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Masters of the machinery: The politics of economic modelling within European Union energy policy

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ABSTRACT

Economic modelling plays a major role in the development, justification and evaluation of energy policies. However, there has been little investigation of how political dynamics systematically influence these models' development and outputs, or the implications for energy strategies, targets and interventions. Using in-depth interviews with 24 European modellers and policyworkers, we illuminate the politics of economic modelling within European Union (EU) energy policymaking, focusing on dynamics of contestation, differentiated influence and power relations within models' a) framing of questions and problems; b) framing of scenarios and solutions; c) structural assumptions and d) definition of quantitative data inputs. We then consider deeper questions of e) access and exclusion, showing how modelling is used to silence critical voices and reinforce incumbent interests. We argue that understanding this politics of modelling is crucial to the implementation of sustainable energy transitions. We conclude with recommendations for researchers and policyworkers seeking to promote the use of alternative/innovative models in energy policy (within and beyond the EU), centring on reflexivity; recognition; and relationship-building. Developing multi-sectoral 'communities of practice' around innovative modelling approaches is vital in challenging a vicious circle of evidence and policy that legitimises business-as-usual in a dangerously warming world.

1. Introduction

Computer models of various kinds are deeply embedded within energy policymaking, providing representations of many aspects of energy transitions, from future energy supply and demand, and technological change, to the costs and benefits of different climate policy scenarios. Economic models, such as the Price-Induced Market Equilibrium System (PRIMES), have played a major role in European Union (EU) energy policy over several decades, and remain influential; for example, informing recent policy scenarios for the European Green Deal and EU Climate Target Plan impact assessment.[2] The reliance on economic computer models in creating energy policy evidence within formal assessment and evaluation procedures of the European Commission (EC) – as well as within the forecasting and planning of industry actors (such as grid operators[3]) and the advocacy work of non-governmental organisations (NGOs) (Teske et al., 2011) – remains largely unquestioned in mainstream energy policy communities.

However, in recent decades, critical social science research has challenged the assumption that models represent a knowledge panacea for (energy) policymaking. Notably, the idea of a simple evidence-policy cycle,[4] has been widely critiqued, with researchers highlighting diverse and complex ways in which evidence and policy shape each other, including through feedback mechanisms (Jordan and Moore, 2020). Such debates matter for energy transitions, and a sizeable political science literature explores the politics of evidence within energy/climate policy. This includes recent work on the EU, for example, on: how (re) framing energy efficiency has consolidated EU authority (Dupont, 2020); the politics of policy-monitoring in relation to the European Green Deal (Schoenefeld, 2021) and power-relations inherent in notion of 'valid' evidence (Royston and Foulds, 2021). This work suggests that

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[2] As stated on the European Commission website at Modelling tools for EU analysis (europa.eu) [viewed 25th Aug 2022].
[3] E.g The Ten Year Development Plans produced by Energy Network Transmission System Operators; see: Planning the future grid - TYNDP (entsoe.eu) [viewed 25th Aug 2022].
[4] See for example: https://www.egu.eu/policy/basics/cycle/[viewed 25th Aug 2022].

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evidence in energy policy is always political.

If models are tools for making evidence, then it follows that models are political as well as scientific objects (Silvast et al., 2020). By politics, we refer to cross-actor dynamics relating to processes of exclusion, contestations, power relations, incumbents and differentiated influences (e.g. Dupont, 2020; Herranz-Surrallés, 2014; Huitema et al., 2018), all of which shape, and are shaped by, the development, maintenance and evaluation of models. Notably, we differentiate politics from policy (which refers to codified outputs of political negotiation, such as rules, laws, standards and protocols). Politics is not just done within official policy institutions, but involves evolving relationships between diverse communities and institutions, including modelling communities. Such politics can be obvious (e.g. whether a model is private/public) or subtle (e.g. those who have good data also tend to have vested interests).

As early as 1986, Midttun and Baumgartner argued that models are used "*to compete for cognitive and methodological hegemony over the definition of the energy future*" (Midttun and Baumgartner, 1986; 241). Their early analysis of the politics of energy forecasting provides a key inspiration for this paper. However, while some work since then has examined how *policy* shapes models (e.g. Süsser et al., 2021), we assert that too little attention has been given to how particular *political* dynamics shape models' development, design and outputs, including the implications for energy policy targets and interventions. This knowledge gap is critical to energy transitions, because at present politically-structured evidence-making retrenches dominant interests and business-as-usual. Aiming to further the use of modelling that supports (rather than hinders) energy transitions, this paper therefore identifies specific political dynamics that steer model development and outputs, and their implications for energy policy. We argue that efforts to improve model-use need this detailed and realistic understanding, to ensure that modelling and policy communities can respond effectively to political challenges. It is not enough to simply produce a 'better' model and hope it gets adopted. As such, the target readership for this paper is academic/expert communities involved in developing and using economic models for energy policymaking. Whilst the core of this paper uses empirical data to interrogate processes that reproduce the status quo, we also offer recommendations on action for change.

We note the following scope and boundaries of the paper. First, there are many different types of models and modelling approaches (Pasqualino and Jones, 2020), with different academic fields, goals and structural assumptions (Li et al., 2015; Pfenninger et al., 2014). We primarily focus here on energy economic models, especially those currently used by the EU. Throughout this paper, we will use the term 'models' as shorthand for 'economic computer models that inform energy policy'. Our findings are mostly concerned with the currently-dominant types of model (largely Computational General Equilibrium (CGE) models), and we recognise that other modelling approaches may already be responding to the problems we highlight. For example, alternative approaches include econometric, system dynamics, agent-based models, and Stock-Flow Consistent models, as discussed by Hafner et al. (2020). Further, we focus specifically on the EU, albeit with consideration of findings' relevance beyond these governance/institutional contexts. The EU serves as an interesting context for the exploration of political dynamics within evidence-making, because it is sometimes described as an exemplar of post-political governance (Garsten and Jacobsson, 2011). As Garsten and Jacobsson suggest, this does not imply an absence of politics, but rather "*unequal power relations tend to be rendered invisible*" (2011; 421) and conflicts are not openly articulated, but continued through "*other routes*" (op. cit.; 422). Our study aims to shed light on some of these invisible workings. As discussed in Section 5, recent work (Grubb et al., 2021; Mercure et al., 2021) already suggests that some findings are relevant in other contexts. Finally, we note that models are just one form of evidence used in energy policy, but given their prevalence, influence, and resourcing, it is worthwhile to focus in-depth attention on this field.

This paper is structured as follows: we begin with a brief review of literature from the Social Sciences and Humanities (SSH) that informs our investigation (Section 2). We then detail our methodological approach (Section 3). Based on the findings of our thematic analysis, the core of the paper discusses five interconnected themes of politics in energy modelling, showing how political dynamics reproduce dominant energy policy interests (Section 4). Specifically, this section considers themes of models' a) framing of questions and problems; b) framing of scenarios and solutions; c) structural assumptions and d) definition of quantitative data inputs. We then consider deeper questions of e) access and exclusion. We finish with recommendations for modellers and those who wish to promote alternative and innovative models, in terms of reflexivity; recognition; and relationship-building (Section 5).

2. Literature review: the politics of models in energy policymaking

Models play various roles within policymaking, including shaping debates and bringing together stakeholders. For example, van Dooren and Noordegraaf (2020) discuss how science may be 'staged'; i.e. brought to the forefront of public/policy debate (Hajer, 2005), with models playing key roles in this. Meanwhile, Silvast and Foulds consider how models can "*enable co-operation and coordination [between] SSH scholars, Engineers, Mathematicians, policymakers, and various other actors*" (Silvast and Foulds, 2022; 42–43). Both Silvast et al. (2020) and Taylor et al. (2014) suggest that the MARKAL (Market Allocation) energy model in the UK gained influence by bringing together communities in this way. However, models' roles can go far beyond enabling communication and co-operation.

Literature has established that models can be 'mobilised' in various ways. In a comprehensive analysis, published in 1986, but highly-relevant to present-day contexts, Midttun and Baumgartner argue that modelling can "*define reality, shape political debates, and … legitimate political decisions*" (Midttun and Baumgartner, 1986; 224). They highlight a range of political dynamics in energy modelling, including: politically-driven selection of variables/data; use of forecasts to legitimise political decisions; lack of transparency regarding assumptions; the tendency of model-commissioners to have vested interests in energy systems; and the use of modelling to silence critical questions and shift debate from the political to the technical sphere. Aykut et al. (2019) support this idea, arguing that model-based forecasting can be used to depoliticise policymaking and exclude 'non-expert' voices from debates (Mahajan, 2008; Miller, 2004). Aykut's (2019) historical study of competing "*predictive policy assemblages*" (Aykut, 2019; 13) within German and French energy policy provides fascinating examples of the use of technical expertise (including the complex coding involved in modelling) to silence questions from policymakers.

Research also draws attention to the importance of scenario-definition within models; for example, Anderson (in Anderson and Jewell, 2019) critiques Integrated Assessment Models (computer simulations that generate pathways for climate-change mitigation), arguing that modellers produce scenarios that they believe to be politically-palatable, and thus under-estimate what can and should be done. Similarly, Carrington and Stephenson (2018) examine 26 recent global energy scenarios and find that they all underestimate solar photovoltaic growth, noting that the influential scenarios of the International Energy Agency (IEA) are amongst the more conservative. This matters for energy transitions because "*low scenario projections such as the IEA's are likely to deter investments in innovation and development that would otherwise occur*" (Carrington and Stephenson, 2018; 2214). Modelling can also be a tool within wider negotiations of power; for example, of EU authority relative to member states (Schoenefeld, 2021).

However, there remains a tendency within energy SSH research on the EU to focus on modelling as informing official processes, governmental institutions and published outputs, rather than attempting to explore the multi-actor contestations 'behind the scenes'. For example, in Schoenefeld's aforementioned (2021) paper, 'politics' mainly

concerns such matters as the relative influence of monitoring agencies, with non-governmental actors receiving relatively little attention, and corporate/industrial actors not mentioned. Schoenefeld states (regarding the European Green Deal policy package) that policy monitoring might become either a "*paper tiger*" (in other words, an ineffectual process) or a crucial institutional condition steering a low-carbon transition (Schoenefeld, 2021; 376). The assumption here is that if monitoring has effects, these will be positive, and that all actors involved share an agenda around low-carbon transitions. Similarly, Süsser et al.'s valuable analysis (2021) shows that energy policy agendas inform modelling evidence, but focuses mostly on policymakers' influence on the models they commission, rather than on the wider multi-actor political dynamics and power relations inherent in the development and use of modelling. This is also notable in UK research; e.g. a recent policy brief by the UK Energy Research Council (UKERC) suggests an apolitical view that the role of models is to "support" or "*underpin*" (Li and Strachan, 2021; 9) choices by decision-makers who are "*constantly seeking the best modelling insights*" (op. cit.; 10). To date, there has been little exploration of how energy-related modelling may reinforce particular agendas, and close down alternative imaginaries of the future (Adams et al., 2009; Jasanoff, 2010).

Another point arising from the literature is that models can be mobilised by less dominant actors. Reviewing the political history of energy modelling, Midttun and Baumgartner draw attention to the role of alternative forecasts provided by the environmental movement, including their innovative use of value-based, bottom-up and backcasting approaches. *"By invading the field of forecasting, the alternative movements gained access to a strategic political tool in a scientifically oriented society"* (Midttun and Baumgartner, 1986; 230). Tellingly, military metaphors of this kind are a recurring theme throughout the literature, and indeed within the findings presented below. For example, Yanis Varoufakis has referred to a "*War of the Models*" (Varoufakis, 2018; 603) within economic policy. Aykut (2019) reports that in the 1970s, activist groups used new modelling techniques to propose alternative future-visions, enabling new forms of political intervention. Interestingly, Schoenefeld notes that "*the EU has often sought to depoliticise monitoring and avoid, for example, ranking countries to enable naming and shaming*" (Schoenefeld, 2021; 375); in contrast, NGOs often adopt exactly this ranking approach as a tool for political pressure; e.g. Guertler et al. (2015). However, there has been little work on the role of civil society advocacy groups or NGOs in regard to modelling for energy policy, especially in the decades since the 1970s. Aykut et al. (2019) recently highlighted the

> "need to gain a better understanding of the diversity of ways of forging futures in policy [and] the variety of actors involved … spanning public agencies and global governance bodies, scientific institutes and think tanks, as well as firms and civil society organisations" (Aykut et al., 2019; 4).

In summary, our review of literature suggests, first, an unmet need for attention to **the specific processes through which political dynamics play out** within the development and use of models in present-day energy policy. Secondly, our review suggests knowledge gaps in terms of the **implications of these political dynamics**; the impacts that these modelling decisions have on energy policy and transitions. Finally, in this paper, we are explicitly interested in informing a shift towards innovative and alternative models. We therefore address a third knowledge gap, regarding **the role of non-dominant actors, specifically NGOs, in challenging established modelling-and-policy regimes**. These three knowledge gaps inform our methods and analysis, as outlined in the following sections.

3. Methods

3.1. Data collection and participants

Our empirical approach focused on the experiences and understandings of policyworkers and modellers participating in EU energy policymaking. We intentionally targeted policyworkers in a wide sense (Colebatch et al., 2012), recognising that policies are not only 'made' by those in traditional policymaker positions (e.g. civil servants, elected politicians). The development and implementation of policy programmes are also shaped by an array of actors including (but not limited to) industry bodies and NGOs such as policy think-tanks and charities. Similarly, we recruited a range of energy modellers involved in different EU-focused economic models that the EC uses/funds when negotiating its energy (and climate) policies.

We undertook 24 virtual semi-structured interviews, with six EC policyworkers; seven NGO policyworkers and eleven modellers. EC interview participants included representation from the following Directorates-General (DGs): DG Energy (DG ENER) (x2); DG Climate (DG CLIMA); DG Environment (DG ENV); DG Research and Innovation (DG RTD); and DG Economic and Financial Affairs (DG ECFIN). NGO organisations are not named because, as these organisations have much smaller teams, there would be a risk to participant anonymity. The modellers were based in diverse organisations, including research institutes, private companies and public institutions. Unfortunately, no modellers working on PRIMES accepted our invitation to participate. Interview protocols covered topics of participants' current role and engagement with models; their understanding of different models' advantages/disadvantages; positive and negative experiences of model-policy interactions; communities and cultures; and possible future improvements. Interviews were conducted one-to-one. In the data presented below, participants are labelled with their stakeholder type (NGO for NGO policyworkers; EU for EU policyworkers; M for modellers) and a participant number.

3.2. Analysis methods

All transcripts were professionally transcribed, and analysed via thematic coding using Nvivo software. Coding was conducted by a single analyst, with regular meetings with team members to discuss the emerging framework. An initial inductive phase involved coding six transcripts. Two transcripts were selected at random from each of the three participant categories. Coding was guided by the broad question: what political dynamics play out in the development and use of models? This coding generated six broad initial themes, around: *Scoping; Architecture; Inputs and Scenarios; Access and Exclusion; Communication of Outputs;* and *Model Ecosystem and Trajectories.*

This was followed by a more deductive coding phase, in which all 24

Table 1
Themes identified in analysis, and their scopes.

The politics of …	Scope	Subsection
Framing problems and questions	The questions (not) asked; construction of problems and the agendas underlying these	4.2
Framing solutions and scenarios	The scenarios (not) considered; construction of solutions and the agendas underlying these	4.3
Designing structural assumptions	Assumptions that structure models' design, architecture and mechanisms (as opposed to numerical data inputs)	4.4
Defining quantitative inputs	Specific numerical values assigned to variables (as opposed to structural aspects).	4.5
Underlying issues of access and exclusion	Issues of ownership, transparency and capacity that permeate the design and use of models	4.6

transcripts were analysed and these themes iteratively developed. This refinement resulted in five final themes (see Table 1). Notably, *Scenarios* was separated from *Inputs*, with the creation of a distinct theme of *Framing Scenarios and Solutions*. The *Architecture* theme was relabelled *Structural Assumptions*. Additionally, the three themes of *Access and Exclusion; Communication of Outputs;* and *Model Ecosystem and Trajectories* were merged into a single theme, named *Access and Exclusion*. This theme is substantively different to the other four, which relate directly to specific practices or phases within the development of a model. In contrast, this last theme zooms out to cover cross-cutting issues of access and exclusion that emerge across the wider 'landscape' of modelling within energy policy. These five themes structure Section 4.

The majority of data presented here is from the NGO participants, with less from the EU policyworkers, and relatively little from the modellers. Future publications from our study will focus more on these latter groups. While all transcripts received equal attention in the analysis process, the NGO transcripts provided much more content relevant to the specific research focus on political dynamics of modelling. For this aim, the NGO data is especially valuable, as it offers insights from those with a good understanding of the processes involved (as active players within the policy process), but also the capacity to provide critical views on the status quo. It is of course crucial to remember that all participants bring their own agendas, and that the accounts presented below represent personal experiences and opinions. Nonetheless, the perspective provided by these stakeholders (rarely engaged in past work in this field) sheds new light on the messy contestations within EU energy policymaking, that can sometimes be obscured by the apparent "post-political" consensus.

4. Findings and discussion

4.1. Introduction

Analysis revealed that political dynamics shape models and their outcomes in diverse ways, which can be understood within five main themes (Table 1). Each theme represents an area of contestation, infused with power relations, often serving to reinforce dominant interests and agendas. This section (4) is structured around these inter-related aspects of the evidence-making process, and thus comprises five subsections. The scope of each subsection is presented in Table 1. In brief, subsection 4.2 focuses on the framing of problems and questions within model development; subsection 4.3 then builds on this to consider the framing of scenarios and solutions. In subsection 4.4 we examine the design of models' structural assumptions, and in subsection 4.5 we consider the definition of quantitative inputs. The final subsection (4.6) zooms out to address underlying issues of access and exclusion that recur throughout the process of model design, implementation and use.

For each theme, the section discusses ways these dynamics play out in practice; and their outcomes – both direct outputs, and longer-term outcomes such as reproducing dominant interests. Throughout this section, where bold emphasis is shown in quotes, this is added.

4.2. The politics of framing problems and questions

This subsection is concerned with the formulation of modelling questions and problems, and the fundamental assumptions embedded in model design at this early stage. These decisions are crucial because they feed into all other aspects of model design. One modeller explained the importance of question framing:

> *"You start actually with* ***questions*** *you want to answer using this model. So that also gives you the* ***scope*** *that tells you what you have to look at, which* ***interactions*** *you have to take into account, which* ***elements of the real world*** *you have to take into account into the model, and where the* ***boundaries of your systems*** *are."* (M9)

NGO policyworkers (e.g. NGO11, NGO7) stressed that these decisions are not neutral, for example:

> *"Impact Assessments are inherently political … if you look into the* ***assumptions and what were the questions asked****, it gives you a lot about the belief system of the person who has ordered it."* (NGO7)

This phase of model development is crucial in terms of what models do/don't 'see'. For example, Schoenefeld (2021) highlights the question of whether only territorial greenhouse gas emissions (not the full footprint) are included within the scope of a model. In our findings, the definition of which impacts to include emerged as an especially important aspect of framing questions. One EU policyworker gave the example of evaluations that deliberately do not measure certain impacts (such as air quality), saying, "*this is something that is done by purpose, because it could be very challenging to have bad results for the political level, for our political masters*" (EU1). They also explained that Impact Assessments have to be carried out quickly, by non-experts, so social impacts are often not integrated well, a point echoed by NGO9 regarding inadequate accounting for differentiated impacts on different groups. NGO10 explained that in 2014 the Commission only calculated the benefits of energy efficiency in terms of energy import cost saving, resulting in low policy ambitions. Since 2018, they have included a range of benefits, with air quality especially affecting the outcomes, alongside health costs. Prior to this, inaction used to look very cheap and action very expensive in modelling (NGO10). Another major issue is models' treatment of costs of climate change damage which have often been neglected (NGO8, NGO6, NGO12, NGO10), as also noted by Hafner et al. (2020).

Interviews highlighted the importance of decisions around whether to (in one participant's words) "*backcast rather than forecast*" (NGO6). Some models are designed to address the problem of achieving a pre-set goal (an ex-post approach), while others adopt a projection (ex-ante) approach to exploring future outcomes. If an end goal is chosen, decisions must be made: what is the metric, what is the value, and what is the timescale? When models are commissioned by policy actors (as opposed to research-led modelling, such as that funded through Horizon Europe) these decisions are likely to be made by the policyworkers and presented to the modellers. However, there may be a reproducing cycle in which these kinds of models reinforce particular policy trajectories. These decisions about the framing of problems and questions are bound up with policy developments. For example, an NGO policyworker explained that the Paris Agreement represented a "*big change*" (NGO6), since it enabled NGO modelling work to backcast from a target of net zero emissions by 2050. This helped NGOs advocate for strong, immediate action on climate change (See also Aykut's (2019) discussion of the important emergence of "bottom-up" models during the 1970s in re-imagining the forecasting of demand.).

More fundamentally, this scoping phase may embed politically-loaded assumptions, such as centring of economic growth. NGO12 said a key problem was "*obviously the complete focus on GDP [Gross Domestic Product] … being the true indicator of the human population's well-being*", while NGO6 worked on bringing in new impacts such as equality and diversity, to create models that "*flipped the logic*" of "*growth of the economy as the first goal*" and put environmental goals first.

This issue of goals raises a bigger issue: the use of modelling to justify or demonstrate a pre-set outcome. Some NGO participants had deliberately commissioned modelling work to challenge conventional thinking:

> *"The way we critique the Commission's work is by showing that there is another way …. There are more levers than what you think there are."* (NGO7)

> *"We wanted to challenge the political thinking …* ***using alternative models to develop evidence that showed the outcomes that we believed to be true.****"* (NGO6)

One modeller similarly wanted their model to show the benefits of

post-growth policies (M4). Such normative goals directly translate into models' scoping and question-framing. Fundamentally, NGO participants were clear about the EU and other actors (including themselves) using modelling to serve political goals:

> *"I've never ever seen policy based on evidence. What you do is* ***you pick what you think is the necessary level of ambition and then you go off and you justify it*** *… [The Commission's approach] was all about constraining the modelling to justify a political choice."* (NGO10)

> *"The thing about all these stakeholders going around commissioning reports, which we do, and the other side does, is … we're trying to get a published data that shows what we think we know already."* (NGO9)

Similarly, an EU participant (EU4) explained that biofuel policy agendas at the end of the 2000s were based "*more on a whim than on the basis of good factual evidence";* by the time evidence on impacts had been established, the policy objectives were already fixed. We return to this issue of temporality in Section 5.

Some modellers supported this view; one (M7) said that model outputs are sometimes used to give policymakers confidence in a policy they already have planned, while another went further:

> *"What is important for the policymaker is that they have* ***modelling results which can be some justification for them for the policies …*** *I am not sure if they are really interested in how these results are obtained and if they are reliable or not."* (M1)

However, other modellers described their models as ultimately neutral tools for assessing options (M6; M5). The following sections delve deeper into the specific ways in which model design is mobilised by various actors to achieve political goals.

4.3. The politics of framing scenarios and solutions

This subsection concerns the types of futures and policy options that are 'seen' by models. In scenario-based models, the definition of specific scenarios is of course a critical decision. However, all models involve some definition of solutions, which inevitably shapes their outputs:

> *"When you set up a model … you* ***limit the answers the model can give you.*** *Because things that are not implemented in the model cannot be part of the solution*." (M9)

Several modellers highlighted the importance of designing scenarios/solutions to meet policymakers' needs (e.g. M8; M1; M3). Participants stressed the nature of scenarios as uncertain, political and requiring careful design and communication (e.g. M9), especially when disruptive or radical future policies are modelled (M4). The definition of baseline scenarios is also a matter of judgement (EU4).

Target definition for scenarios is highly political. For example, NGO11 said that, during the Impact Assessment for the 2030 climate target, the EC:

> *"… did not want to check a higher target than 55% for political reasons … if the scenario does not include any option, any pathway towards 65%, then ….****you configure the entire debate and you steer it*** *… some more progressive national governments … asked the Commission to model also a 100% renewable energy scenario. But … they went on with rather conservative and more fossil fuel-based scenarios."* (NGO11)

Another example relates to a model produced by the International Energy Agency (IEA), which was critiqued by one participant (NGO7) as containing only one scenario compatible with the emissions reductions set out in the Paris Agreement; another described the IEA as promoting "*incumbent fossil fuel interests*" (NGO6). This echoes Anderson's finding (in Anderson and Jewell, 2019) around limited climate scenarios, as well as Midttun and Baumgartner's observations on the "*scenario game*" (Midttun and Baumgartner, 1986; 233) in French nuclear policy, in which scenarios based on energy conservation were *"never seriously modelled"* by state agencies (1986; 233) because the political goal was electricity capacity expansion.

Four NGO participants (NGO8, NGO9, NGO11, NGO12) highlighted scenario-politics in grid-planning, especially through the influential Ten Year Development Plans produced by grid operators. One participant argued that grid operators' scenarios are:

> *"at the heart of the decision-making process …* ***if you're in charge of offering the menu … They [policymakers] choose what they want off the menu, but you're the one writing the menu and that gives you a huge amount of power."*** (NGO12)

Another claimed that:

> *"****The gas side, in particular, still uses the scenario building as a tool for their very specific particular lobbying aims*** *…* ***they are not keen on calculating these kinds of [gas phase-out] scenarios*** *….You have a lot of very optimistic assumptions on the future of fossil gas still in the official Ten Year Network Development Plan scenarios."* (NGO11)

NGO11 argued that this modelling leads to the inclusion of fossil gas projects in EU investments (such as recent recovery and resilience packages, and the European Green Deal), affecting billions of Euros of funding. All this is shaped by a complex politics, involving contested relationships between national grid operators, their European umbrella organisations, the regulatory body, the EC and member states (NGO12). However, we note that grid-operators were not included as participants in this study, and might well give alternative accounts.

Equally, negotiation of scenarios is a complex and contested issue for NGOs in their own work. One NGO participant described a modelling exercise they had been involved in:

> *"The NGOs were clearly pushing for diet change … But … industry groups or other stakeholders, they were actually saying, "Well, don't touch diet". …* ***there was a tension because people had different interests.***" (NGO7)

Another said bioenergy is a concern for many NGO partners in collaborative scenario-building:

> *"You have to … not integrate too much bioenergy into your scenario, otherwise you might create a conflict with biodiversity issues."* (NGO11)

It is clear that the definition of scenarios and solutions is imbued with political dynamics, regardless of the actors involved.

4.4. The politics of designing models' structural assumptions

This subsection is concerned with the fundamental structural aspects and assumptions that define the model (as distinct from the specific numerical inputs that are used in running the model). A major issue here is the distinction between Computable General Equilibrium (CGE) models and alternatives (e.g. agent based models, systems dynamics, neural network or artificial intelligence models). This issue has been extensively covered elsewhere (Grubb et al., 2021; Hafner et al., 2020; Mercure et al., 2021). We will therefore only note that participants (especially in NGOs) reinforced established critiques of CGE models, highlighting a range of problematic assumptions in conventional models, including assumptions of *"perfect markets"* (M11), *"full employment"* (NGO10; M2) and that people are *"economically rational"* (EU4; NGO9). While some participants called these *"silly"* (M2) or a *"joke"* (NGO10), these are current assumptions within the EC's dominant models. NGO10 described a 2016 shift from the Commission focusing on CGE model outputs to using Cambridge Econometrics outputs (based on the econometric model E3ME[5]) as a "*big break through*", generating totally different GDP impacts of higher emissions ambitions, and supporting much stronger policy efforts. They said that this

[5] https://www.e3me.com/. Accessed 07.11.2022.

difference was because the conventional CGE model:

> "*would assume near optimal economic conditions, with no spare employment capacity, no spare investment capacity, which means that if you were looking to try and meet more ambitious energy efficiency goals, you would have to strip investment from other areas in the modelling. You would have to strip workers from other areas in the modelling …. which would create a shock effect in the modelling, which would lead to negative GDP"* (NGO10).

In contrast, when the more "*real world*" macro-economic modelling was used, *"suddenly higher levels of ambition were showing 2 to 3% percent GDP increases by 2030*" (NGO10). There is a complex politics around the dominance of CGE-type models, and their role in contested energy transitions; we return to this in Section 4.6.

A complex area of contestation concerns the treatment of demand (as highlighted in past work, e.g. Midttun and Baumgartner, 1986; Silvast and Foulds, 2022). NGO6 pointed out that, *"typically up until very recently they [companies and industry actors] were modelling exponential demand growth"*. EU1, NGO8 and M2 all highlighted a neglect of behavioural aspects as a major gap in Commission modelling, while NGO11 argued that conventional models (including those used by grid operators) struggle to model disruptive elements such as major growth in prosumers. Meanwhile NGO6 argued that rethinking demand was a key contribution of their organisation's own modelling, including accounting for reuse of resources, and a shift towards service-based business models, enabling them:

> *"… to imagine net zero emissions for industry … You can't do that using the typical economic assumptions and models of the economy, which are overwhelmingly linear."* (NGO6)

They argued that these supply-based linear economic models are developed and promoted by incumbent fossil fuel interests.

Participants also raised wider questions around how conventional models (such as PRIMES) struggle with interactions and feedback loops (e.g. M1; NGO6; NGO8; NGO11) and with climate risk and tipping points (NGO12). On a related point, an EU policyworker highlighted that important circular economy considerations are neglected in Commission models;

> "not for good reasons, but for technical reasons … the framework of models is very sophisticated and introducing a new element is very, very complex and it can challenge all the architecture" (EU1).

They argued that this means that achievable levels of energy efficiency are underestimated. An NGO participant criticised modelling used by grid-operators as *"blind"* (NGO11) to interactions between sectors, such as the potential for storage technologies and demand-side response from industry and households to respond flexibly to supply changes. Instead, these models assume that gas-fired plants are needed to fill any possible gaps in supply; as noted in Section 4.3, above, NGO11 argued that this assumption pervades EU investment decisions, resulting in lock-in to fossil fuel infrastructures.

These issues are of course not confined only to CGE-type models. Another issue of architectural politics concerns optimisation models, namely: what do these models optimise? One modeller aimed at "*least-cost optimisation of electricity supply"* (M1). Another said, *"the default, I guess, is cost-optimal"* (M11). As noted in Section 4.2, this centring of economic impacts was critiqued by some participants. One modeller also explained that certain optimisation models (the Low Emissions Analysis Platform (LEAP) and TIMES/MARKAL[6]) struggle to encompass demand flexibility (M1). We return to this issue of different model-types in Section 5.

As the accounts in this section have shown, a range of structural assumptions have major implications for models' outputs and although they may seem to be matters of mathematics, they are rarely neutral.

4.5. The politics of defining quantitative inputs

One of the most commonly raised, and controversial, topics for participants concerned the inputs to models: the specific numbers assigned to variables such as costs of capital, technology cost curves, and assumptions about the energy mix. As Midttun and Baumgartner note, such"*parameters are apparently technical questions but they are politically loaded when alternative possibilities are* supported *by conflicting interests*" (Midttun and Baumgartner, 1986; 222). These inputs have major impacts, for example, an EU policyworker noted that:

> "*Because of the way that [cost of manufacturer obligations] is reflected in the models, it still makes it appear too expensive, for example, to carry out energy efficiency actions."* (EU4)

Cost of capital was raised as a major current issue by many participants (including NGO11, NGO7, NGO6, NGO10). This is an important input because it strongly affects the cost of borrowing for energy efficiency and renewables investments. If the cost of capital is high, this makes investments in energy transitions appear expensive. NGO7 called the Commission's excessively high assumptions of the cost of capital "*disconnected from the reality",* despite affecting investments of billions.

Another contested input is technology cost curves (i.e. current and future estimates of technology costs). This input matters because it affects how expensive energy transitions appear to be, and how different technological scenarios (such as fossil-fuel based and renewable-based ones) perform against each other. As well as poorly recognising the dynamic nature of innovation in technologies (according to M2), *"the Commission consistently over-estimates the costs of renewables"* in the view of NGO12. Participants highlighted how biased actors overestimate the risk/cost of clean technologies (including in the most recent Impact Assessment for the 2030 climate target plan) (NGO8, NGO11), while simultaneously overplaying innovation and cost-reduction in areas such Carbon Capture and Storage or nuclear power, for political reasons (NGO7, NGO12). NGO7 recollected a recent controversy when renewables actors fought back:

> *"There was a* ***big battle*** *around assumptions around technologies, where … [the] wind lobby and solar lobby really pushed hard on the Commission because their prices were not at all in line with these trade associations' own analysis …. people were sending in Excel sheets."* (NGO7)

Participants gave revealing insights regarding the political negotiation of inputs. A key example related to the negotiation of emissions and efficiency targets during 2014:

> *"****They were talking about how they could tweak the numbers … they said that openly in one of the meetings I was in with the Commission****. They could tweak to make sure the outputs were what they wanted … Every scenario they came out with, they politically had a cap of a 40% emissions target … Obviously, they had done this on purpose … The [models] were political tools by the Commission."* (NGO12)

Another NGO participant explained how this "tweaking" was achieved by changing certain assumptions about the energy mix, thus leading to different output figures for emissions:

> *"There was a kind of deliberate attempt to hold back ambition levels because it was believed that if the modelling justified going for higher levels of ambition, but that these higher levels of ambition were seen as being politically impossible to secure, actually* ***the modelling was gonna be putting the Commission in a really difficult position and so … in the more ambitious energy efficiency scenarios they would increase assumptions of coal use*** *… so that the greenhouse gas emissions would actually not be too low …* ***There was no justification. It was just numbers you put in the modelling."*** (NGO10)

[6] MARKAL is the Market Allocation model. TIMES is the related model, The Integrated Market Allocation Energy Flow Optimisation Model System.

The participant went on to explain that when political circumstances changed, the same tactics were used to justify different choices. This suggestion is also, to some extent, backed up by an EU policyworker in relation to a recent policy process:

> *"Sometimes, of course, instead of having an evidence-based or a model-based policy, we have a policy-based model - exaggerating a little bit - but when there is a political decision, it was the case of the Green Deal, to increase the GHG emissions reduction by 50 or 55%,* ***the models were focussed on these objectives.*** *So, they were looking at the good combination of instruments … **to reach these objectives, they didn't go beyond or below.** And at the end you find … "Oh, I reach this, but this will have a consequence on energy crops, so **better I ignore this problem, because otherwise my political masters are going to be very nervous.**"* (EU1)

In explaining the reasons for these adjustments to inputs, participants referred to wider political contexts (such as the challenge of getting coal-producing countries to agree to major targets) and even Brexit. They also discussed tensions between DG ENER and DG CLIMA (e.g. EU4, NGO12), with another saying: *"**they both have little empires that they build and defend … The model is where a lot of that battle plays out**"* (NGO9), for example, through an ongoing *"battle"* over the levelised cost of energy (NGO9).

Again, it was apparent that the NGOs themselves engaged in similar tweaking activities:

> *"[The modellers we commissioned] shared some preliminary results with us, so that we could see like, "Okay, here's the kind of results it looks like we're getting. Why is that? Do we need to tweak something in the model?" … we know that industry does this on the other side and pays for the research that they want … **quantitative evidence is for sale**".* (NGO9)

However, it is important to note that some modellers (e.g. M5, M6, M7) spoke of these kinds of negotiation between policy goals and modelling processes in a fairly neutral way (as informing the development of relevant scenarios and useable outputs) (and M8 denied any *"altering"* of outputs happened at all).

Underpinning the issue of the buying of evidence, and indeed all issues raised throughout this section, are the politics of access and exclusion.

4.6. The underlying politics of access and exclusion

This final subsection is concerned with underlying issues of differentiated participation within the evidence-making process: who has the capacity to understand the assumptions and inputs of models, to alter them to suit their needs, or even to run their own modelling to support their goals?

First, there are issue around the relationship between policyworkers and modellers. Policyworkers often do not understand the inner workings of the models they commission, leading one EU policyworker to describe modelling contractors as *"masters of the machinery"* (EU1). This links to Schoenefeld's (2021) suggestion that monitoring agencies became more powerful as a side-effect of the growing role of monitoring within EU governance. There may also be challenges of lock-in, with policyworkers finding it hard to switch to new models once they have committed to a particular model (mentioned by EU1, EU4 and EU13 as well as NGO participants). Despite this, a recurring theme in this data was that the commissioners/funders of modelling have a large amount of power, with modellers generally attempting to meet their needs. This was clearly expressed by one modeller, who gave an example:

> *"When we had this assignment for the [national plan] we collaborated closely with the government and **sometimes they were unhappy about the results and they asked to change their assumptions …** to make them more politically-acceptable … they asked us to achieve some acceptable numbers, acceptable outputs so that there would be no protests from the population, so **we had to modify the assumptions and scenarios to make them happy … We adjust the results in the way they want. We work for them more-or-less so** they are involved all the time." (M1)*

Modeller-policyworker relationships will be explored further in future publications from our study.

Furthermore, as highlighted in Section 2, past work (e.g. Aykut, 2019; Midttun and Baumgartner, 1986) has found that models have historically been used by dominant actors "to silence critical questions and challenges" (Midttun and Baumgartner, 1986; 224). Similar dynamics were strongly identified in our findings. For example, a key reason for NGOs doing their own modelling was to gain a voice in debates they would otherwise be excluded from (NGO9, NGO11, NGO7). As Aykut et al. (2019; 4) argue, "Policy intermediaries and knowledge brokers invest in anticipatory practices to sustain their role in changing policy environments". However, not all actors have the same role and capacity in providing data. Concerns were particularly highlighted around grid operators' organisations (as mentioned above), which;

> *"have an institutional role in making decisions … but they are also a lobby group, basically, for a set of companies, and all that data mainly comes from these companies." (NGO8).*

This supports the earlier finding that key energy-forecasting actors are often linked to specific energy-industrial interests (Midttun and Baumgartner, 1986). As another NGO participant explained:

> *"… the people that have the expertise sit around the table … But they have a clear vested interest … And very few NGOs have the capacity to engage … **it's a perfect example of a captured, supposedly evidence-based system.**" (NGO9)*

They added; "**the ability and the resources to gain evidence and create evidence gives you loads of political power"** (NGO9). NGO8 explained that more widely, model results from industry bodies "matter politically" and are the most established numbers, so NGOs are forced to use them, although they are "a lot more conservative than they should be". Meanwhile, a modeller commented: "**the industry side will say their data is much better than our data** … but indeed, this data is not public most of the time" (M7).

Related to this issue of data-transparency, a recurring theme was lack of transparency around Commission models (EU1, NGO8, NGO12, NGO9). One participant said that access to PRIMES "became super political within the Commission" (NGO9) during debates about energy efficiency targets and Emissions Trading Scheme (ETS) prices, explaining:

> *"DG ENER … and DG CLIMA had huge clashes about it, and we were meeting with DG ENER a lot and saying, "We don't understand how PRIMES works. Can you tell us?" And they're like, "We don't understand, either. DG CLIMA won't tell us." **Those who held access to knowledge about the model held power, because they could say, "Yeah, well, PRIMES says the ETS price should be this and efficiency targets should be that."** (NGO9)*

NGO12 explained how NGOs have been systematically excluded from debates by this opacity:

> *"A guy in DG ENER … tipped us off ….otherwise, how would we have known anything about discount rates and how fundamental they were to the outputs that the model was spitting out?.. **The Commission was hiding behind the models and saying, "Oh, well, that's what the model says, what can you do?" Whereas politically, they'd already agreed what the numbers were beforehand."** (NGO12)*

They added that, "the people running [models] … **have an interest in not making you more understanding of how they work**" (NGO12). Another similarly said that model outputs are communicated late, and in over-simplified form, deliberately to limit debate; "Because

they didn't want people to start unpicking the model ….[The Commission] want just backing for their own number" (NGO7). These quotes reinforce the idea within the literature of models' authority being used to silence critical voices. As Aykut et al. put it:

> *"The emergence of complex, socio-material "machineries" of anticipation (*Nelson et al., 2008*: 549) … confers political influence to the expert communities that control the 'means of anticipation'" (Aykut* et al., *2019; 4).*

The power dynamics at play here are multiple and complex. NGO7 raised the issue that rich countries can run their own model analysis, but poor countries cannot afford to do so (or to employ specialists who understand the complex world of modelling), and so have to rely on outputs from big business associations. Models are mobilised not only within power struggles between renewables interests and fossil fuel interests; but also between DGs within the EC; between the EC and its member states; between industries and their regulators; between the EU and the EC; and as one policyworker explained: "models are … real political instruments in the European policymaking and it's a tool that countries use against each other" (NGO8). It is clear that 'mastering the machinery' of models is a complex game, in which the political stakes are high.

5. Conclusions and policy implications

This paper set out to explore the political dynamics of the development and use of economic models within EU energy policymaking. We aimed to address specific knowledge gaps around the processes through which political dynamics shape the development and use of models in present-day energy policy; the implications of these dynamics for energy targets, strategies and interventions; and the role of NGOs within the landscape of modelling for energy policy. Our findings strongly support the idea (suggested by past literature) that processes of evidence-making are deeply political. However, we go further, showing the diverse ways in which economic models are mobilised as political tools within EU energy policymaking. Our findings reveal that models are non-neutral from their inception, through the framing of problems and questions in ways that privilege certain goals (such as economic growth), and the framing of scenarios and solutions that limit the futures that can be envisaged. In particular, the role of incumbent actors in defining the "menu" (NGO12) of options serves to reproduce existing fossil-fuel-centred agendas. Often, structural assumptions about economic systems, demand and linearity (among other things) within the currently-dominant models are strongly weighted against low-carbon innovations and reinforce the status quo in energy policy. Meanwhile, participants elucidated the huge impacts of the politics of quantitative inputs (especially various cost figures), with revealing accounts of how these are manipulated in support of "empires" (NGO9) and "battles" (NGO7, NGO9) between key policy actors. This supports Yanis Varoufakis' idea that major political struggles often play out through a "War of the Models" (Varoufakis, 2018; 603).

Finally, our findings on underlying issues of access and exclusion draw attention to power relations within model ownership and transparency, and how capacities to engage in model-based debates vary between actors at a range of scales. A powerful theme here is the systematic exclusion of critical voices, and the use of models to reinforce the authority and legitimacy of established interests. Recent work already suggests that some of these findings are relevant in contexts beyond Europe. For example, research drawing on China, India, Brazil and the UK, as well as the EU, suggests modelling may reinforce incumbent interests within energy systems, through conventions such as reducing all impacts to economic metrics, and insufficient attention to policies' interactions, uncertainties and distributional impacts (Grubb et al., 2021; Mercure et al., 2021). However, different governments have varying approaches to evidence gathering including the need to include wider social impacts in policy appraisals and modelling Aykut (2019). The political dynamics of modelling are also not limited to the energy field. Further research could usefully consider, for example, how these issues of power, exclusion and contestation play out in evidence-making around the COVID-19 pandemic, or economic responses to financial crisis.

While these accounts may suggest a negative picture, reflecting on these observations can nonetheless provide useful insights to support action for change. A key insight from our findings is that these political dynamics play out across a range of policy 'sites', involving diverse actors, in various (not always obvious) patterns of alliance and contestation. Recognising these dynamics is a crucial first step in responding to them, and adopting collaborative and creative approaches to challenging them. While we do not have scope here for an extensive discussion of how changes in knowledge practices contribute to wider change, a useful reflection on this is provided by Aykut (2019).

It is also important to note that our aim has not been to compare the advantages and disadvantages of different models for informing energy policy. That is a major field of research in its own right, as reviewed by, for example, Hafner et al. (2020). Likewise, our present data-set, with its intense focus on the models currently dominant in EU energy policy-making does not allow us to draw conclusions about how political dynamics might vary across different types of models. We stress that we do not see certain models as more 'political' than others. Our fundamental premise is that the making of evidence is a political practice, regardless of the tools through which it is pursued.

However, among the participants in our study, and within the wider literature, there is a growing movement that challenges the assumptions of currently-dominant models and their underlying theories, and that proposes alternative and innovative modelling approaches. For example, Grubb et al. (2021) and Mercure et al. (2021) outline a framework called Risk Opportunity Analysis that aims to address some of the weaknesses within conventional policy appraisal approaches so as to facilitate a wider engagement with policy and modelling in the context of rapid low-carbon transitions. Our findings suggest that a more diverse 'ecosystem' of models could help to break up the presently-dominant regime of evidence-making, which seems to serve incumbent interests. We therefore conclude by offering some insights and recommendations for those involved in developing and promoting alternative and innovative models. These could be policyworkers in governmental and non-governmental organisations, as well as modellers. The recommendations also have relevance for those interested in understanding and informing energy policy more generally, and we hope they may spark reflection and discussion across the various parts of the modelling community. These recommendations are interconnected, and their ordering does not reflect importance.

5.1. Reflexivity

A first recommendation is that those involved in developing and promoting models should be aware of their own role within the political process of making evidence. Cornilleau (2019) (examining global agriculture and food security governance) argues that modellers can act as 'institutional entrepreneurs', deploying various strategies to promote new kinds of modelling. As researchers, we can ask: How are agendas structuring the modelling work we engage in? Can we be transparent about these? This is not just an ethical objective: it will also inform how we implement action for change (e.g. with whom we build alliances). Furthermore, if modelling is political, as these findings suggest, we should apply similar standards to modelling (our own, and that of others) as we would apply to other political processes, for example;

> *"Are all relevant societal interests well represented? Are the basic assumptions made clear and open to public debate? How fair and open are the procedures for model and forecast selection? How impartial is the implementation system when it comes to implementing alternative energy futures?" (Midttun and Baumgartner, 1986; 241).*

Similarly, Aykut et al., 2019 raise "questions pertaining to the accountability of modellers, and to possible ways of 'democratising' anticipatory expertise by associating wider publics in modelling or scenario building." (Aykut et al., 2019; 4). This point about wider publics relates to the concept of participatory modelling, which we do not have scope to discuss here; a comprehensive review of literature, including the benefits and challenges of participatory modelling, is provided by McGookin et al. (2021).

The findings of our study emphasise the need for meaningful transparency, access and inclusion within modelling. This reinforces arguments by UKERC[7], and links to the EU's agendas on Responsible Research and Innovation, and on Open Science.[8] As responsible stakeholders, it is essential that we consider transparency and inclusivity within the models we develop and promote. This may involve providing open access to models, data and assumptions, but we recognise that this kind of transparency is not enough alone, and is unhelpful if stakeholders are unable to understand the material. Equally important is communicating about models to diverse stakeholders (such as civil society groups) in ways that facilitate their meaningful engagement in the debate. This is a long-term and challenging commitment. Crucially, this is not just about end-of-pipe sharing of selected model outputs. Modellers can also make efforts to work more closely with non-traditional providers of data (e.g. using the NGO Paris Accord Compatible (PAC) scenario[9]). Such co-creation and opening up of development processes will make final outputs stronger. Modellers should equally be alert to the direct/indirect ways in which vested interests currently influence their work (for example, through provision of data), and seek opportunities to challenge these.

Another aspect of responsibility relates to the ways in which model outputs are used more generally. Silvast et al. (2020) point out that many modellers are very cautious about model outputs, and do not believe they should be used for policy-planning, but rather "as a tool to challenge existing assumptions or 'mental models'" (2020; 3). Similarly, in our interviews, modellers often described models more as thinking-prompts than as predictive tools or guides towards/against particular policy choices. However, it is clear that in the battleground of energy politics, models are used as a "weapon" (Aykut, 2019; 22) to strengthen dominant interests and silence dissent. Those with expertise in modelling, as responsible researchers, could play a more active role in highlighting models' limitations, and advocating for their use in opening up, not closing down, policy debates.

5.2. Recognition

It is clear from the findings presented here that there are major political barriers to change in the use of models in energy policy, and a need for realism about facing them. A newly-developed model will not be adopted just because it is more accurate or sophisticated. It is therefore important to reflect on all the above dynamics of political influence, and consider their implications for effective development and promotion of alternative models. For example, it will be useful to engage with a range of policy stakeholders at the earliest stages of a new model's development, to facilitate open discussion of their priorities and assumptions (which may differ). It is important to note that change in this field is likely to be gradual, due to the influence of established interest-coalitions within the modelling-policy landscape. Participants highlighted serious problems of lock-in and monopoly in the selection of models (while recognising that there have been some recent improvements) (EU1, EU4, NGO7, EU13). Those involved in developing and promoting new models will therefore need to pay sustained, ongoing attention to opportunities for change, wherever/whenever they arise within political cycles. For modellers, this may include developing a deeper understanding of policy processes and commitments, including what different policy documentation actually means (for example, the EU Green Deal is only a communication, not a legislative commitment). Modellers can also aim to synchronise their production of evidence with policy cycles (as suggested by Schoenefeld (2021)). Close working and communication between policymakers and modellers is obviously vital here; as discussed in our final recommendation.

Our data also hinted at different political processes operating at various phases of the evidence-policy cycle, e.g. agenda setting, policy formulation and adoption, implementation and evaluation, as discussed in Süsser et al. (2021). For example, there may be particular challenges associated with Impact Assessments (which are conducted prior to policy implementation) and others associated with post-implementation evaluations (where there can be a tendency to seek evidence that justifies past decisions). Further research with specific attention to the temporality of evidence-making would be valuable in interrogating these processes, and helping inform timely interventions.

5.3. Relationship-building

An important practical recommendation of this study relates to the building of communities and coalitions. Accounts show that actors working together can challenge the strong coalition of vested interests. For example, DG ENER has worked with NGOs to challenge the black box of PRIMES, and the Climate Action Network consortium of NGOs has collaborated to develop the PAC scenario[10] and worked with modellers to implement it within models. NGOs have also pooled resources to commission influential modelling work, from reputable modelling agencies, that they could not afford alone (as described by NGO9). This suggests that challenges of access and exclusion can sometimes be addressed through the power of cross-sectoral relationships and coalitions. The building of such communities needs to be based on shared understandings of what models can and cannot do, as well as the recognition that no model is perfect, so multiple assumptions and projections should be challenged and explored. We argue that building relationships of mutual understanding is an important part of embedding transparency, access and participation throughout the modelling and policymaking process. Crucially, it will enable the integration of the different knowledges of actors such as modellers, policyworkers and NGO experts. This is a core goal of the Economics of Energy Innovation Systems Transition (EEIST) consortium[11], which is building Communities of Practice involving diverse stakeholders in India, China, Brazil, the UK and the EU. It is our hope that the findings and recommendations presented here will aid the efforts of all those working towards modelling that supports low-carbon transitions, in order to challenge a vicious circle of evidence and policy that legitimises business-as-usual in a dangerously warming world.

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CRediT authorship contribution statement

Sarah Royston: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review &

[7] Energy models and transparency | UKERC | The UK Energy Research Centre [viewed 25th Aug 2022].

[8] For example, within Horizon Europe; see: Open Science (europa.eu) [viewed 25th Aug 2022].

[9] A net-zero EU is possible: Findings from NGOs' Paris Agreement Compatible energy scenario - CAN Europe [viewed 25th Aug 2022].

[10] The Paris Agreement Compatible (PAC) scenario sets out our vision for a speedy energy transition - CAN Europe [viewed 25th Aug 2022].

[11] https://eeist.co.uk/about/[viewed 25th Aug 2022].

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Declaration of competing interest

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