of risk, such as leverage and indirect ownership of risky assets[61,65], where its use of scenarios remains limited to ascribing transition risks to the credibility of climate policy.

Support for policy design through the IPCC

Our general point is that to generate actionable insights in the policy design or policy impact assessment phase, one must determine the likely behavioural responses of agents to potential new policy with some degree of scientific confidence. In other words, if a policy course is implemented, would it be effective in reducing GHG emissions whilst observing social and economic concerns? This, unavoidably, requires analysis of human behaviour[66] and past policy successes[41,43]. We suggest that the limited use of such models is largely what blocks the IPCC's scenario exercise from informing policy design.

One way forward for the IPCC scenario process is to move towards informing how to achieve national NDC targets and analysing the socio-economic consequences of different strategies. That is, moving away from an implicit but unstated policy prescription of carbon pricing, towards assembling modelling evidence on the effectiveness of policy instruments such as the removal of fossil fuel subsidies, the creation of markets, support for technology diffusion, *as well as* carbon taxes and emissions trading schemes. This could be done on the basis of two perspectives: using new models with alternative methodological foundations designed for tackling those questions[67], and looking back at past successes (see e.g. ref. [19]).

Current descriptive theories of technology development are based on evolutionary and complexity theories (e.g. ref. [68–70]), as well as sociology and history[71–73]. Critically for the low-carbon transition, where many of the key technologies already exist, the process of innovation, selection and diffusion follows the long and complex innovation chain from idea to market[13]. New technologies face a competitive disadvantage because they start off expensive and unknown. Subsequently, higher rates of take-up lead to economies of scale, more efficient production methods and increased competition, all of which drive down prices[74,75].

Moving on from normative assumptions about perfect knowledge, foresight and economic rationality, theory and models can be broadened considerably. Since the level of demand in addition to the productive capacity is what matters to understanding decarbonisation, demand-driven and supply-driven models should work alongside each other. Various schools of economics have developed the connection between demand, productive capacity, investment and the banking system[76,77], which matters when assessing the capacity to transition, financial risk and stability. Understanding money and finance is crucial for determining the impacts of climate policy[14,63,78–80].

Furthermore, there is also the interpretative dimension of complex dynamics pertaining to the climate change problem that has often been neglected in the economic modelling of the scenarios, but more openly embraced in other strands of economic thinking[81–84]. This approach could bring new insights for more effective and versatile climate solutions[85].

Few climate-economy models are developed around theory that incorporates the dynamics of innovation, technology diffusion, investment and finance as they are observed empirically. The DEFINE model[86] combines demand-driven economic analysis with a detailed financial sector and climate analysis. GINFORS[87] provides highly disaggregated sectoral detail, although less on finance and technology. The DSK model[88–92] integrates innovation scholarship with demand-driven economics. The GEM-E3-FIT model is a computable general equilibrium model that has incorporated aspects beyond traditional equilibrium analysis, for example on innovation and the financial sector[93,94]. Agent-based models (ABMs) of labour markets enable the user to explore the ability of workers to transition between occuppations[95]. Other ABMs have been used to explore dynamics within carbon markets[67]. That these models have been developed with an aim to inform policymakers over a variety of questions, rather than just input scenarios for IPCC reports, explains their wider range of analytical policy options. Most of these models are not part of the database of 1,202 scenarios vetted by the IPCC and, where they are included, their capacity to assess policy instruments remains underused.

An illustrative example of an alternative climate-economy model

We provide an example of policy analysis modelling that goes beyond carbon pricing, based on the combined E3ME-FTT community modelling framework (see Methods). The model does not address all the concerns raised in this paper, which would require a large ensemble of diverse models. However, it has a long track record in informing a wide range of granular policy proposals for the European Commission, national governments and international organisations. Ten E3ME scenarios are available within the AR6 database, but are not included in the climate assessment due to limited reporting of non-CO_2 emissions (IPCC, 2022).

We consider an ambitious basket of policies that reduces CO_2 emissions to levels that are consistent with a 1.5°C peaking emission target. The full set of policies, described further in the Supplementary Information, are:

- Ambitious energy efficiency mandates.
- Carbon prices that are set at national level, linearly increasing to meet $250/t$CO_2$ in real terms by 2050.
- Feed-in-tariffs and subsidies for renewable electricity generation, accompanied by a ban on building new coal electricity plants.
- Subsidies for electric vehicles, higher fuel taxes and the enforced phase-out of inefficient vehicles.
- Incentives to electrify household heating.
- Public procurement to 'kick-start' the take-up of new technologies in key emitting sectors.
- Biofuel mandates for transport sectors that cannot electrify (e.g. aviation).
- Mandates to decarbonize production in State Owned Enterprises mainly in East and South East Asia.

We consider these policies important to achieving the 1.5°C target, but we do not suggest that this portfolio is optimal, unique

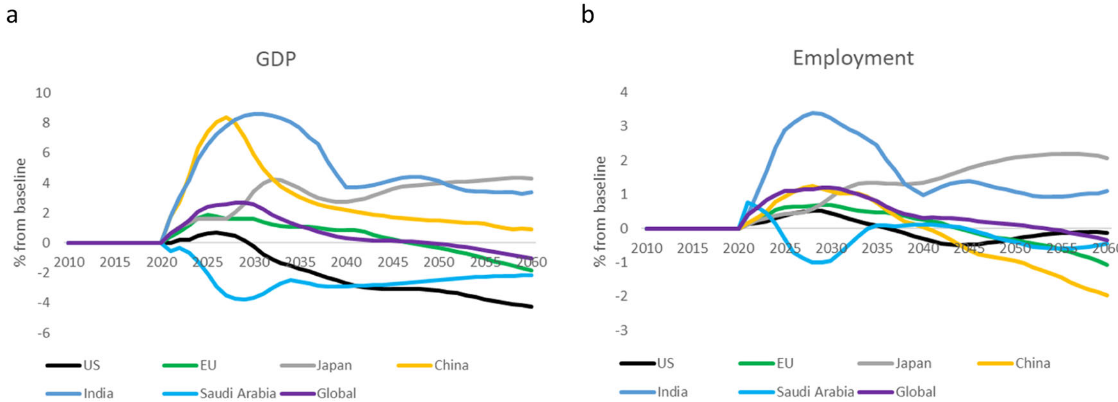

Fig. 2 Net impacts on GDP and employment, selected regions, % from baseline. **a** In a scenario with deep decarbonisation, GDP may increase or decrease in different countries, with the impacts not necessarily constant over time. **b** Employment effects also vary between countries and over time, depending on the economic responses to the modelled policies.

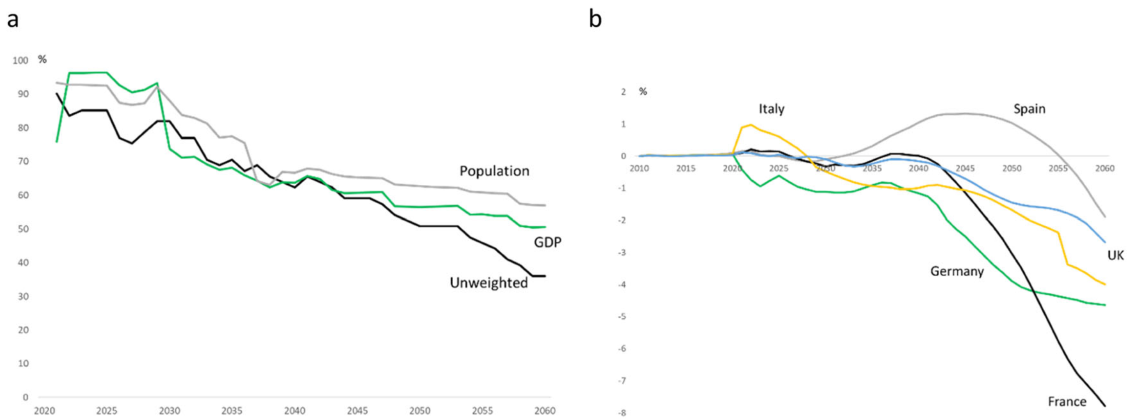

Fig. 3 Distributional impacts between and within countries, % from baseline. **a** The proportion of regions in the E3ME model with positive GDP impacts in the 1.5°C scenario, unweighted and weighted by GDP and population. More than half of the countries modelled see positive impacts up to the 2040s. **b** Impacts on real incomes of the 1.5°C scenario policies, for the lowest earning quintile in each example European country, % from baseline. The impacts may vary substantially between countries.

or necessarily better than others. The modelled scenario assumes immediate implementation (which is uncertain but necessary to meet the target) and CO_2 emissions decline broadly linearly to reach net-zero by 2055. The fiscal policy choice is made that any net public revenues from carbon taxes minus public investment costs and lost fossil fuel royalties are balanced by changes in income and labour tax rates.

Example results for key issues

A policy impact assessment ideally assesses outcomes for a range of metrics, because the information basis upon which policy decisions are taken can vary widely between places and contexts. Here, we present results for five indicators/issues that are often of interest to policymakers: GDP, employment, structural change, distributional effects and policy interaction. Results are compared to a baseline case that has no additional policies beyond those already implemented in 2022 with no further strengthening.

Figure 2 shows the net impact of the scenario on GDP and employment. There is an immediate stimulus boost to global GDP that gradually declines over the projection period. Notably, the boost occurs in the timeframe that policymakers are typically most interested in.

The pattern of results is explained in[14,80], and a discussion that was addressed in AR6 Chapter 15 on whether models are demand-driven or supply driven, how the finance of low-carbon spending is modelled, and whether crowding-out is assumed to take place. Here, the scenario demands rapid investment in renewables and energy efficiency. Much of this investment is financed by private debt, which boosts spending power and creates additional demand in the economy (as discussed in e.g. ref. [96,97]). Over time, however, debts are mostly repaid, which slows down spending. The accelerated growth of GDP therefore declines again when the stimulus ends. Whether a country sees a rising or declining GDP essentially depends on the relative importance, in terms of employment and output, of brown versus green sectors (whether there is more economic activity to gain than to lose in the transition).

There remain important limitations in the modelling. It does not represent explicitly many of the elements that drive financial markets and the cost of capital (e.g. country risk, net international investment positions, currency). Nonetheless, the results are more informative than assuming strictly positive costs. There are other models that go into additional financial detail, again not included in the scenario generation process of the IPCC.

One indicator frequently perceived as the most important by policymakers is employment, which falls outside the IPCC scenario exercise. Figure 2 shows that employment patterns mirror those for GDP, although with lagged effects because the labour market can be slow to adjust.

These results can be disaggregated by sector and occupation, which informs a key potential transition challenge, structural change and the Just Transition. At present E3ME-FTT does not incorporate how easy it may be for workers to move between

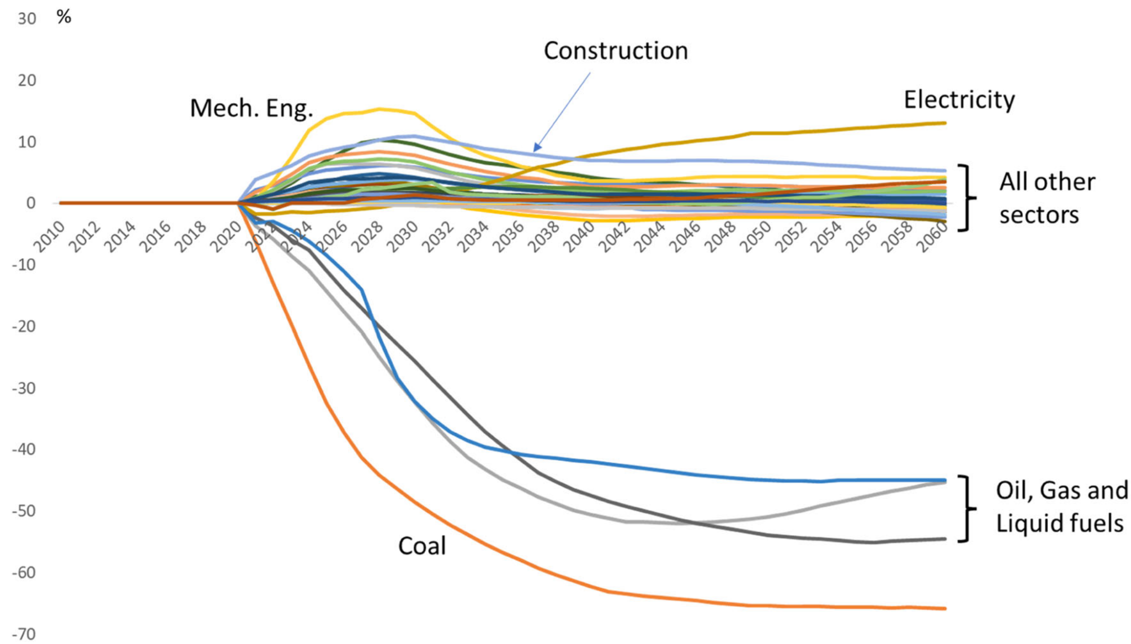

Fig. 4 Impacts on sectoral production, % from baseline. Although there are large production losses in the energy sectors, most other economic sectors see small increases in production. Construction and engineering stand out in periods when low-carbon investment is most intensive.

occupations in the transition[95]. AR6 and earlier ARs do in places touch upon the Just Transition debate (see for instance AR6 Chapter 3 Section 3.6.4). However, it remains a question for policymakers why this key debate is not addressed by the scenario process.

Distributional effects could occur either between or within countries. If we approximate welfare changes using changes in GDP, then the modelling suggests that 50 of the 61 regions could benefit from a low-carbon transition by 2030 (31 by 2050), shown in Fig. 3. In reality, the range of potential regrets for policymakers goes much beyond GDP.

The modern economy is in a permanent state of structural change, which will be accelerated in the transition[98,99]. For policymakers, this represents a key challenge because it creates both new resources (e.g. energy or mineral inputs, adequately trained workers) and the potential for stranded assets and unsuitably skilled workers. However, this detail is lacking from the IPCC scenarios database.

Figure 4 shows disaggregated sectoral trends from the model results, to offer a better understanding of how the economy is transformed. Higher investment levels drive growth in the mechanical engineering and construction sectors early on. The major losses are in the fossil energy sector. Energy-intensive manufacturing wins and loses at the same time because it must supply materials that are required for the transition while facing higher costs that dampen demand. The model shows that, while the economic losses are concentrated in a few carbon-intensive sectors, the gains are distributed across many sectors.

The potential for policy interactions stresses the importance of considering real-world policies, rather than just carbon prices. Policies may conflict if they have different objectives. The complementary effects may also be more important. The model observes, for instance, that the carbon price equivalent of certain regulations is effectively infinite and that they cannot be replaced by a pricing measure. Different policies are also needed at each stage of the innovation cycle[13] and a mix of policies is required to develop new technological capabilities and to manage better technological-social interactions. For example, to induce a change in behaviour, consumers must both know about alternatives and be incentivised to pursue them.

The FTT model has been used to estimate policy combinations that synergise to accelerate the transition in passenger vehicle fleets faster than the sum of the effectiveness of the individual policies[100]. The authors find that carbon pricing has little to no effectiveness in vehicle markets, while early regulatory measures combined with electric vehicle (EV) subsidies achieve the fastest emissions reductions.

DISCUSSION

Following the full publication of AR6, the IPCC now lies at a crossroad. IPCC AR6 chairman Hoesung Lee suggested that it should become solution-oriented. However, our assessment suggests that this goal remains some way off. And should the IPCC re-orient itself towards solutions, if it seeks to remain policy agnostic? The physical sciences report currently makes the case well for addressing climate change, without need for the mitigation report. A movement towards solutions would inevitably require an introduction, however minor, of some explicit policy/political subjectivity, rather than implicit, as well as faster, reporting rates. Policymakers urgently need advice on effective policy design, and the IPCC would need to provide this without adopting a strong advocacy position.

To increase relevance with policymakers, we suggest that the IPCC's scenario process should address four major hindrances in its current structure, particularly in relation to climate change mitigation policy responses:

1. The IPCC's scenario process is policy prescriptive despite aiming not to be. This emerges from its adherence to the principle to be 'neutral, policy-relevant but not policy-prescriptive', but this makes it promote by default an implicit simplistic policy prescription for carbon pricing alone. This positioning impedes its ability to inform practical climate policy design, because it effectively suggests that none is needed.
2. The IPCC's scenario process seeks to set standardised climate policy narratives rather than address the emergent

heterogeneous practical needs of the policy community worldwide in addressing climate change.

3. The needs of the policy community evolve and do not necessarily follow the narratives of the IPCC's scenario analysis. The scenario analysis risks therefore being seen as academic and impractical.
4. The IPCC process is discrete rather than continuous, offering insights only twice per decade, reviewing information that may be outdated, based on a timescale that is likely more suitable for climatology than policy analysis.

The capacity needs of policymakers in the realm of climate change is a reality that international institutions must face. Helsinki Principle 2 of the Coalition of Finance Ministers for Climate Action states the goal of sharing capacity to 'promote collective understanding of policies and practices for climate action'. This official statement offers a clear sign that finance ministers require help in addressing climate change in their core functions, particularly in developing countries. Other government departments involved in business, transport, energy, trade and environmental management are likely to be in the same position. Building capacity for practical climate policymaking is one of the most important practical contributions that the global community of climate experts could provide to help in the fight against climate change. The IPCC and its scenario process could, in a new iteration, address this need, but this may require rethinking much of the IPCC's WGIII scenario process.

The IPCC could help to meet this need by better-addressing policy issues. It may even need to do so if it is to stay relevant within the policy community. However, to offer the required support, the IPCC would need to adapt its quantitative analytics to address the real granularity of climate policy, adopting an economic plurality approach, and step back from normative axioms over global uniform carbon pricing to trigger emission reductions. A cross-disciplinary special report on real-world policy options to reduce emissions could make a clear statement that this is the route the IPCC plans to take. It could motivate the development of a new set of modelling tools that could then be used in wider policy assessment.

METHODS

Review of the IPCC process

The qualitative analysis is based primarily on published literature, of which the starting point is the IPCC's Assessment Reports and Special Reports. Supplementary literature is focused on the policymaking process and the role of large-scale modelling in supporting the policy process. Publications that were referenced from within the IPCC reports were taken first, followed by references in these publications. Finally more recent additions to the literature were added through more general searches.

The E3ME model

The E3ME model[53,101] is a demand-driven macro-econometric model in which behavioural relationships are estimated based on historical time-series data. The model is like a multiplier analysis that includes price-based relationships and supply-side constraints[102]. It does not make assumptions about economic equilibrium, nor utility maximisation, and in fact does not use an optimisation solver at all; instead, human behaviour is assumed to follow historical patterns (which is also a limiting factor in a large-scale transition). The level of production, determined by demand, is understood to lie below maximum productive capacity, even in the long run. Economic evolution is path-dependent and does not revert to a mean in the long run. Investment is determined independently from savings, the balance originating from debt creation (or repayment), meaning that climate investment does not automatically 'crowd out' other useful expenditure, although the model would benefit from explicit inclusion of the financial sector. Unemployment (including both voluntary and involuntary) is determined as the difference between labour supply and demand. E3ME splits the world into 70 regions, with 44 economic sectors in each one.

The FTT (Future Technology Transformation[103]) family of models assesses the path of technology diffusion, making projections on the basis of observed trends. The model solves from the perspective of the investor, who has a choice of technologies (e.g. different types of power generators). The investor is influenced by price but also by how well established competing technologies are, reproducing the observed S-curve of diffusion. The approach combines a wide range of technology options with a bounded rational representation of human decision-making for the power sector[104], personal transport[105], household heating[106] and the steel sector[107]. It features an asset-by-asset representation of oil and gas markets.

Of critical significance here is that the E3ME-FTT framework offers the user a wide range of policy options, with particular focus on non-pricing mechanisms, and a wide range of outcome metrics demanded by policy-makers[104–107].

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

DATA AVAILABILITY

The data presented in this article are available upon request.

CODE AVAILABILITY

Enquiries about code for the E3ME model should be made to Cambridge Econometrics.

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AUTHOR CONTRIBUTIONS

H.P. coordinated production. H.P., J.F.M. and T.S.B. developed the paper structure and led on initial writing. P.S. and S.S. provided specific inputs and reviewed content.

COMPETING INTERESTS

The authors declare no competing interests but the following Competing Financial Interests. TSB is a director and part owner of Cambridge Econometrics. TSB is a trustee of the Cambridge Trust for New Thinking in Economics, the charitable trust that is majority owner in Cambridge Econometrics.

ADDITIONAL INFORMATION

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