UK Energy Research Centre

Energy Modelling in the UK

Briefing paper 2: Strengths and weaknesses

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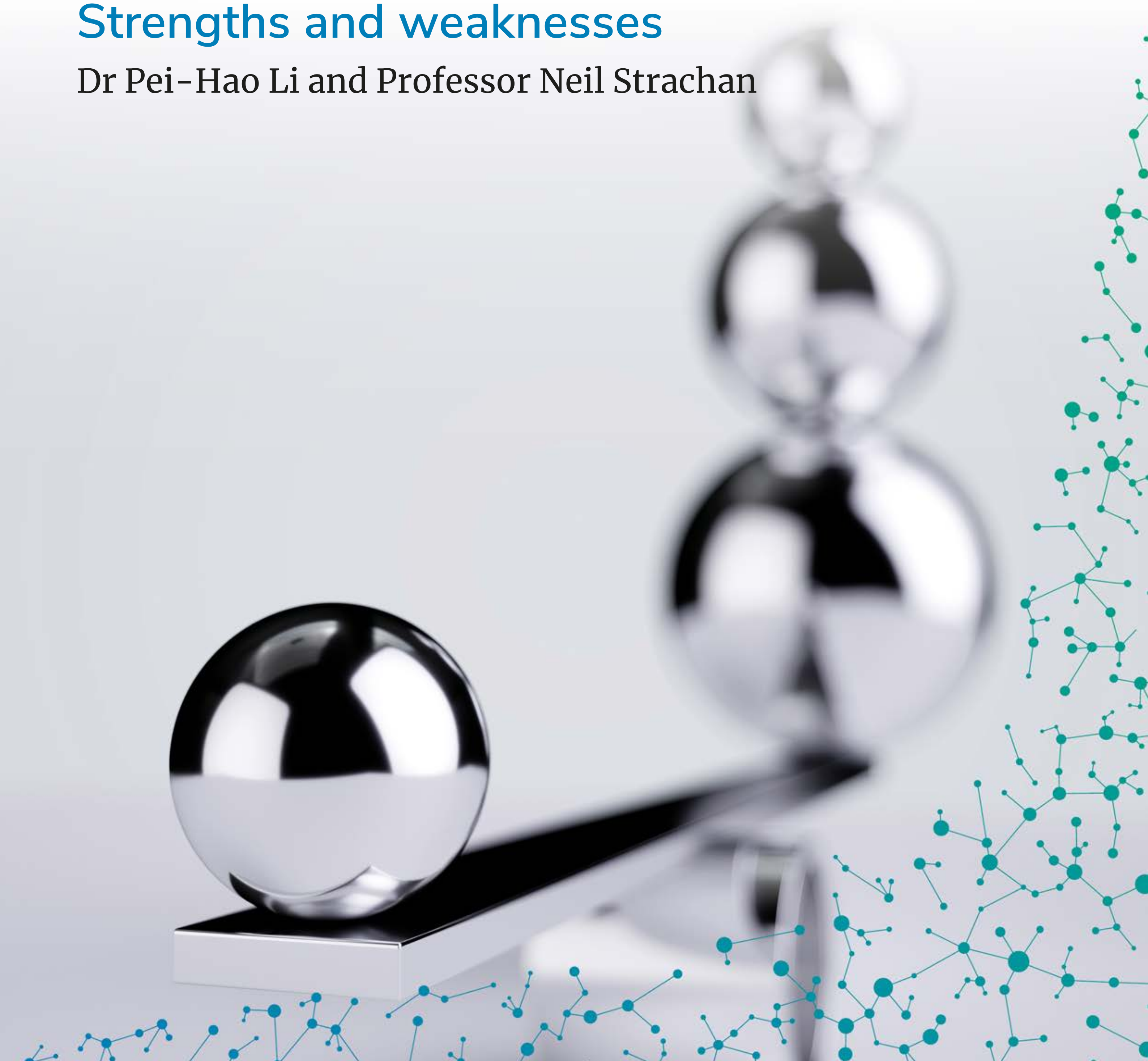

Introduction

The energy transition is a huge challenge, encompassing many different economic sectors, a wide variety of fuels and technologies, a host of different actors, a range of environment impacts, and a plethora of possible policy responses. The energy transition therefore needs to be considered across a variety of geographical scales – from neighbourhoods to the world, and across different time-frames, from sub-hourly operation of technologies, to decadal turnovers in both infrastructures and societal attitudes.

Energy models provide the underpinning evidence to support decision makers across policy, industry and civil society, helping them to understand strategies and trade-offs in the energy transition. No single model can cover all the elements required to understand the energy transition; the limits here include:

- Conceptual issues, in terms of alternate theoretical underpinnings of this interdisciplinary topic.
- Practical issues, given the extensive data requirements, and the computational difficulties of (very) large models.
- Explanatory issues, as modellers need to understand the insights (and limitations) of their models and communicate these to policy (and industrial) decision makers.

Previous typologies of energy models (e.g., Li et al., 2015, see figure 1)[1], have tried to convey how an ideal energy model would aim to cover everything. It would explicitly consider technological and economic details, realistically represent behaviours of market players (e.g. consumers, investors and regulators), understand the temporal nature of the energy transition and how it develops through time, account for wider macro-economic and environmental feedbacks, and capture how societies change.

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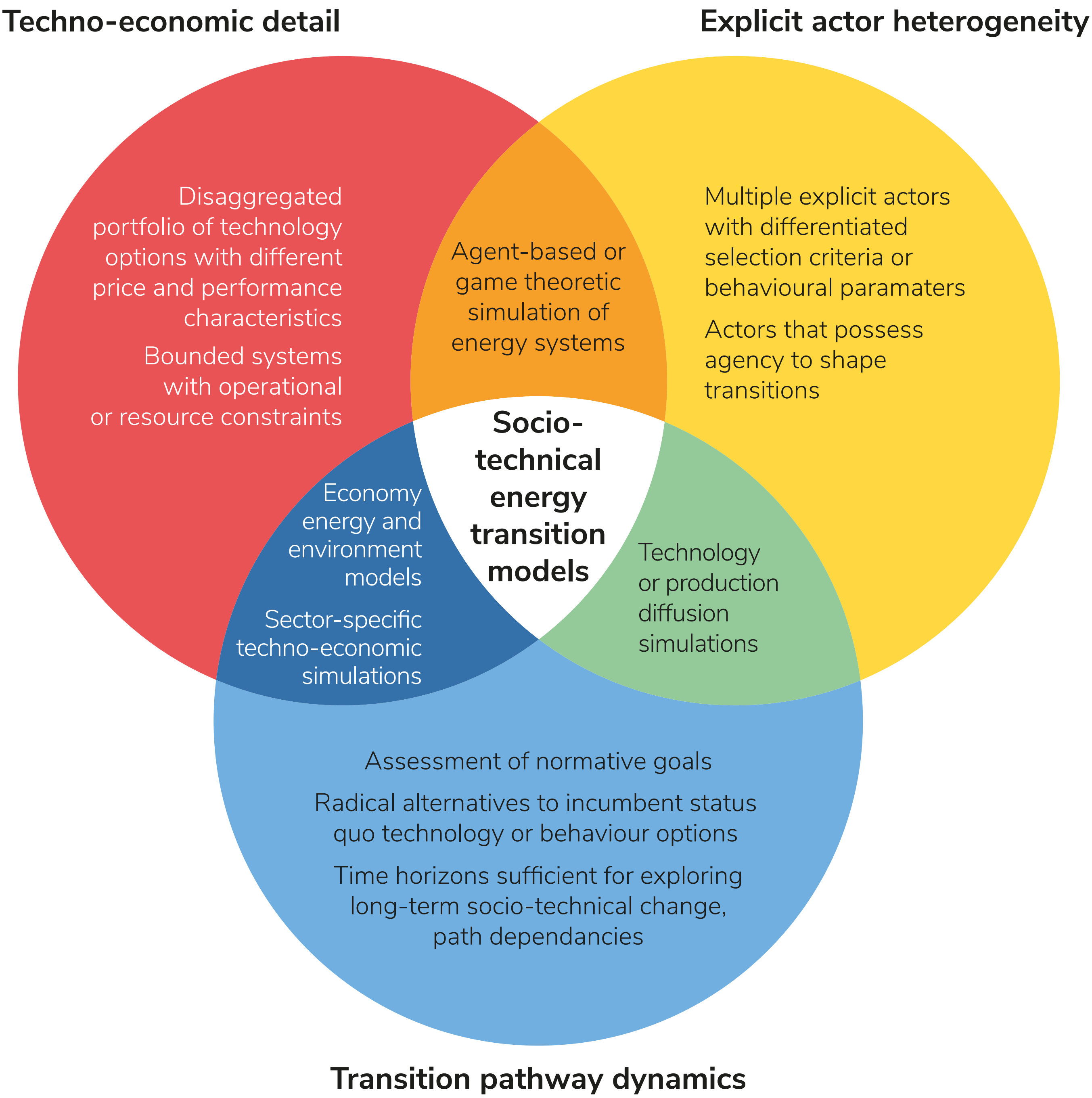
[1] Li, F., E. Trutnevyte and N. Strachan (2015). A review of socio-technical energy transition (STET) models. Technological Forecasting and Social Change 100: 290-305.

Figure 1 Assessment of energy models in terms of key policy-related dimensions



Reproduced with permission from:Li et al., 2015.

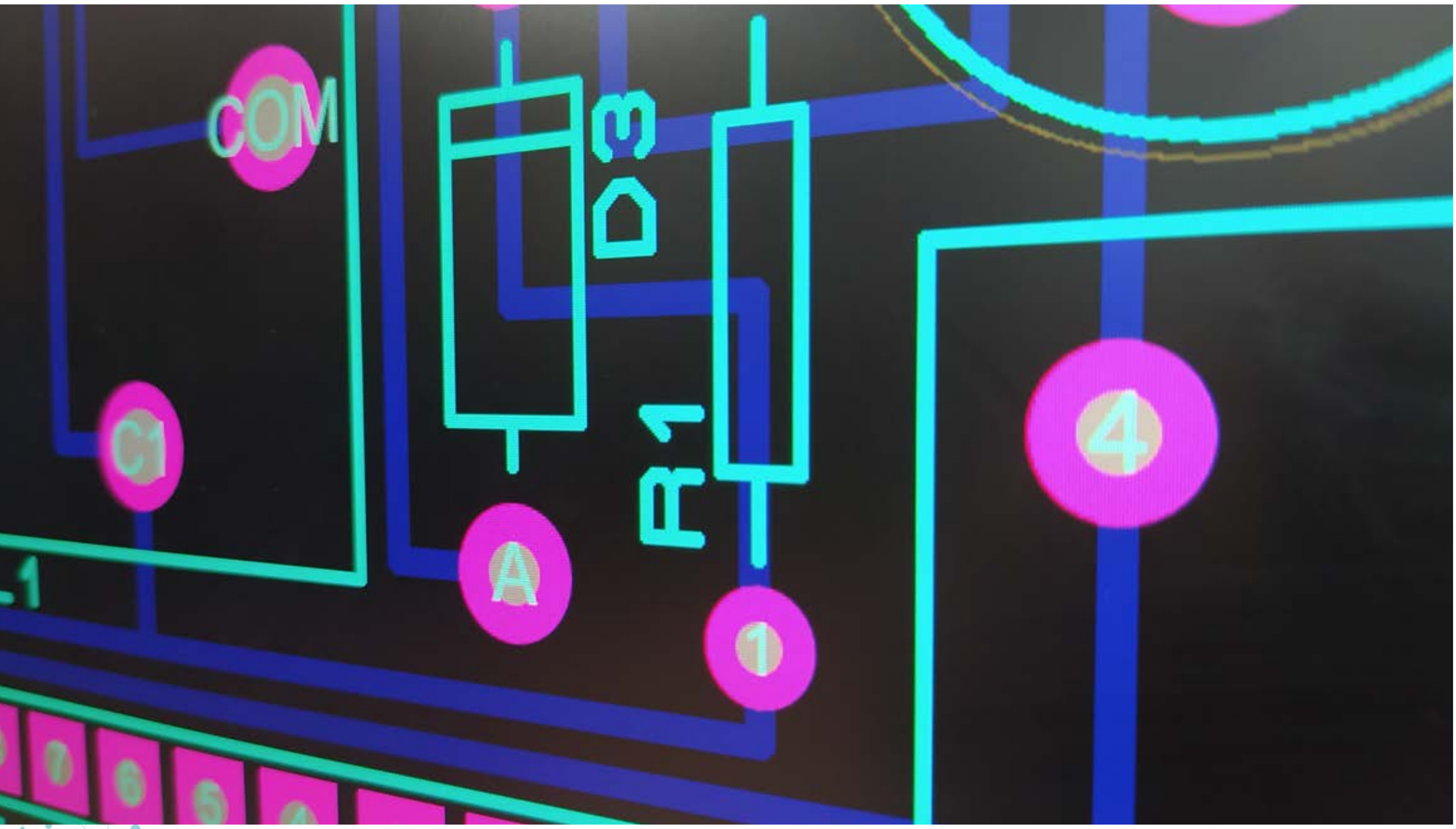
Policy-makers can thus benefit from a fleet of distinct energy models that cover the full energy policy space. They also need to understand the workings of any given model, such as:

- How does it solve, how does it deal with time and space, what sectors and technologies does it cover?
- What are the model's inputs and outputs?
- What external drivers it uses
- What key insights it offers, and what impacts has it had?

To investigate this critical issue, and gain an understanding of the energy models in use in the UK, UKERC's Energy Modelling Hub coordinated a ground-breaking survey of all UK energy models. This is advised by a Steering Group of key policy stakeholders[2]. The survey was broadcasted among major energy research communities, such as UKERC, EnergyRev and other flagship energy projects, to government departments that use energy models for decision-making and to energy consultancy firms.

Whoever is willing to participate in the survey can freely log-on to the online survey to provide model information. As of 1st April 2021, there are 76 UK energy models reported in the database[3]. This is much more comprehensive than past reviews that relied only on models with accessible published information, as a substantial amount of models hosted by governments and consulting firms are also included in the database, as shown in brief #1 which looks at the breadth of modelling in the UK. Nonetheless, there will still inevitably be potential gaps and biases.

This policy brief (#2) is the second of four from UKERC's Modelling Hub survey. The first brief on the UK energy modelling landscape, detailed the diversity of organisations who host and run models, their methodologies and coverage, and their major outputs. In this second brief we focus on the findings from the survey that shed light on the strengths and weaknesses of UK energy models.



Initial findings

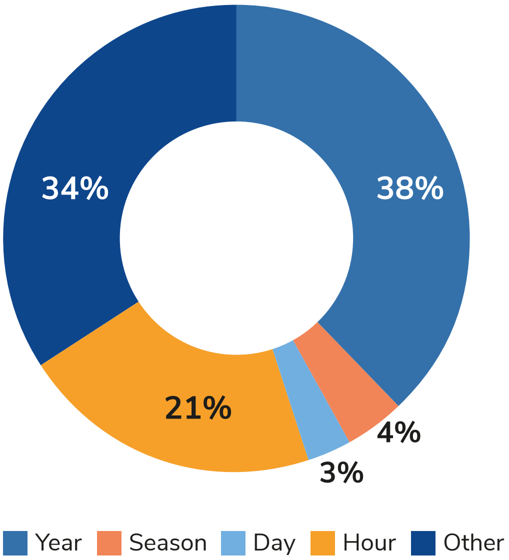
In considering the strengths and weaknesses of the UK energy models captured in the survey we focus on four key areas:

- How the models deal with time, in terms of temporal detail and overall time horizon
- How the models deal with space, in terms of geographical detail and capturing infrastructures
- How the models deal with technologies, in terms of technology learning and inclusion of key mitigation options
- How the models deal with behaviour, in terms of consumer responses and broader societal trends

UK energy models and time

Modellers choose the temporal resolution of their models (figure 2), depending on the research question in focus. A little over a third of models (38%) adopt yearly temporal resolution, ignoring intra-annual or intra-day variations. However around one third of models consider more granular temporal resolutions, such as hourly (21% of the models) and even shorter resolutions. Much of this temporal detail is focused on incorporating variable renewable energy (VRE) such as offshore wind and solar PV which have been regarded as the most cost-effective technologies for the provision of low-carbon electricity. According to National Grid's projections[4], the share of VRE should be higher than 70% of total electricity supply in order to reach net zero targets. This focus on system flexibility often also reflects temporal variations in energy demand, this can include transport use and patterns of heating and cooling in buildings. Finally, a handful of models can freely adjust their temporal resolutions for different analysis purposes..

Figure 2. Temporal resolution of models



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[2] UK Research and Innovation (UKRI), UK Government (BEIS), Scottish Government, Northern Ireland Government, Committee on Climate Change, Energy Systems Catapult, and the National Infrastructure Commission

[3] The survey remains open for additional modelling entries, or for updates to existing model entries

[4] National Grid (2020) Future Energy Scenarios, www.nationalgrideso.com/future-energy/future-energy-scenarios

2050

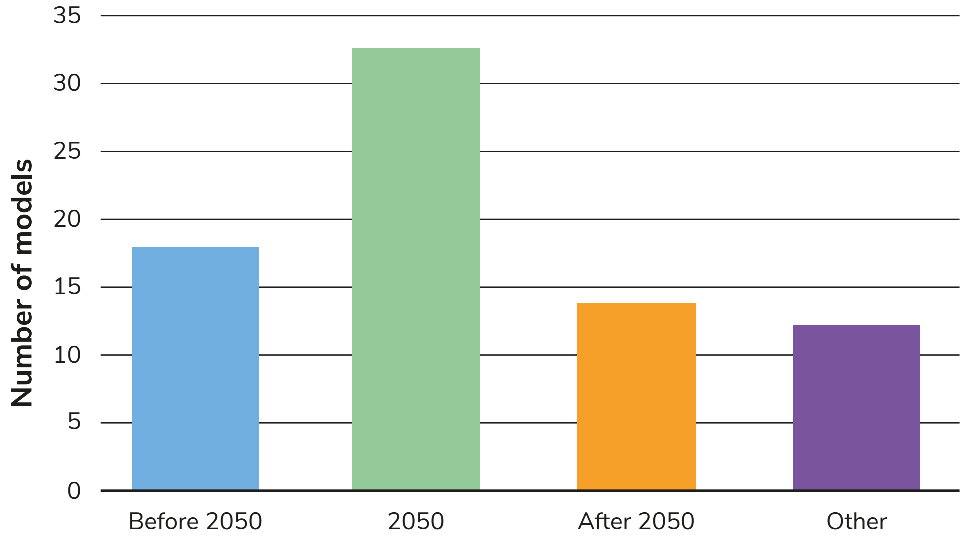
42% of models have 2050 as their target year

UK energy models consider a wide range of target years (figure 3). This is linked to the temporal resolution of the model, as computational and data limitations means that highly disaggregated models with long timeframes are less common. Models with alternately short and long horizons enable researchers and policy-makers to explore different dynamics in energy transitions.

In response to the challenge of reaching the legally-binding 2050 targets, many models (about 42%) have focused on evaluating how to reach a deep-decarbonisation future, with 2050 as their modelling target year. As the Paris Agreement also concerns GHG emissions in the second-half of this century, a few models (about 18%) further extend the modelling horizon to beyond 2050. These models allow policy-makers to investigate the possible delays in meeting net zero targets by 2050, the strategies to maintain low-carbon energy systems and even further contributions to global GHG abatement.

Some of the models (about 23%), focus on short-term or medium-term energy system transitions by adopting years in the near future as target years. These models might aim to tackle the more pressing issues facing today's energy systems.

Figure 3. Target year of energy models

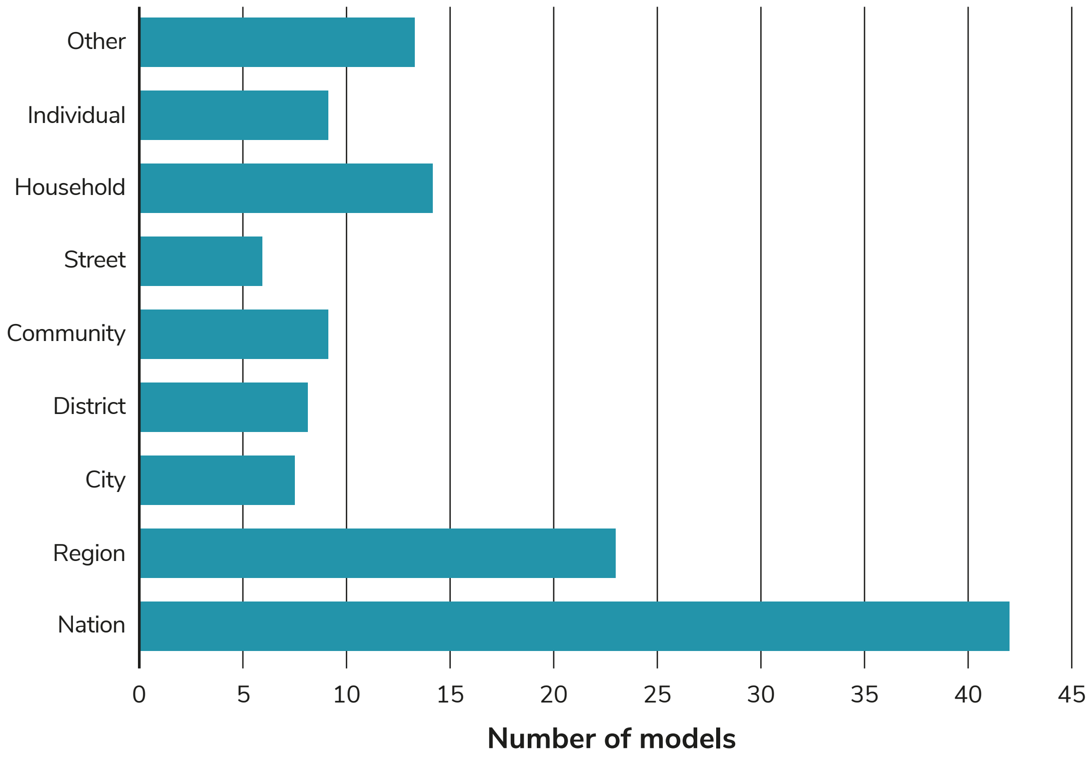


UK energy models and space

Similar to considerations of time, modellers generally need to choose the spatial resolution of their models depending on the research question of focus.

With the focus of UK policy on overall decarbonisation (embodied by the Climate Change Act in 2008), the majority of energy models (about 55%) only consider system transitions at national scale (figure 4). More recently it has been realised that the role of subnational/local systems will become more and more critical in reaching net zero targets. Devolved governments, such as the Scottish government, have thus gradually developed their own models to better consider spatially different potentials and limitations in regions, however, less than 30% of models take subnational characteristics into account.
A subset of models adopt more detailed spatial resolutions, such as street level. These models usually only cover specific regions, to reflect detailed spatial characteristics such as demographics, economics and land-use. A future challenge will be the development of subnational models to determine more robust local energy transition strategies.

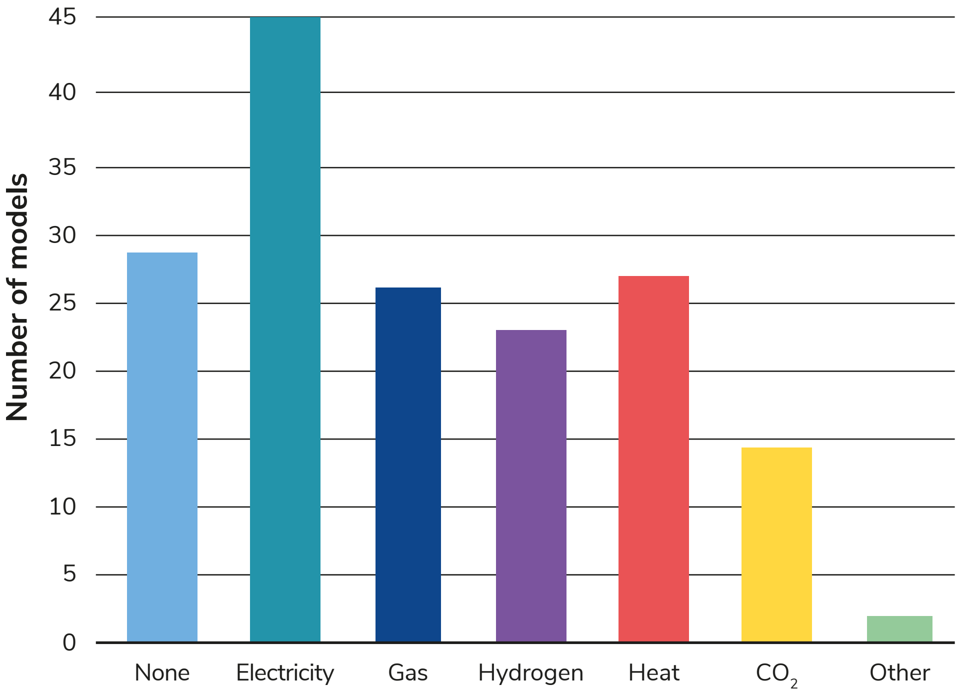
Figure 4. Spatial resolution of models



Energy systems comprise multiple energy infrastructures and vectors which require a spatial treatment (figure 5). Overall, electricity grid infrastructures (transmission and distribution) have been well considered by UK energy models (about 60%), which is logical given its role as an early energy transition investment and a key enabler of decarbonisation in transport and buildings. In addition, about 30% of the models also explicitly represent hydrogen or heat transmission grids. These models can be useful to evaluate the decarbonisation of the heating sector and the scale-up of the hydrogen use in different sectors. However, relatively few models (about 18%) take into account CO_2 transmission infrastructure, which is a critical component of CCS technologies.

In terms of multiple infrastructures within the same model, the most common pairing is electricity and gas, with hydrogen and/or heat being added to a smaller subset. This follows the logic of the current dominant infrastructures in the UK, with more recent model developments targeting the potential synergies of new (or greatly expanded) alternate infrastructures.

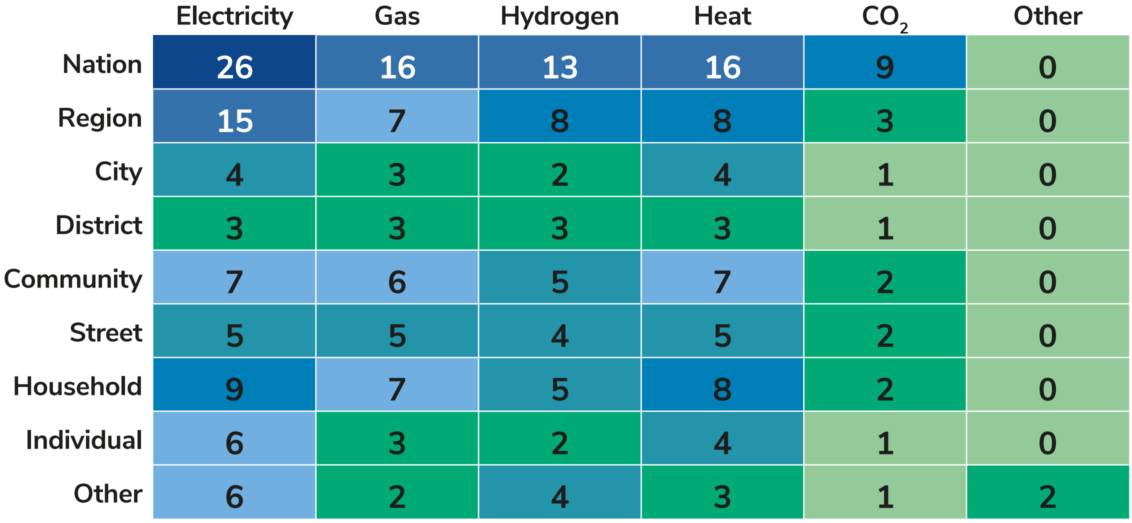
Figure 5. Representation of transmission and distribution infrastructure



However, just because a model considers infrastructures, it may not have been accounted for in spatial detail. Figure 6 shows how most modelled infrastructures are captured at the national level and often in a stylised way (for example only overall costs and constraints of electricity transmission capacity). In contrast, models with higher spatial granularity can better inform policy-makers of how to expand infrastructures to meet spatially heterogeneous energy demands. But these models might only cover specific subnational areas, and hence could be used in conjunction with national models.

Relatively few models take into account CO_2 transmission infrastructure

Figure 6. Spatial resolution versus covered grid infrastructure



	Electricity	Gas	Hydrogen	Heat	CO_2	Other
Nation	26	16	13	16	9	0
Region	15	7	8	8	3	0
City	4	3	2	4	1	0
District	3	3	3	3	1	0
Community	7	6	5	7	2	0
Street	5	5	4	5	2	0
Household	9	7	5	8	2	0
Individual	6	3	2	4	1	0
Other	6	2	4	3	1	2

Interconnection with other countries is crucial to balance the electricity system

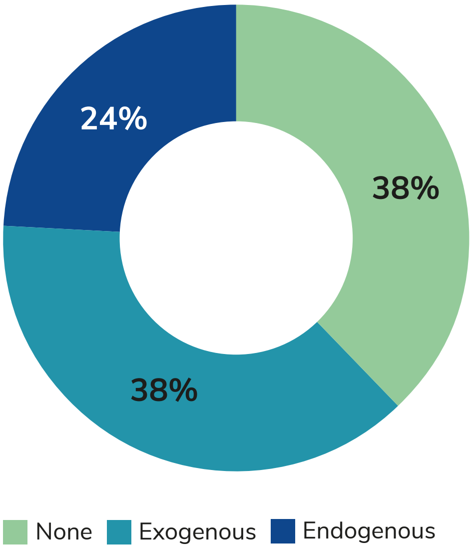
Looking internationally, interconnection with other countries is a crucial measure to balance the electricity system, especially when more VRE technologies are deployed into the system over the coming decades. According to National Grid's estimations, cumulatively, around 3% to 20% of total electricity supply in 2050 it likely to be imported, depending on the share of VRE, to fill the gaps between electricity supply and demand. To that end, over half of the models (about 54%) represent various number of interconnections with other energy systems. Interconnection between UK energy systems and other countries' systems can therefore be fairly well considered.

UK energy models and technologies

Linking to the discussion of time, a critical modelling issue is how technologies are treated and in particular then change through time in terms of lowered costs and improved performance. Deployment of decarbonisation technologies at scale can significantly reduce their costs through technology learning – solar PV panels are a powerful example of this, with their cost halving over the last decade. In the long-term, technology learning will affect the cost-effectiveness of decarbonisation pathways and should therefore be considered.

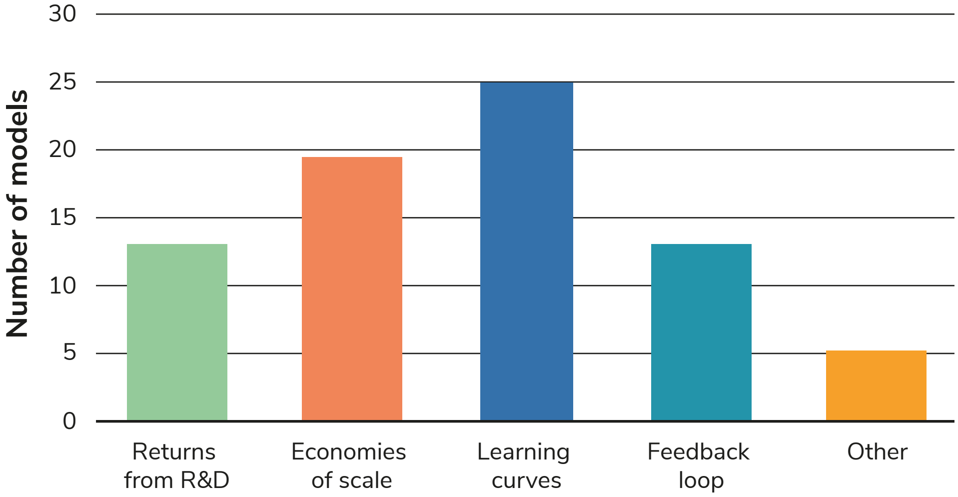
Around a third of models do not consider technology learning (figure 7) – which is likely correlated to those models who do not focus on time but rather on a detailed snapshot of the energy system and its components. About 62% of the models do take technology learning into account, most often exogenously (the learning is calculated outside the model, perhaps on a global scale) with some models capturing learning endogenously (calculated inside the model).

Figure 7. Representation of technology learning



How technology learning is captured by models is important (figure 8). The prevalent approaches measure the impacts of the uptake and scale-up of technologies on their improvement, using learning curves (30% of the models), followed by economies of scale (25% of the models). A smaller number of models focus on the returns from innovation (R&D) or broader feedbacks with policy and other drivers. However, as discussed in the previous brief (#1), our survey tells you about the mechanisms models employ, but not how sophisticated these mechanisms are.

Figure 8. Type of technology learning in UK energy models



Another important technology characteristic of models is if they explicitly include key technologies. To illustrate this we focus on negative emission technologies (NETs), these extract CO_2 from the energy system and hence allow some sectors to continue to use fossil fuels in specific applications and still reach net zero targets by 2050. Two of the most common NETs are biomass with carbon capture and storage (BECCS) and various form of enhanced land management (e.g. afforestation, crop management, and soil management). Of these, CCS technologies are relatively well represented among all models (about 45%), with a focus on energy systems approaches. However, land management measures are much less common, with only 15% of the models incorporating these abatement approaches. This discrepancy could be due to a combination of the lack of data, the disciplinary perspectives of modellers, and the focus of models just on the energy system.

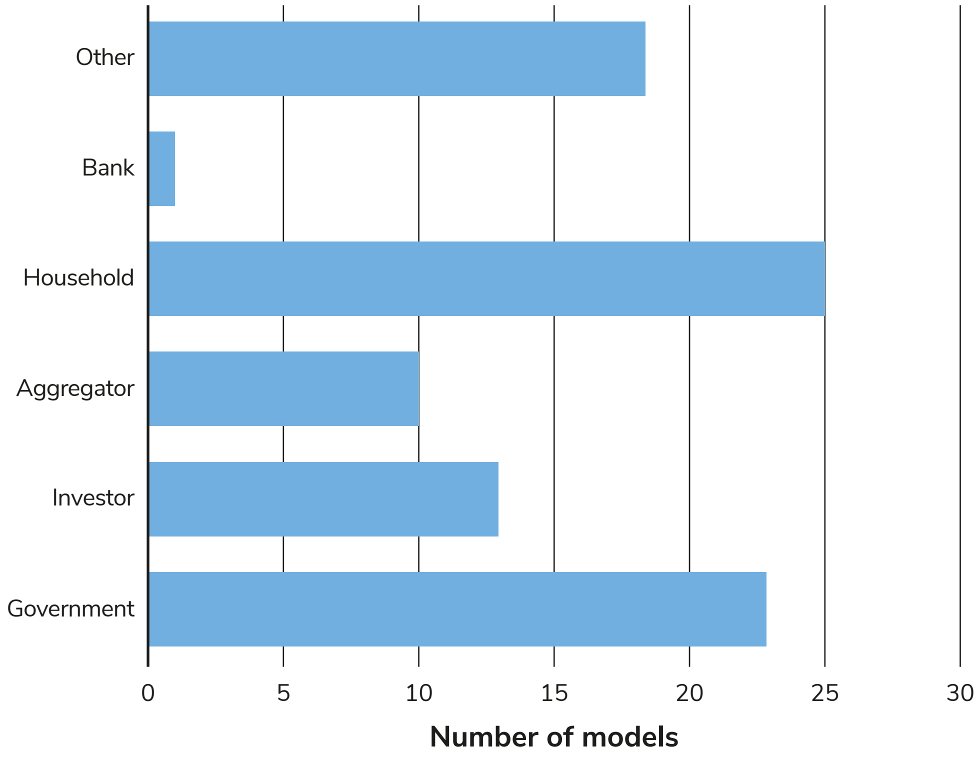
Energy models and behaviour

Policy brief #1 in this series outlined how UK energy modelling has in recent years started to shift from a predominate focus on techno-economic elements to also include societal and individual behaviour. For more information, please refer to figure 9 in brief #1.

One key aspect of this shift is the consideration of different decision makers and market participants – modellers call this the heterogeneity of agents. Energy system transitions heavily rely on consumers' energy demand decisions, on firms' willingness to invest in new technologies and on policymakers setting the correct incentives and rules. A large share of models (about 55%) still assume there is one overall decision-maker which acts rationally to maximise the cost-benefit of the energy system. This may seem a big simplification, but these models often trade off this assumption against very considerable detail on the temporal, spatial and technological aspects of the energy system.

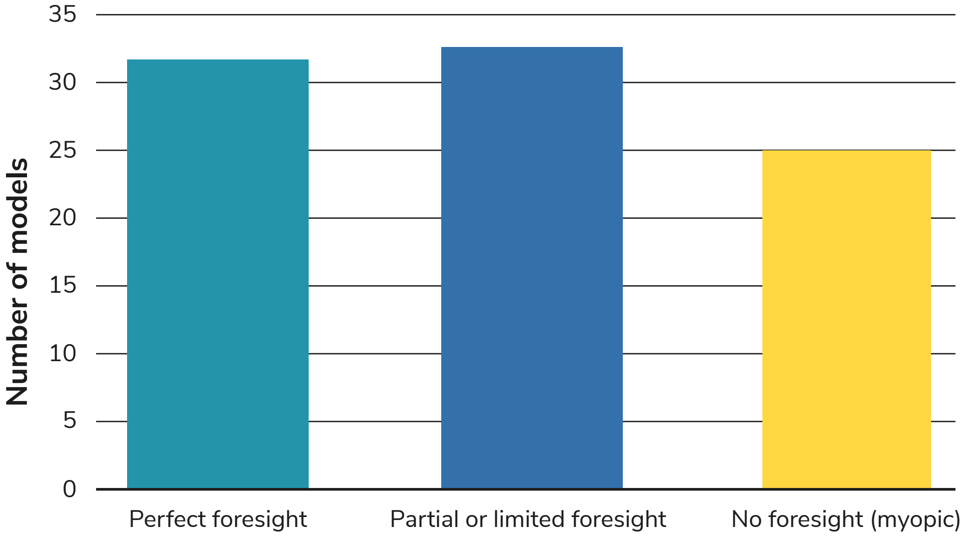
However, 45% of the models consider multiple agents in their modelling frameworks. This allows them to explore different motivations, knowledge, financial positions and attitudes to risk. The most common agent depiction (figure 9) are households (locations, income etc.), followed by government agents (e.g. national vs. local), representing this critical interaction in the policy process. Agent disaggregated models also pay close attention to market mechanisms by explicitly incorporating investor and (consumer) aggregators. Actors in other sectors, such as the industrial or finance sector, have not been well considered to date in UK energy models and these fields might need to be further explored in the future.

Figure 9. Different (heterogeneous) agents in models



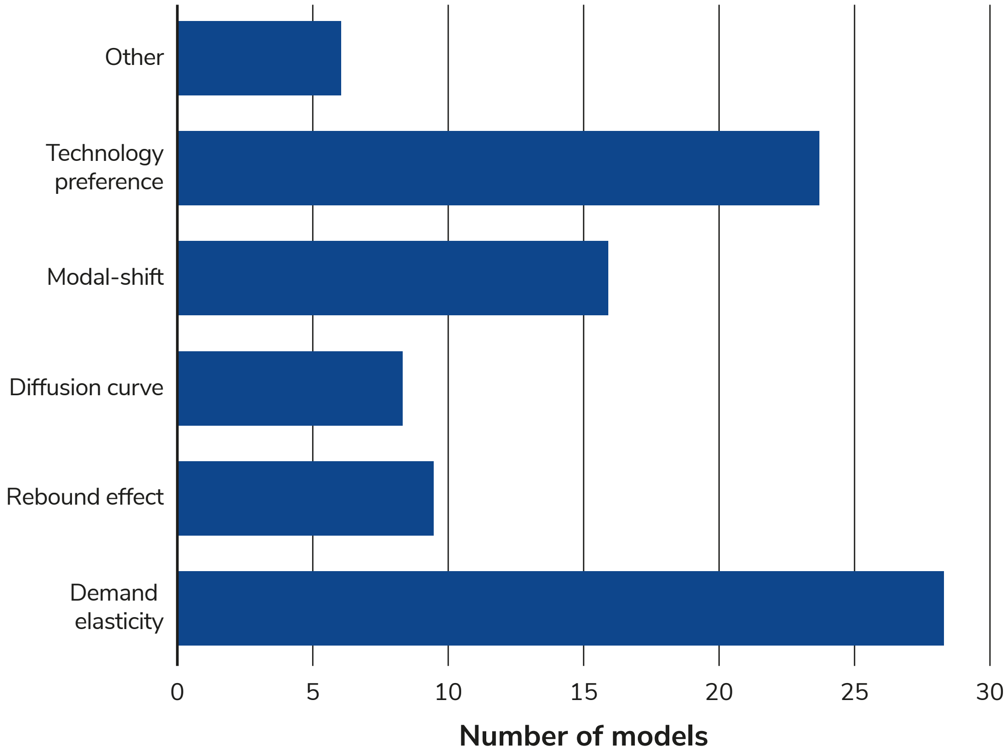
Another important characteristic of agents is their information availability, concerning future uncertainties (figure 10). Clearly, this links back to how models treat their overall time horizon (see figure 3). Around a quarter of models assume there is no information on future trends. Alternatively, around one third of models assume perfect foresight of future trends which again illustrates the computational and explanatory trade-offs in the overall level of spatial and technology detail. However in reality, decision-makers have some limited information on key developments, anticipating some trends, with other changes being a surprise, and the third of models with partial foresight should give different answers to those with no or perfect information availability.

Figure 10. Foresight capability in the models



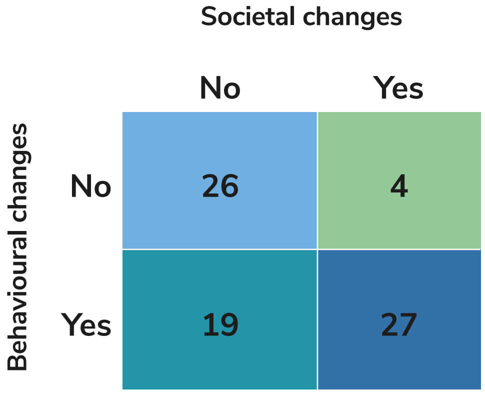
Similar to how technology learning is captured by models (figure 8), how models capture end-users' behaviour learning is also important (figure 11). Among all behavioural changes, demand elasticity (changing demand down/up as prices move down/up) and technology preference (consumers favouring a technology due to specific attributes such as convenience) are the two most commonly considered mechanisms, which are employed by around 30% of the models. The range of other mechanisms employed indicate the complexity of consumer behaviour across different energy sectors.

Figure 11. Type of behavioural changes considered



Overall, around 60% of models have mechanisms to account for behavioural change. Hence behaviour is better represented in UK models than broader societal change which is incorporated in around 40% of models and covers aspects such as demographics, education and environmental awareness. There is also a correlation between the consideration of behavioural change and the consideration of societal change (figure 12). This makes sense as individual behaviour takes place within the context of broader societal trends. When behaviour change is absent from the models, it is likely that societal change is also not explicitly taken into account, and the focus of those models is then on the techno-economic aspects of the energy systems (likely with greater spatial and temporal disaggregation).

Figure 12. Representation of behavioural changes and societal changes



Behavioural changes	Societal changes: No	Societal changes: Yes
No	26	4
Yes	19	27

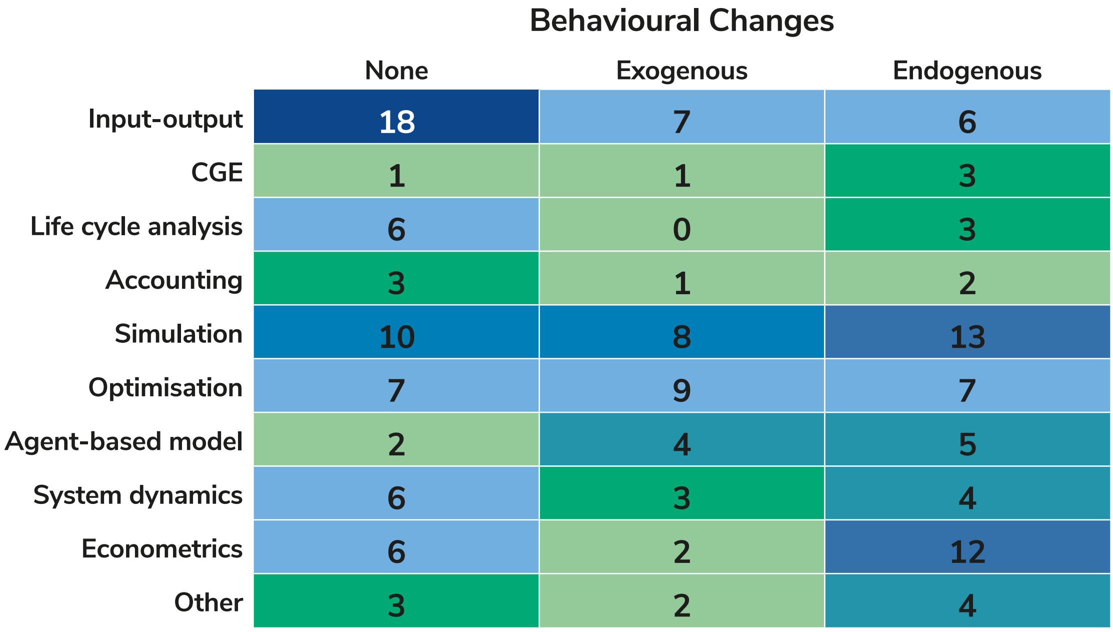
Figure 12 also implies the trade-off in models' focus on behaviour/societal factors and on technology/economic factors. Examining this in more depth, figure 13 and figure 14 respectively classify the type of treatment of behavioural and societal treatment as none, exogenous (outside the model) or endogenous (inside the model).

Looking across the models by type we see how many models do not consider societal changes at all or only as an external driver of the model. This illustrates in part a lack of data, and also the use of scenarios or narratives to capture societal change. Societal change involves many intangible or qualitative factors that might not be easily clarified in numerical terms. It also shows the prior focus of many UK models on how best to manage or change the energy system in terms of prices, technology operation and environmental impacts.

Behaviour change is more commonly targeted within specific model types, for example the underlying approaches of econometric and simulation models lend themselves well to this issue, with the latter covering the range of behaviour changes as detailed in figure 11. However a majority of models (notably input-output approaches) do not explicitly incorporate behavioural changes.

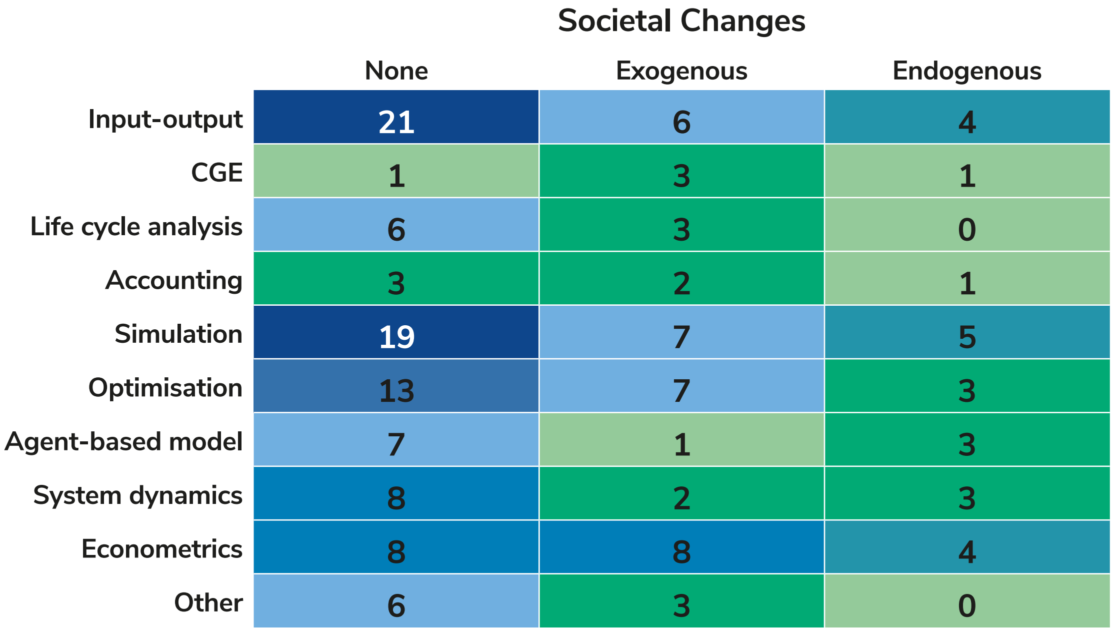
60% of models have mechanisms to account for behavioural change

Figure 13. Analytic method versus consideration of behavioural changes



	Behavioural Changes		
	None	Exogenous	Endogenous
Input-output	18	7	6
CGE	1	1	3
Life cycle analysis	6	0	3
Accounting	3	1	2
Simulation	10	8	13
Optimisation	7	9	7
Agent-based model	2	4	5
System dynamics	6	3	4
Econometrics	6	2	12
Other	3	2	4

Figure 14. Analytic method versus consideration of societal changes



	Societal Changes		
	None	Exogenous	Endogenous
Input-output	21	6	4
CGE	1	3	1
Life cycle analysis	6	3	0
Accounting	3	2	1
Simulation	19	7	5
Optimisation	13	7	3
Agent-based model	7	1	3
System dynamics	8	2	3
Econometrics	8	8	4
Other	6	3	0

Summary

This policy brief has highlighted how no single energy model can cover in detail all the elements of the energy system. The UK energy system encompasses different economic sectors, a wide variety of fuels and technologies, a host of different actors, a range of environment impacts, and a plethora of possible policy responses. Therefore there is always a trade-off in any one model's focus and design. This trade-off can be due to the conceptual underpinning (academic discipline and theory of the model) driven by the practical availability of data and computational power, or be shaped by the need to explain and communicate the findings to key decision makers.

In considering the strengths and weaknesses of UK energy models from the UKERC survey we focused on four key areas: time, space, technologies and behaviour.

Table 1 summarises the strengths and weaknesses of the full set of 76 UK energy models captured in the survey. When considered as a group, they represent the complexity of the real world energy system.

However, policy and industrial decision-makers should not only rely on a single model to underpin and evaluate their iterative choices as some dimensions would inevitably be missing or highly simplified. It is much better to be informed by a set of models from different disciplines and with different design criteria. To be comprehensive, policy-makers should consider linking model's inputs and outputs to derive new insights on the energy system's most intractable problems.

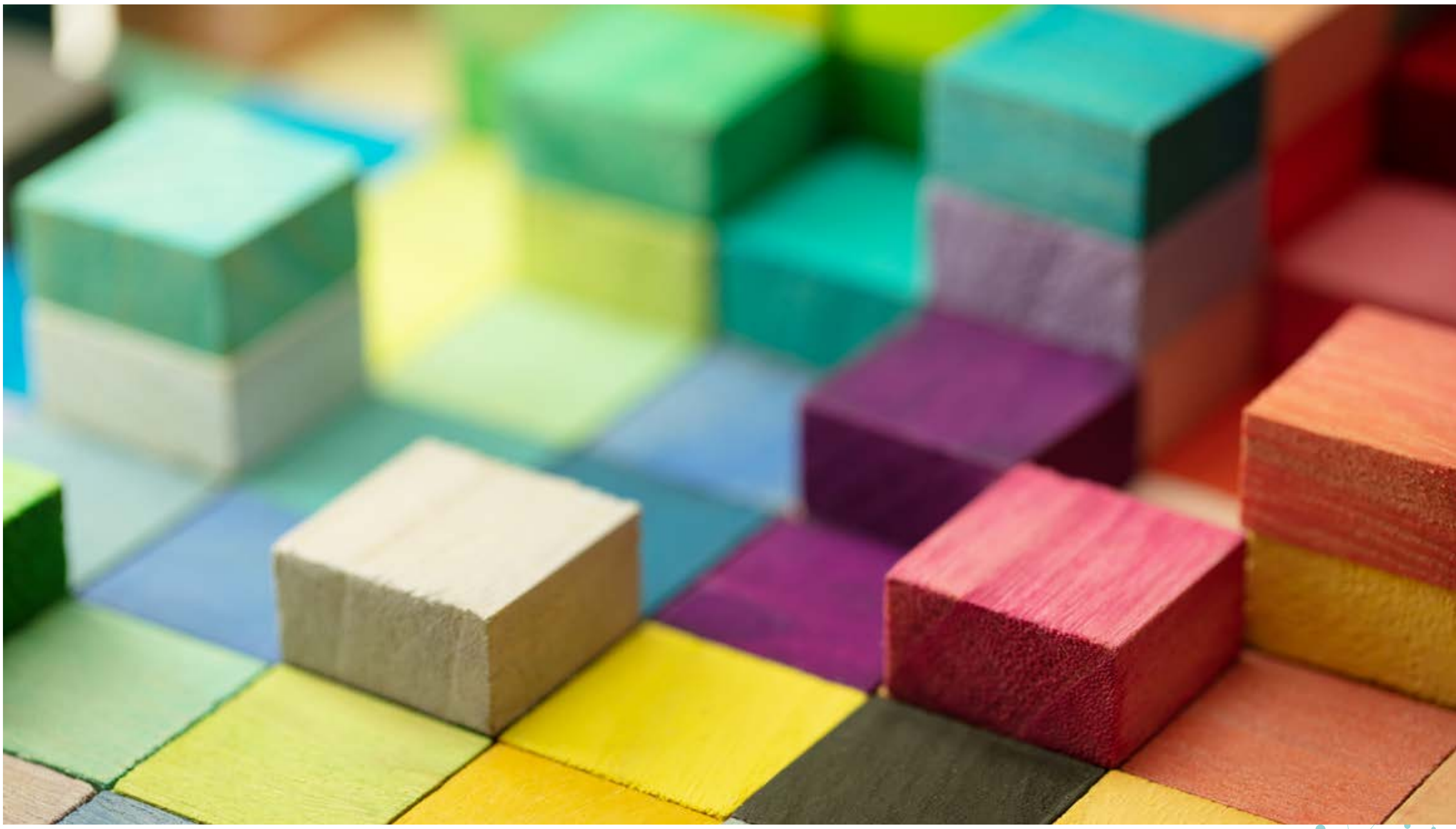


Table 1. Summary of the strengths and weaknesses of UK energy models

Category	Strengths	Weaknesses
Temporal representation	● UK energy models cover a wide range of target years (years in near future and after 2050) ● Both long-term transition and short-term variability can be well investigated with energy models	● Models with high temporal granularity (e.g. hours to minutes) are less likely to cover long-term transition horizons
Spatial representation	● Both national and regional/city levels are covered by energy models ● Electricity infrastructures and international interconnection well covered	● Models with high spatial granularity might usually cover specific subnational regions ● Sometime infrastructure depiction is stylized ● Heat, hydrogen and CO_2 infrastructures are relatively less common in many models
Technological representation	● Critical abatement measures (e.g. carbon capture and hydrogen) have been well represented in the models ● The influences of technology learning are reasonably reflected	● Learning mechanisms are often exogenous (external) to the models ● Relatively few energy models can take land-use management into account
Behavioural and societal representation	● Complexity of decision-making processes of heterogeneous (different) agents is reflected in many UK energy models ● Households and policy-makers are well represented ● Imperfect ("real-world") foresight in model horizon often captured	● Financial agents are less likely to be considered ● A greater variety of behavioural changes should be explored in the future ● Broader societal trends are generally overlooked or only incorporated via an external scenario

The future policy briefs in this series of four from the UKERC modelling survey will focus on (brief #3) the construction, maintenance and transparency of models and (brief #4) on applications to decision making in government and industry.

These subsequent briefs will continue the discussion on how the strengths and weaknesses of different models (or a combination of models) can most effectively influence decision making.

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