Modelling the interactions between national and local energy systems: research gaps

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Introduction

Decarbonisation across sectors and different scales of the energy system - national, regional, and local - is necessary to meet the UK net zero carbon emissions target by 2050. Interactions between these multiple scales of the energy system goes beyond the difficulty in modelling technical components and flows of energy and involves people, institutions (finance, national-local governments etc) and potential tensions and feedbacks.

To investigate these issues, the challenges for modelling local and regional energy systems are outlined, and the capabilities of selected UKERC energy system models (CGEN, TIMES and Strath ES) with a focus on interactions between national and local energy systems are assessed.

We identify how the modelling tools can support specific research questions (i.e. mapping research questions to the models), and we summarise gaps in current modelling capability and the potential for further model development. This includes utilising the appropriate choice for spatial and temporal resolutions, modelling the increasing complexity of regional and local systems (electric vehicles, distribution generation, demand side management) and integrating human behaviour, social/market structures and governance.

Interactions between national and local levels of the energy system

Meeting the UK net zero carbon emissions target by 2050 will require a decarbonised electricity power system and substantially lower heat-related emissions from buildings (CCC, 2019). These are formidable objectives and will require laying the foundations for these emission reductions in a timely manner. Local energy systems have been identified as being important to meet the "net-zero" emission target in the UK (UKERC, 2020). The local optimisation of decarbonised supply and demand is likely to reduce the whole system costs of decarbonisation (UKRI, 2022). In addition, the UK regions and local authorities have a great deal of influence on decarbonisation, especially with regards to infrastructure planning which could focus on local circumstances such as availability of land, wind resource for wind farms and interactions with industrial clusters for waste heat. Local and combined authorities could also introduce incentives (Webb et al., 2017) to insulate social and private rental housing, discourage car miles travelled, increase cycling routes while also supporting technologies and networks such as district heating systems and electric vehicle infrastructure.

In contrast, national systems and policies could impact the financial and technical viability of certain options available locally. For instance, substantial upgrades in transmission network and generation (e.g. nuclear) capacity could impact local energy system investment. Also, potential constraints such as inflexible generation at transmission level may incentivise local and integrated energy systems if they show certain levels of flexibility (Bell and Gill, 2018; Mancarella and Chicco, 2013). The challenge is how to align national policies and local decisions to maximise the exploitation of the low carbon resources/technologies in a way that benefits both local (e.g. air quality) and national objectives.

Several studies (Chaudry et al., 2014; Mancarella et al., 2016) have assessed the operation and planning of future low carbon energy systems. However, whole energy system representation, considering spatially distinct local energy systems and connections to national gas and electricity transmission system models is extremely challenging (Pfenninger et al., 2014, Hawker and Bell, 2019). The level of detail and amount of data required makes these models difficult to build and computationally demanding to operate over high temporal resolutions (e.g. hours) over long time horizons, i.e. more than 30 years.

Planning of low carbon systems may also fall into the remit of bodies not traditionally involved with energy planning in the UK, such as local authorities and community groups. Actions taken by such groups – such as setting local targets for carbon reduction with a greater ambition than the wider system or supporting localised financing of low carbon technologies – may be taken unilaterally and without consideration of how they fit within the trajectory of the wider system. This both creates opportunities such as 'learning by doing' and playing to the strength of local actors to advance the decarbonisation agenda ahead of national-scale policy, but also creates tensions in potentially disrupting the planning activities of incumbent energy system stakeholders[1].

This report outlines the capability of energy system models available across UKERC's research on Local and Regional Energy Systems with a focus on modelling interactions between multiple levels of the energy system. We identify how the modelling tools can be used to address specific research questions (i.e. mapping research questions to the models). We summarise gaps in current modelling capability and potential linkages with other UKERC research.

1. In GB, National Grid operate the national gas and electricity transmission system. Regionally there are multiple gas and electricity distribution companies such as Cadent, Wales and West Utilities, Scottish power, SSE, Northern PowerGrid, Electricity Northwest etc.

Overarching challenges for regional and local energy systems

The strategy for net zero UK greenhouse gas emissions is expected to include locally or regionally integrated systems for heat, power, transport and energy storage. In theory, integrating smart technologies (including storage, demand-side response, and efficiency) on a local scale improves the system's ability to optimise its use of distributed power generation. It may also improve the 'whole system' economics of clean energy by helping to balance supply and demand on a network with high levels of variable renewable electricity. Localised systems are also expected to optimise use of any available heat (and surplus electricity) sources for district heating (DH) with thermal storage, reducing the total costs of heat decarbonisation. New local and regional energy business models are in turn envisaged as a means to retain value, and improve productivity, welfare and energy justice in local economies. These policy ambitions are surprising, given past UK emphasis on economies of scale from centralised generation and markets.

Technical challenges

The change in focus has appeared in response to several important challenges that have started to affect the UK energy system. For instance, growth in distribution connected renewable electricity generation[2] is presenting technical challenges for network operators and the regulator in managing power flows in distribution networks which were designed as largely passive, one way, distributors of electricity to end users, and not as two-way balancers of supply and demand. In particular, growth of micro renewables and storage at the domestic level, and the expected electrification of transport and some heat, are adding uncertainties over local network planning, costs and operation.

Whilst managing these variable two-way flows of power presents technical challenges, there is scope for the development of local flexibility, both through demand-side response and storage, to reduce the need for new capital investment in networks. A range of 'flexibility marketplace' pilots, designed around local aggregators and storage, are underway to explore the role of these services in decarbonised energy systems. For the regulator, there are particular questions about standards for electricity distribution services, flexibility procurement and market platforms, while avoiding perverse incentives.

In addition, the decarbonisation of heating is likely to involve a significant role for both electrified heat and heat networks (Lowes et al., 2020). The electrification of a significant proportion of heat demand will increase the peak capacity and throughput requirements for electricity systems increasing the challenges, discussed above, of managing electricity network investment and incentivising distribution-level flexibility services (Rosenow et al., 2020). Heat networks are projected to meet approximately 20% of heat demand by 2050, up from 3% currently, and can supply heat from a range of decarbonised sources such as large-scale heat pumps, and 'waste' or residual heat sources (accumulated heat) (BEIS, 2021). The development of heat networks necessitates local planning to match local heat sources and demand. These challenges in decarbonising heating have led to increased focus on the role of local energy system planning and the integration between heat and power systems.

2. In GB over 35% of total installed generation capacity is connected at the distribution level (Gordon et al., 2022).

Societal interests

Technical change is only part of the drivers towards more localised energy system; there are social drivers towards more localised energy systems. The declaration of a 'Climate Emergency' by over 80% of UK local authorities since 2018 has focussed many local authorities on their role in energy systems and emphasised the role of democratic decision making in climate action. Additionally, debate about decarbonising heat has highlighted the potential for locally differentiated solutions, requiring local authority (LA) planning. Many LAs have ambitious plans, but investment varies, and projects are prone to stalling. Political uncertainty, limited funding to develop feasible and investable business plans, and a perceived maze of government departments, financial sources and procurement rules are all barriers to more coordinated action at the local authority level. In addition, UK devolution has resulted in a system whereby considerable powers relevant to energy systems are held by the Scottish and Welsh governments, providing scope for different approaches to decarbonisation to be pursued across the devolved nations and England.

UK central and devolved governments are exploring new frameworks, albeit investment is limited. UK department of Business Energy and Industrial Strategies' (BEIS) Local Energy Programme funded development of outline strategies by (English) Local Enterprise Partnerships with £1.6 million in 2017. A £4.8 million programme has established five pilot Local Energy Hubs in England. Scottish and Welsh governments also propose LA engagement, but local and regional governance is constrained by powers reserved to Westminster. The Scottish government has the only proposal for new LA statutory powers for heat and energy efficiency strategies and district heating regulation, but there are political tensions over resourcing.

Interactions between technical modelling and societal interests

Solutions cannot emerge from data, engineering models and technical innovation alone. Technical modelling and societal interests are inextricably interconnected, as exemplified in the 2011-2019 Smart Systems and Heat (SSH) programme led by ETI/Energy Systems Catapult (ETI, 2021). SSH envisages that local heat planning, informed by cost-optimised modelling tools and coordinated by local authorities, will support markets for heat services. However, three pilots revealed the gulf between engineering models and LA approaches to energy and spatial planning, given a lack of LA resources, and difficulties in aligning LA, DNO (Distribution Network operators) and developer responsibilities, timetables, and valuation metrics.

The SSH scenarios also highlight that different actors may assume differing roles for local government: while the SSH scenarios highlight that providing "heat as a service" could be beneficial, this involves local energy planning with a significant role for LAs, whereas, in reality, decisions around changes to heat provision may be more likely to be based on market choices by individual owner occupiers. This reality means that local democratic participation in a workable consensus over renewable heat is marginalised.

Overall, there are questions about whether localised or regionalised energy systems, which serve local goals and encompass net zero 'whole system' benefits, can be realised in UK liberalised, centralised markets. Contested assertions about finance, technology, types of provision, regulation and ownership create new demands on governance for potentially different local, regional and national priorities, with differential risks, costs and benefits. New developments are addressing some uncertainties. Examples include the £102.5 million UK Industrial Strategy Challenge 'Prospering from the Energy Revolution' for local energy system demonstrators, designs and research. Additionally the ED2 price control process for distribution networks is requiring DNOs to provide enhanced evidence of consultation with local stakeholders and promoting the integration of local authority and DNO priorities through the development of Local Area Energy Plans (LAEP).The National Infrastructure Commission 2019 Report also proposes greater devolution of regulatory processes for infrastructure investment, including local scale where spatial planning interacts with network regulation.

Additionally, there is also a need for comprehensive, stable support for thermal retrofit of buildings to reduce system costs; incentives for net zero integrated local systems, including socio-technical demonstrators; a transparent, standard framework using socio-economic metrics for options appraisal, so co-benefits can be integrated into decision making; and a local citizenship focus, recognising clean energy as a public good in inclusive, democratic societies.

Variation in powers across the devolved governments of Scotland and Wales also creates potential for different approaches to energy system decarbonisation across the UK central and devolved Governments. Powers over regulation, licensing, and tax of energy *supply* in England, Scotland and Wales are reserved to the UK Parliament, but many *demand* side policy powers, for example relating to energy efficiency, are devolved. In addition, the Scottish and Welsh Governments are also responsible for many policy areas relevant to energy systems including economic development, land use and development planning and consents, environment and climate law, local government and taxes, housing and building standards (Webb and van der Horst, 2021). This creates questions about whether some areas of the UK will progress faster on some aspects of decarbonisation or take different strategic decisions about priorities. Modelling these interactions will be challenging and contingent on the questions being asked and simplifications may well be required.

National, regional and local UKERC energy system models

Three UKERC models are utilised to investigate the interactions between local, regional and national energy systems.

The characteristics of three UKERC energy system models

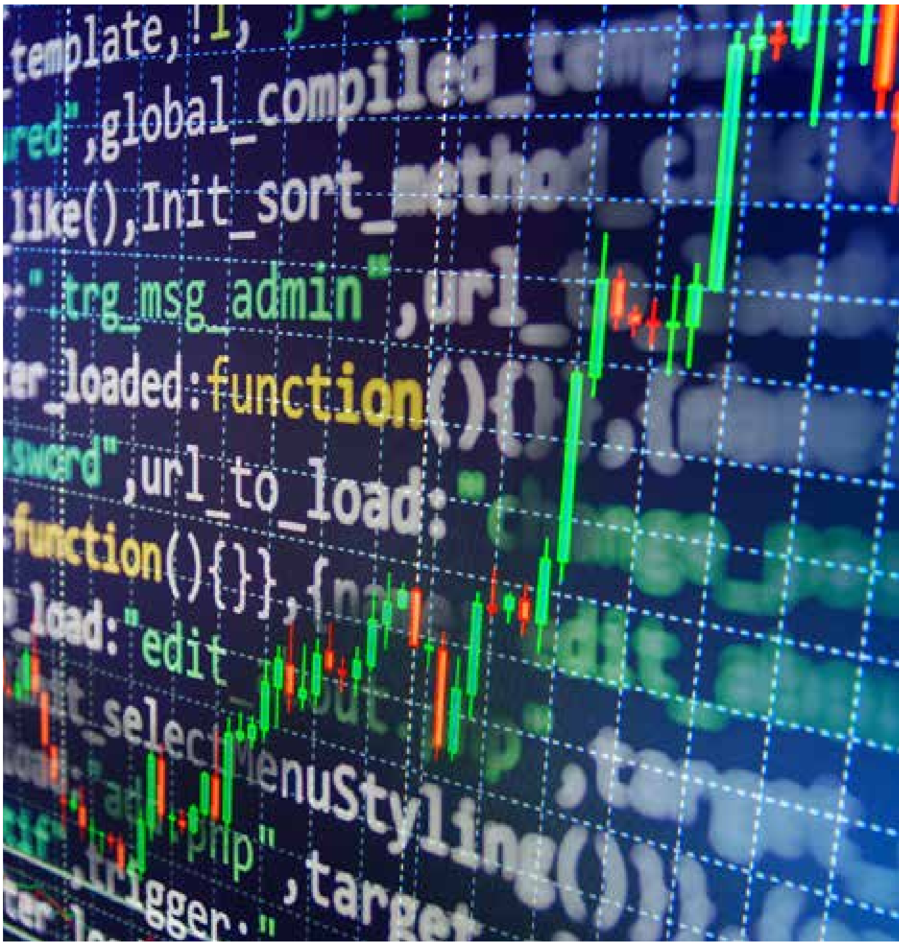
The energy system models differ in terms of methodology, temporal and spatial granularity and key assumptions as shown in Table 1:

Table 1. Summary of selected UKERC energy system models

	UKERC Energy System models		
	CGEN (Combined Gas and Electricity Network)	Strath ES	UK TIMES
Model updates and variations	CGEN + Energy Hubs	UKERC Phase 3 (local), Scotgov hydrogen modelling (regional), Phase 4 resilience (national)	
Methodology	Operational cost optimisation	Hybrid optimisation (weighted least-cost/least-emissions).	Least-cost Optimisation minimising total discounted system cost.
Operational planning	Yes (through costs, can set differing objectives for national/regional/local systems)	Yes, but for a static single-horizon system	Yes
Infrastructure planning	No, but can interact with a planning model (new infrastructure)	Yes, but for a static single-horizon system.	Yes, annual infrastructure planning into future (e.g. 2050).
Spatial resolution	Up to user (multiple nodes across transmission-distribution scales)	Pseudo-spatial representation of each network level, typology-based rather than real-world.	Single node national level for UK incl. NI
Temporal resolution	Yearly to hourly (up to user)	15 mins to hourly (using time masking for improved computation)	Yearly broken down into representative time-slices. Options include 1, 6, 16, and 192 time-slice versions.
Assumptions (inputs)	Energy demand (kWh/MWh) for each location (node), time and sector. Technology OPEX	Energy service demands by location, time and sector, technology CAPEX/OPEX	Energy service demand drivers by sector over time. Techno-economic data describing technology options at all levels (CAPEX, OPEX, efficiencies, availabilities, etc.) Constraints on speed and depth of system changes.

	UKERC Energy System models		
	CGEN (Combined Gas and Electricity Network)	**Strath ES**	**UK TIMES**
Demand side representation	Demand can be set by sectors (transport, residential, industry, services, agriculture, etc), location and at energy transmission and distribution scales.	Energy service demands by sector (disaggregated into domestic and industrial/commercial only) at each network voltage/ pressure level.	End use energy service demand by sectors (transport, residential, industry, services, agriculture, etc) Basic retrofits and efficiency improvements can lower demand in chosen sectors.
Supply side modelling	Energy supplies (gas, renewables/ imports) - transmission systems (gas/ hydrogen and electricity) - Distribution system through energy hub modelling of gas/hydrogen/ electricity/heat systems - Modelling of conventional plants (Nuclear/CCGT) and intermittent renewable generation (PV, Wind)	Time-variant renewable resource (wind/solar) by time of day and season (historical sampling) - interconnectors as fixed import/export (to be improved) - electricity generation merit-order stack - natural gas as fixed-price commodity - hydrogen system as merit stack of sources	Whole system representation of the supply side including: - upstream extraction and processing of all fuels - renewable resources per type and category - basic land use and bioenergy options - imports / exports of (near) all commodities - transformation and supply to all downstream sectors - power sector including wide ranges of conventional and VRE options - sectoral technologies for e.g. heating, transport, industrial activity etc.
Notes	Designed to derive optimal operation over transmission (electricity/gas) and distribution systems (Energy Hub - gas, electricity, hydrogen, heat networks). Model can accommodate additional operational constraints locally or nationally or adjust the operational objective function.	Broadly designed to derive optimal network capacity and costs/emissions associated with the optimal dispatch of given technology scenarios for static future years, rather than to determine the optimal mix of technologies or to model the transition.	Designed to derive cost optimal whole system design – including technologies in all sectors, including power and upstream sectors. Runs to meet existing CCC carbon budgets and our NZ target in 2050 over all GHG emissions (CO2, CH4, N2O, HFC) accounted for overall and in each sector. Can accommodate complex constraint structuares on any combination of cost and operational parameters. Does not account for feedbacks, behavioural and non-linear aspects.

All three models described are, at their core, optimisation models. Typically, an optimisation model minimises the total investment costs and/or total operating costs of the energy system. The cost minimisation is subject to emission targets, policy goals and other technical constraints (e.g. energy output limits, resource or technology availability etc) of the energy system. The optimisation in the CGEN and Strath ES models can be modified to include multiple objectives (e.g. using a function that includes least costs and emissions weighted to some degree) – this allows for multi-criteria optimisation.



The intention of these optimisation models does not aim to reproduce the idealised activity of a perfectly-functioning energy market, but rather to identify the technologies and behaviours within scope which, if sufficiently invested in / incentivised, will lead to the maximum emissions reduction across the economy.

In essence these three models are ideal as test-beds for alternative configurations of complex systems to highlight important dynamics and tipping points within the energy system, emphasise technical barriers that need to be overcome or non-obvious system-wide configurations that can help to reach common goals. The identification of key inter-relations in the energy system can then help support future policy decisions or to input into broad design principles for the decarbonisation of a large-scale system. While this has obvious benefits in being able to provide a holistic view not apparent within individual sectors, a key weakness in optimisation models is the behaviour known as 'penny-switching' whereby the model will shift between technologies if one is seen as even infinitesimally cheaper than another, which does not reflect real-world investment. This can be addressed by the use of e.g. sensitivity analyses where the robustness of the result of the optimisation is tested by making slight changes to input parameters and re-running the model.

Complexity of energy system models

Due to the number of technologies, spatial elements and timesteps involved, energy system models can have a very high number of dimensions and input/output parameters, making them potentially extremely computationally intensive to solve (i.e. requiring significant computing resources to solve). As a result, most energy models will have to exercise some form of compromise over the level of detail that they use to represent the system. Depending on the focus of the model or of the study at hand, this may involve aggregating spatial and temporal scales, reducing the number of technology options available in a given sector, or otherwise simplifying how complex sub-systems are represented.

Looking at the models described here offers examples of these compromises and trade-offs. The UK TIMES framework looks at the full supply chain of energy services across the different sectors of the economy with a view to map the transitions required as holistically as possible in relation to our future energy targets. As a result, the operational detail relating to integrated energy systems has been aggregated when considering e.g. electricity and gas transmission and distribution systems. The system takes an energy balance approach to matching supply, storage and conversion to satisfy demands at each planning time step in each sector. In contrast, CGEN as an operational tool describes the detailed operation of integrated gas and electricity networks. The CGEN model includes the operation of seasonal gas storage, gas linepack, compressor stations, and power ramping of electricity generators. These operational models allow the investigation of interdependencies in operating integrated energy systems. By choosing to detail the operational side of the electricity and gas systems however CGEN will necessarily compromise on representing, for example, detailed demand sector energy transformation and use. The Strath ES model exists between the two, featuring planning of static future energy systems based on constrained technology mixes and optimising capacities of chosen elements (such as network capacities and/or storage technologies based on existing infrastructure and upgrade costs).

Models at multiple scales and across methodologies

There are a multitude of models as documented by Li & Strachan (2021) and Hall et al., (2016) who reviewed and categorised prevalent UK energy system models. Both papers highlighted modelling focus on the national and to a lesser degree regional scale. The Climate Change Committee (CCC) and BEIS currently use UK TIMES and ESME for preparing carbon budgets and strategies on heat, bioenergy and hydrogen, alongside soft-linked sector-specific modelling. No single model (at present) can represent multiple energy vectors across scales (transmission/distribution) and sectors. Traditionally regional and local scale models tend to be focussed on demand, and disconnected from supply systems, including distribution and transmission, as demonstrated in Sola et al.'s (2020) review of urban scale energy models. Despite this, urban energy modelling is a dynamic area of activity, with increasingly sophisticated approaches being developed there is a need to better understand the application and integration of models at different spatial scales.

An alternative methodology to the optimisation tools presented is Agent-Based Modelling (ABM) where the behaviour of energy system actors is captured and simulated in order, for example, to come closer to reproducing observed market behaviours, or the actions of consumers with regards to technology uptake. ABM is not an area of expertise within UKERC's local and regional energy systems research, but there exists such capability within the Energy Infrastructure Transition Theme.

Mapping selected UKERC models to research questions

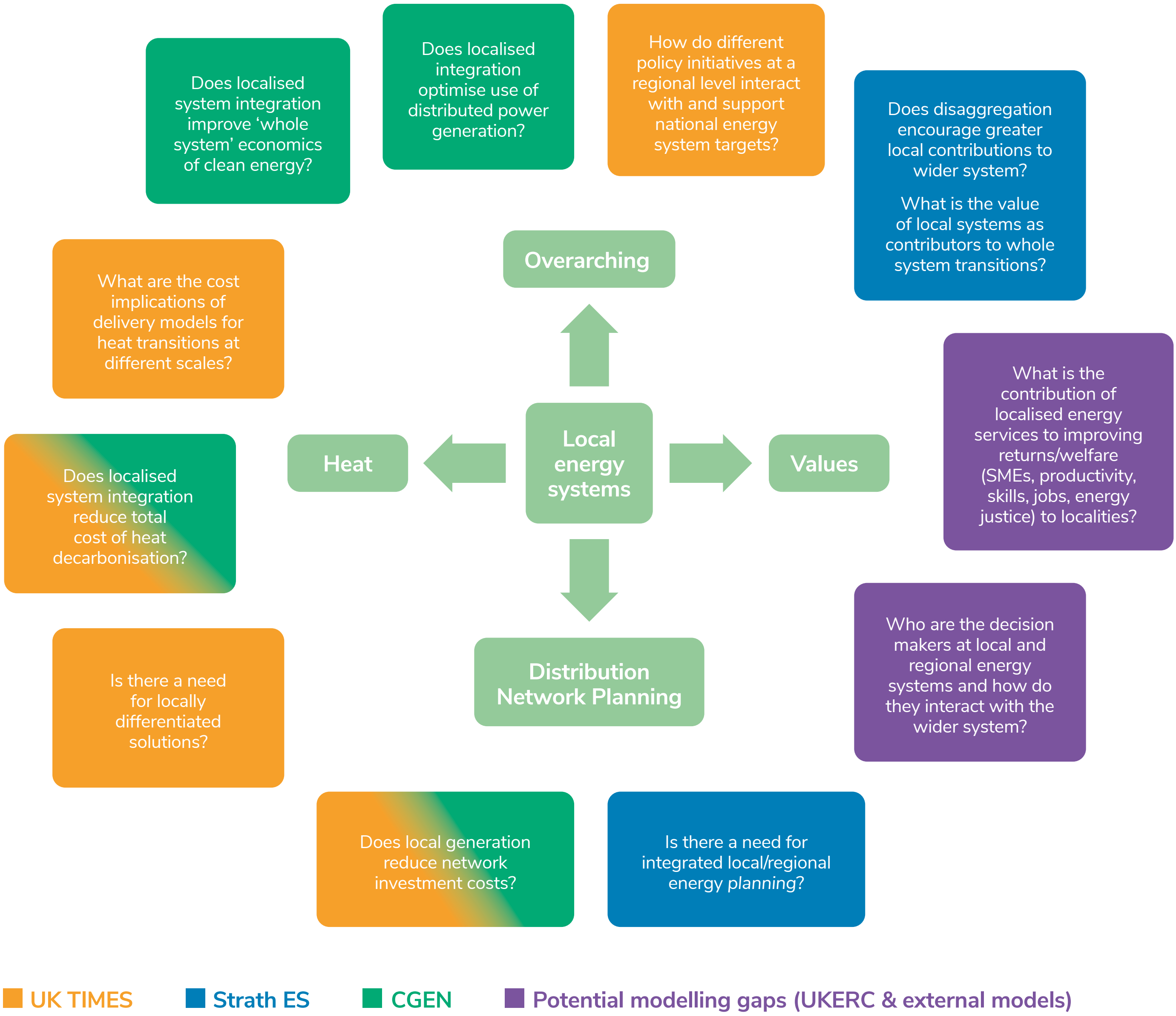
Reflecting the diversity of issues noted in the introductory paragraphs of this paper, policy experts both across UKERC and within the wider energy research community cover a wide range of social, technical, economic and policy specialisms. As a result, research questions that appear in this mapping exercise reflect the expertise of members alongside the opportunities for integration across research areas.

Taking account of the whole energy system context described above, UKERC researchers took part in an open discussion and mapping exercise to highlight clusters of compatible research questions that span social, regulatory and policy aspects for local energy systems (see Appendix A for workshop details). The result of this discussion is outlined in the four research areas put forward below. The models available within the UKERC Local and Regional Energy Systems theme were then paired with the research questions. This was done in relation to their current state but also with a view to their ongoing development and their theoretical ability to consider given thematic questions. This defined what questions could be addressed with existing models and therefore highlighted gaps in modelling capability. The outcome of modelling-research question mapping process is encapsulated in Figure 1.

Research issues were divided into four sections –

- **Overarching** – identifying the broad opportunities afforded by facilitating local energy systems;
- **Heat** – assessing opportunities in the specifically local problem of reducing emissions from residential and commercial heat demand;
- **Values** – the extent to which local energy systems facilitate or interact with broader societal functions and externalities, such as health and wellbeing, productivity and employment, or consumer empowerment;
- **Distribution Network planning** – the specific case of how Distribution Network Operators are planning for future changes in energy demand and decentralisation of resources via their submissions to the RIIO-ED2 framework.

Figure 1. Mapping selected energy models with research questions[3]



The three selected UKERC energy modelling tools[4] offer insights on technical capability, cost and emissions of the energy systems, but very limited outputs around 'value' (e.g. skills, jobs, justice etc) and interactions between various decision makers (e.g. local authorities, devolved governments and UK government, or local energy system operators and DSO, ESO), but again with an 'idealised' representation of decision making based on perfect foresight and economic rationality. Additionally, a range of questions regarding how the outputs of models are used in decision making (e.g. how do uses/needs differ across scales, what sorts of analysis do multi-scale models enable, by whom and how do different decision-makers understand inputs, outputs and limitations) needs greater attention especially with regards to evaluation of models which would in turn support further modelling enhancements.

3. Note that Figure 1 maps the theoretical capabilities that the UK TIMES model will display once regionalised.
4. The research questions addressed by the current models in UKERC's research on local and regional energy systems are outlined in Appendix B.

Conclusions

We have identified gaps with current models and requirements for future modelling of local and regional energy systems and interactions with national infrastructure. We note that collaborations between modellers and social scientists are necessary to adequately address gaps. Modelling is also not necessarily applicable to all of the gaps identified.

There are several challenges that need to be addressed as we consider model improvements including:

Choice of appropriate resolution with respect to time and space: as we move to a decarbonised energy system dominated by renewables, the requirement for adequate flexibility and storage capacity will increase. From a modelling perspective this may well require more detailed spatio-temporal resolutions. In particular, consideration should be given to peak/stress events as those which shape the energy systems on which society relies, rather than averaged flows of energy.

Treatment of uncertainties: there are many existing and novel sources of uncertainty, for example - wind/PV generation potential and variability, changes in system design/ policies, emergence of new energy vectors and technologies, major shock/losses, prices/ costs etc - a more formal manner in which to accommodate and explore uncertainties is required.

Growing complexity of the energy system especially as local systems are modelled: smart devices, EVs and distributive technologies are expected to grow within local and regional systems, this will increase modelling complexities and will need to be managed in order to ensure tractable models. Additionally, greater emphasis is likely to be placed on modelling regional and local energy systems and their interactions with national/ transmission networks.

Integrating human behaviour and social risks and opportunities: local energy systems are where consumer behaviour interacts with decarbonisation policy, and where behavioural interventions or demand-side participation will be enacted. This requires understanding of the motivations and reactions of consumers, such as how people plan their energy use, their awareness and treatment of carbon intensity, and how they react to financial and non-financial incentives to modify their energy use. In order to capture this in energy models, the extent to which people act as rational economic consumers, and how energy users respond to system stress events should be investigated by reference to the social science literature. Integrating these behavioural aspects into techno-economic energy simulation and optimisation is complex, but may reveal substantial new opportunities for alternatives to capital-intensive supply-side investment.

The research gaps identified are relevant across multiple UKERC themes - and the wider energy research community - and there is a strong case to coordinate efforts to address common research questions. Requirements for future model development need to take account of local energy vectors alongside the backbone national system to assess credible pathways to supply regional and local energy demands whilst meeting economic, sustainability and resiliency objectives.

Lastly, the audience for such modelling is highly diverse, encompassing a range of local and regional energy actors, with a wide spectrum of pre-existing knowledge and awareness of extant and future systems and technologies. Integrated modelling of such systems needs to consider the communication of outputs to stakeholders. Results of modelling should be communicable, explicable, and actionable – if not generating policy/investment recommendations themselves, then at least providing evidence in a manner that can be utilised by stakeholders within their particular decision-making context.

References

BEIS. (2021). *Heat and Buildings Strategy*. HM Government.

Bell, K., Gill, S. (2018). Delivering a highly distributed electricity system: technical, regulatory and policy challenges. Energy Pol. 113, 765–777. https://doi.org/ 10.1016/j.enpol.2017.11.039.

Chaudry, M., Jenkins, N., Qadrdan, M., Wu, J. (2014). Combined gas and electricity network expansion planning. Appl. Energy 113, 1171–1187. https://doi.org/ 10.1016/j.apenergy.2013.08.071.

Clegg, S., Mancarella, P. (2016). Integrated electrical and gas network flexibility assessment in low-carbon multi-energy systems. IEEE Trans. Sustain. Energy 7, 718–731. https://doi.org/10.1109/TSTE.2015.2497329.

Climate Change Committee (CCC), (2019). Net Zero the UK' s contribution to stopping global warming

https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

Energy Technologies Institute (ETI) – https://www.eti.co.uk/programmes/smart-systems-heat, website accessed 01/2022.

Gordon, S., McGarry, C., & Bell, K. (2022). The growth of distributed generation and associated challenges: A Great Britain case study. *IET Renew able Power Generation, 1.* https://doi.org/10.1049/rpg2.12416

Hall, L.M.H., Buckley, A.R. (2016). A review of energy systems models in the UK: Prevalent usage and categorisation, Applied Energy, Volume 169, 2016, Pages 607-628, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2016.02.044.

Hawker, G.S., Bell, K.R.W. (2019). Making energy system models useful: good practice in the modelling of multiple vectors. Wiley Interdiscip. Rev. Energy Environ. 1–15. https://doi.org/10.1002/wene.363.

Li, P., Strachan, N. (2021). Energy Modelling in the UK: Strengths and weaknesses, UKERC, https://ukerc.ac.uk/publications/modelling-strengths-weaknesses/

Lowes, R., Rosenow, J., Qadrdan, M., & Wu, J. (2020). Hot stuff: Research and policy principles for heat decarbonisation through smart electrification. Energy Research and Social Science, 70, 101735. https://doi.org/10.1016/j.erss.2020.101735

Mancarella, P., Chicco, G. (2013). Integrated energy and ancillary services provision in multi-energy systems. In: Proceedings of IREP Symposium: Bulk Power System Dynamics and Control - IX Optimization, Security and Control of the Emerging Power Grid, IREP 2013. IEEE, pp. 1–19. https://doi.org/10.1109/IREP.2013.6629423.

Rosenow, J., Lowes, R., Broad, O., Hawker, G., Wu, J., Qadrdan, M., & Gross, R. (2020). The pathway to net zero heating in the UK. UKERC, https://ukerc.ac.uk/publications/net-zero-heating/

Sola, A., Corchero, C., Salom, J., Sanmarti, M. (2020). Multi-domain urban-scale energy modelling tools: A review, Sustainable Cities and Society, Volume 54, 2020, 101872, ISSN 2210-6707, https://doi.org/10.1016/j.scs.2019.101872.

Pfenninger, S., Hawkes, A., Keirstead, J. (2014). Energy systems modelling for twenty-first century energy challenges. Renew. Sustain. Energy Rev. 33, 74–86. https://doi.org/10.1016/j.rser.2014.02.003.

UKERC, (2020). Review of energy policy 2020, https://ukerc.ac.uk/publications/review-of-energy-policy-2020.

UKRI, (2022). Smart local energy systems: the energy revolution takes shape, https://www.ukri.org/publications/smart-local-energy-systems-the-energy-revolution-takes-shape/

Webb, J., Horst, D.v.d. (2021). Understanding policy divergence after United Kingdom devolution: Strategic action fields in Scottish energy efficiency policy, Energy Research & Social Science,

Volume 78, 2021.

Webb, J., Tingey, M., & Hawkey, D. (2017). What We Know about Local Authority Engagement in UK Energy Systems: Ambitions, Activities, Business Structures & Ways Forward. UKERC, http://www.ukerc.ac.uk/publications/what-we-know-about-local-authority-engagement-in-uk-energy-systems.html.

Appendix A

UKERC Local and Regional Energy System research modelling workshop 20 November 2020

Key research questions on the interactions between national and local or regional energy systems/stakeholders; highlighting what is expected from modelling work, and what areas need quantification from modelling outputs.

Research Questions

- RB: The cost implications of different delivery models for heat transition at different scales: Market-led, based in incremental upgrades on the basis of individual consumer decisions vs. national scale roll out vs. regional/local scale investment programmes

- To what extent can models incorporate contributions from local energy systems e.g. single community-owned wind turbine? Does aggregation of data mean that contributions on this scale get 'lost'?

- Does localised integration of heat, power, transport and storage improve 'whole system' economics of clean energy on a network with high levels of intermittent renewable electricity? (eg. by helping to balance supply and demand through local flexibility services; other demand management; demand side response)

- Does localised integration of heat, power, transport and storage optimise the use of distributed power generation?

- If so, under what 'necessary and sufficient' conditions?

- To what degree, and under what conditions, can distributed power generation resources connected to the electricity distribution network be used to reduce/avoid costs of capital investment in reinforcing networks? (Eg. by monetising local flexibility services to optimise use of network capacity.)

- Does localised system integration reduce total costs of heat decarbonisation?
  - If so, under what 'necessary and sufficient' conditions? (eg. use of available waste or residual heat (and surplus electricity) for district heating (DH) infrastructure with/without extra thermal storage).

- Does cost optimised heat decarbonisation require *locally* differentiated solutions?
  - If so, does this require local planning? (eg as conceived in Scottish Gov proposals for mandatory Local Heat & Energy Efficiency Strategies – LHEES).

- Is systematic local or regional energy planning necessary to optimising costs and benefits of whole system 'net zero' transition? (see current Energy Systems Catapult/CSE proposals for Local Area Energy Planning).
  - If so, at what scale, under what conditions?

- What do energy systems models suggest about the contribution of local and regional business models to retaining value, and improving productivity, welfare and energy justice, in local economies?

- What are the strengths and weaknesses of the different models for addressing questions about the value of local and regional integrated energy systems as contributors to whole system transitions?
  - And what criteria of value are used by these different models?

- What is the evidence about how model outputs/scenarios are used to inform political-economic decision making about local and regional energy systems?

Outline structure for discussion

1. Mapping models to research questions – are certain models more suited to answering some of these questions than others?
2. Questions for social scientists. E.g. if inputting further information into the models, what data is needed? In what format? How can social science insights be combined with modelling approaches?

Appendix B

Next steps for UKERC 'Local and regional Energy Systems' modellers

Utilising the current models, research questions and next steps are summarised:

Cardiff/CGEN:

1. Does localised/regional integration support use of distributed power generation?
2. Can generation connected to the distribution network be used to reduce costs of investment in electricity networks?

The CGEN+ Energy Hub model is utilised to assess the impact of regional energy system (heat, gas, electricity, Hydrogen) integration and its interaction with the wider national (GB) energy system.

The modelling focuses on year 2050. A limited number of scenarios (electrification and hybrid) of the GB energy system are used to operationally assess different infrastructure alternatives with respect to heat decarbonisation options.

UCL/UK TIMES:

1. How does adding regional disaggregation to the UK TIMES whole systems energy model change (i) its ability to reach our NZ targets and (ii) the pathways it follows to reach said targets?
2. Is there a need for locally differentiated solutions?
3. Does localised system integration improve 'whole system' economics of clean energy and how does this affect centralised energy system design?
4. How do different policy initiatives at a regional level interact with and support national energy system targets?

The overarching objective for UK TIMES is to disaggregate the model into a regional representation of the UK – moving away from the simplistic single node representation that it currently uses. The expectation is that this will enable a more refined understanding of how different parts of the UK will support or fall short of stringent climate and energy targets. The first objective therefore is to understand, on a purely operational level, how model results shift under a well parameterised regional approach and to highlight the changes against a standard single node counterfactual. This will include describing the benefits and drawbacks that a regional analysis provides for understanding the role of Variable Renewable Energy (VRE) systems, clean energy produced at a local level, as well as the variations in system choice on a geographical basis.

Going further, this regional version of UK TIMES will be used to explore the interplay between regional, national, and UK level decision making and target setting. The objective is to better represent and understand the dynamics that will underpin successful pathways to net zero for the UK, and to map the role of decision making at the local level in designing and enabling these pathways.

Strathclyde/Strath ES:

1. Does disaggregation encourage greater local contributions to the wider system, including investment by non-traditional energy actors?
2. What is the aggregate value of local systems as contributors to whole system transitions?
3. How can local system planning best reflect the needs of consumers and incorporate understanding of changing energy use behaviours?

In combination with modelling activity within the Infrastructure Theme, Strathclyde will proceed with the creation of 'archetypal' energy system scenarios which characterise particular structural aspects of the energy system (such as the interface between transmission, distribution and municipal-level planning). These scenarios will not be heavily predicated on existing data and the specifics of extant networks but will instead be structured to demonstrate specific aspects of the planning and operating interfaces of the system, with the intention that they illustrate the joint opportunities and tensions that exist within the flows of energy, investment streams, and the impact on total energy costs and emissions (and how these differentiate into upstream and downstream effects).

The intention is that these archetypes can be used to usefully illustrate the contributions of decentralised and local systems, without overcomplicating the necessary discussion by high dimensionality or spatial and temporal detail. By uncovering the broad issues that affect the value and costs of local and regional energy, this will permit deeper investigation of these issues by the other two modelling efforts, which may instead quantify these impacts for the extant energy system at a greater degree of detail.

These archetypal models can be presented to local energy stakeholders (such as network operators, local authorities, housing planners and community energy representatives) to investigate responses and the impacts on investment of different local energy case studies. This will allow investigation of the extent to which higher-level coordination is required to 'unlock' greater decentralised participation in future local energy systems.

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