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Energy systems integration as research practice

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ABSTRACT

This article adopts frameworks and methods from Science and Technology Studies for examining Energy Systems Integration (ESI). ESI, the integrated operation and planning of multiple energy supplies and demands, can contribute to improvements in energy reliability, security and flexibility, and therefore facilitate a transition to a low carbon economy. The article examines UK research towards integrated computer models of energy system 'vectors'. The research is based on fieldwork and participation in a large ESI research project in the UK, drawing on interviews, workshops and observations. We highlight three main contributions to the studies on ESI and STS research of modelling. First, ESI researchers are aware of the social, economic and political context of their work, though many of these contexts are difficult to incorporate in any useful modelling process. Second, issues that touch on both science and policy around energy systems were the motivation for ESI researchers yet were also underemphasised in project work. Third, we develop unique mixed ethnographic methods to study ESI and that enable researchers to build relations of trust with research participants that contribute to the discussion of sensitive topics such as the politics and ethics of energy modelling approaches.

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Introduction

The aim of this article is to adopt frameworks and methods from Science and Technology Studies (STS) to examine Energy Systems Integration (ESI). ESI means the integrated operation and planning of multiple energy supplies and demands, such as natural gas and electricity supply, heating and electricity, transportation and energy networks and so on. This integration of energy systems is not merely a technological problem but must bridge between multiple markets and institutional structures of different energy sectors and demands (Kroposki et al. 2012; Abeysekera, Wu, and Jenkins 2016; O'Malley et al. 2016; Taylor and Walker 2017). Therefore, ESI does not operate in a socio-political vacuum. Our article complements and advances these discussions by examining how ESI researchers themselves understand their relationships to society as part of their working practices.

There are not many studies that examine the relationships between ESI as research practice and the normative implications of energy integration in the making. This article rises to this challenge and explores how integration is driving energy system research and development with a focus on the following questions:

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- How do energy system model researchers conceptualise energy integration?
- How are system models thought to aid communication between science and policy?
- How can ethnographic research methodologies in STS address these issues?

The article explores UK research towards integrated computer models of energy system ‘vectors’. The research is based on fieldwork and participation in a large ESI research project in the UK, drawing on interviews, workshops and observations.

The article begins by providing a background on the emergence of ESI and a framework for examining the enactment of ESI in computer models, followed by a discussion about the materials and methods deployed in this research. Three sections then deal with each of the above research questions in turn. The first report’s findings from asking ESI researchers about their awareness of the social, economic and political context of their work. The second presents a discussion about the use of models as a communicative aid between science and policy. The final research question addresses the role of social sciences and humanities in energy research with a particular focus on the impacts of mixed ethnographic methods in interdisciplinary energy research projects. The last part concludes and outlines the contribution of this study to existing scholarship on ESI.

Framework: the enactment of ESI in computer models

Energy provision has been frequently conceptualised as a layered *socio-technical system* (van der Vleuten 2004; Schot and Geels 2008). Such a system brings together not only technologies and physical infrastructures but also institutions, regulations, laws and other social and technical components understood as a single (complex) system. This literature links energy systems and integration processes to technical and social components, which are necessarily integrated with economy and society more widely (Silvast 2017).

This narrative fits well with infrastructure studies that explore how infrastructures operate as distributed webs of systems and networks (Edwards 2010). Despite being interdependent, infrastructures and systems tend to be treated heuristically as distinct fields in order to understand and manage them, which then gives the impression that they are distinct. ESI acknowledges that overlapping systems might function better if aligned to gain advantages or efficiencies – that is, through integration.

In the field of energy systems, a focus on integration has been hastened by significant changes driven by attention to climate change. An increasing proportion of distributed renewable generation – initially of electricity and biogas – entails significant technical challenges to infrastructure designed to work with large, centralised power plants and hierarchically organised grids. The emergence of an increasingly decentralised grid that incorporates dispersed producers, as well as consumers, has brought urgent attention to the need to rethink how to ‘optimise’ systems and the potential to use adaptable infrastructures that combine generation, demand, and storage. ESI recognises questions that manifest the need for integration: Could charge electric vehicles be used as temporary energy storage to manage the fluctuating generation from wind and solar power, for example, and could other forms of energy storage – beyond existing capacity for gas or pump-hydro-electricity assets – emerge from coordination or integration between different energy vectors such as different fuels, demand management or trade-offs between systems?

These kinds of questions were at the forefront in the founding of an international network of academics and practitioners in 2014, the International Institute for Energy Systems Integration (iiESI), which aimed to address cross-sectoral integration of multiple energy systems and their technical challenges. In 2016, the Institute published a paper by eleven international scholars and practitioners that outlined the ‘value proposition’ of integrated energy systems:

> Energy Systems Integration (ESI) is the process of coordinating the operation and planning of energy systems across multiple pathways and/or geographical scales to deliver reliable, cost-effective energy services with minimal impact on the environment. (O'Malley et al. 2016, 1)

Framing ESI around the value of coordination between various kinds of energy systems focuses on the simultaneous reaching of technical (reliability), economic (cost-effective) and environmental (minimal impact) goals by means of integration. Figure 1 is an example of illustrations that highlight the multiple scales of integration and the different energy 'vectors' involved in ESI and suggest that ESI requires a system of systems approach.

Since the publication of early technical documents (Kroposki et al. 2012; González et al. 2015), ESI has engendered two narratives. The first analyses were interacting and interdependent energy systems scientifically, primarily by developing computer models (O'Malley et al. 2016; Abeysekera, Wu, and Jenkins 2016). The second has been to make this knowledge available for use by industry professionals, policy makers and other relevant stakeholders (Jenkins 2018; Widl et al. 2018). This aim resonates with the sociology of expectations (Borup et al. 2006) that has been used to examine the 'boundary work' that scientists pursue between science, politics and economy (for example, when pursuing energy sustainability transition: Jalas et al. 2019).

STS has advocated the study of computer models as means to bring different social worlds together (McDowall 2014; Aykut 2019). The very term 'model' has referred to an extraordinarily wide range of methods and entities, including a wide diversity of computer models in use in the energy field (Silvast et al. 2020). Individual models have intricate development stories that are tied to the lives of their developers (Ialenti 2020). This paper understands computer models in a generic way: as simplified bounded representations of aspects of energy systems. Such computer models emerged as an alternative to conventional scientific experimental methods, theoretical methods and laboratory work (Cetina 1995), opening new possibilities but also questions concerning scientific rigour and reliability (Edwards 2010). Scholars have shown that engineers and technology

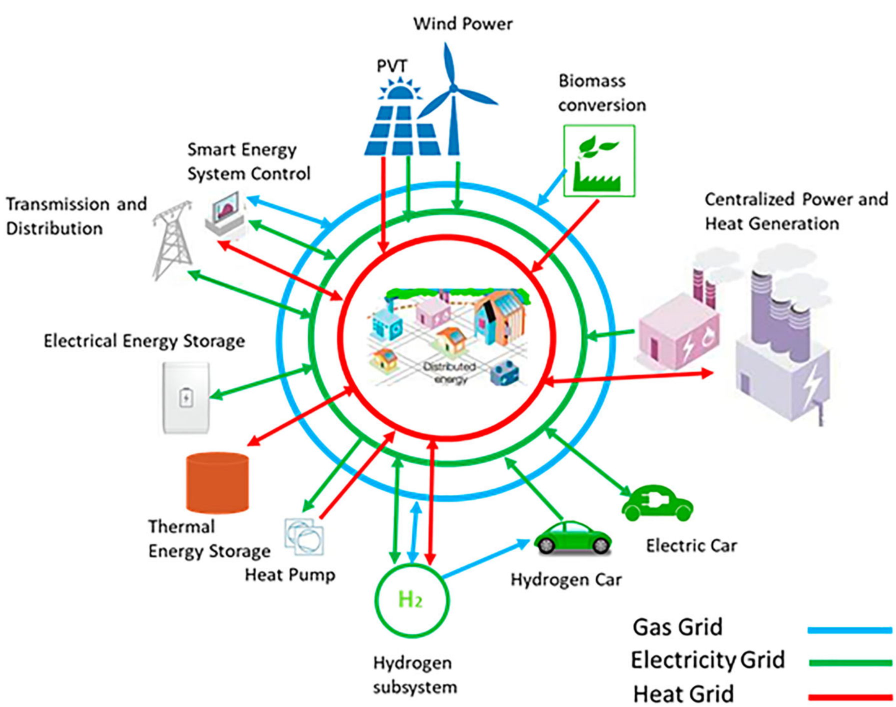

Figure 1. Energy systems integration. Image reproduced with permission from: https://www.utwente.nl/en/et/tfe/research-groups/TE/research/research/Energy_Systems_Integration/.

designers use models and simulations for problem-solving and experimentation either before systems are built (Dodgson, Gann, and Salter 2007) or when they are in use to gain a more detailed understanding of their operation and dynamics than would otherwise be possible.

The research field emphasises that models also have an important role in policymaking and general public communication and understanding, as has been vividly demonstrated in the field of climate science models (Ryghaug and Skjølsvold 2010) and epidemiological models. For these purposes, models need to be useful and credible for the policy community. STS scholars (Knuuttila, Merz, and Mattila 2006) summarise this diversity of roles by stating that computer models are simultaneously political and scientific – mediating between science, policy and public.

This article adopts the analytical strategies developed in STS and applies them to the study of ESI processes. Computer models bring together knowledge bases from mathematics, computer science and often statistics disciplines (Knuuttila, Merz, and Mattila 2006). Modelling ESI introduces additional complexity when compared with modelling conventional single energy systems, such as electricity networks and requires that energy researchers expand the boundary of the system that they analyse (Mancarella 2014). The aim is to overcome established systems and sectoral boundaries, which constitute the vision of modernising energy systems and confronting their environmental issues. Crossing these boundaries may require a plurality of models (Parker 2006) and integration of computer modelling and empirical observations (Sundberg 2006), as we examine empirically in what follows.

Materials and methods: ethnography of modelling processes

The empirical materials of this article were collected by a small number of social scientists working with researchers from engineering, mathematics and physics disciplines in a large research project that seeks to develop more integrated energy systems in the United Kingdom. Funded by the UK Engineering and Physical Sciences Research Council (EPSRC), the project, known as the Centre for Energy Systems Integration (CESI), involves five research universities and several industrial partners. We conducted fieldwork within this project and in broader university research modelling groups to access a wider group of modellers. The fieldwork was conducted over two university terms (2017 and 2018), including interviews, documentary reviews, workshops and meeting observations, using a mix of broadly ethnographic methods. Ethnographic methods imply 'a long-term involvement in a particular field site, during which time a variety of methods are deployed to understand and participate in the relationships and activities ongoing in that setting' (Pollock, Williams, and Procter 2003, 321).

The ethnographic approach involved staying in the research groups of ESI modellers, participating in a project ourselves as representatives of anthropology and the social sciences and observing all these activities systematically. The analysis progressed by empirical grounded observations, in a reflexive process where we would learn from our observations and confront these with the academic literature on modelling and energy issues. The analysis constantly moved between the lived experiences of our informants and the more abstract and general issues recognised in social science literature. While we draw on workplace interviews and participant observation, the methods used are wider and gather all available materials from the fieldwork.

The corpus includes 12 workplace interviews with academic modellers from mainly two of the UK research universities collaborating on the CESI project. A further 28 workplace interviews with modellers in related research groups were conducted with a view to gain an understanding of research modelling processes more generally. Almost all the interviewees were based in the UK in engineering and physical sciences, though some started their research careers outside of the energy field in a variety of disciplines; from architecture and astrophysics to environmental science. Thirteen interviewees (one-third) were female, the rest male. Nearly all were either postdoctoral researchers or Ph.D. students and therefore relatively junior members of university staff. The design of the interviews was drawn from laboratory studies in STS, initially conceptualising the modelling groups similar to those working in a scientific laboratory (Cetina 1995; Doing 2008). Drawing from anthropological inquiries, a more ‘open’ approach was taken, prompting rather than directly asking about modelling practices, such as how the model being developed by the scientist works, how it produces results, and the researcher’s own field, research group collaborations and plans.

Additional material includes participation in project meetings for more than a year and gathering internal project papers and grey literature circulated on mailing lists and in meetings (see Jalas et al. 2019 for a similar strategy in studying a large research project whilst being its partner). One particularly valuable source of data for this paper was a one-day project workshop that we organised with 23 fellow social science colleagues in 2018. This involved a broad discussion on ESI with a range of experts on control issues, energy policy and markets.

In combination, the data allows providing a close view into the scientific reasoning on ESI as scientific actors construct it, using concepts and deploying modelling tools to create new conditions of possibilities for more integrated energy systems in different planning, energy use and operational contexts.

How do energy system model researchers conceptualise energy integration in relation to society, environment and economy?

What ESI is for

The authors of this article organised a workshop in 2018 for CESI researchers, which began with a discussion of industrial history and ESI itself. There was a clear consensus among participants that ESI did not mean a return to pre-privatisation era nationalised industries with central ownership and control. The premise for ESI lay clearly within current ‘Western’ regimes of energy markets, with centralised planning not seen as the intention for ESI. That is, the current context of capitalist democracy, with a hierarchical energy system (transmission, distribution and supply), a centralised regulatory function and market-organised supply and demand, was taken to be enduring and given through to the 2050 analytical time horizon.

Despite prior discussions about the importance of a ‘system architect’ (Taylor and Walker 2017), this was asserted to be quite distinct from the centralised management of an integrated energy system, which was cast as monolithic and potentially dictatorial. Instead, aspects of both vertical and horizontal integration were seen as counters to otherwise inevitable continued disintegrative decentralisation in energy systems. This further implied that integration was not attached to a particular scale – that is, nation-states were no longer seen as determining the size or shape of energy systems; integration could be considered at local, regional or international scales, with diverse benefits and challenges at each scale. This, though, had implications for regulatory regimes which remain largely at national or international scales, once again linking market practices and principles to the notion of ESI. In other words, ESI was not seen as purely a technical process but one embedded in socio-technical frames with potential implications for equality and fairness within a singular socio-historical timeline of progression from centralisation to market-based planning regimes. Despite the context of Brexit, Britain’s continued participation in transnational energy infrastructures and markets was taken as a given. It is on this basis that further detailed discussions of modelling schemes should be understood.

What was clear in the workshop was that participants were aware of the limits to their modelling scope and were generally happy to speculate around ethical and political questions – at least in a separate arena from the modelling activity. The workshop encompassed a lively debate around the role of an energy system and whether energy services should be seen as a basic service (although energy as a ‘human right’ was not explicitly discussed) rather than being driven by profit-seeking. ‘Energy should be treated like the Health Services, and protected from profiteering’, was one suggestion (although the assumption that the UK’s national health service is immune to profit-seeking could be questioned). Another asked, ‘what about the passing on of costs that may leave some paying more than others?', which led to a discussion of the notion of a Basic Income and who should decide what the basic level of service should be.

Energy demand modellers were particularly concerned to highlight that 'two families who look identical on paper might have quite different energy needs', so that 'if you supported incomes, you wouldn't need to consider energy costs so much, but unit costs encourage people to manage their consumption, to discourage profligacy'. On the other hand, if the problem was inequality, 'the answer can't just be "fix the economy", we have to address the energy system'. As the discussion moved towards a discussion of energy governance, suggestions and analyses began to roam more freely over classic political imponderables around how systems are conceptualised, incorporating various moralised positions and assumptions (such as the reference to 'profligacy' above). At the end of the session, however, the project leader summed up with a series of reminders that integration aims to ensure that interactions and interdependencies become better understood rather than taking control of the system per se, arguing that:

> Unintended consequences are easier to avoid if you take a broader system-level view. That is rather than trying to solve say, a gas problem in the gas sector, see what might be possible to solve through the electricity sector or using blended solutions.

In sum, participants agreed that 'models can show how scenarios have implications, but they cannot force anyone to act on them'.

One observation that is apposite was the manner in which this discussion highlights an epistemological boundary between models and their application. Workshop participants described the broader sociological and political issues around energy systems that they hope their models might contribute to alleviating, but outside the arena of demand-side modelling, we suggest the models themselves were designed to be independent of these contextual dilemmas (or trilemmas). If modellers incorporated ethical issues into their models, these seemed to be primarily related to adjusting cost settings or greenhouse gas emission calculations that should then be 'applied' to policy decisions. Through the workshop, it was stated in various ways that models should fit the positivist scientific method of providing non-partisan or objective data, even while it was acknowledged that the choice of data to model, the setting of parameters, or exclusion of factors would have significant effects on the model outcomes and potential uses.

It goes almost (but not entirely) without saying that ESI is operationalised on the basis of quantitative, computer modelling methods, with links into physical or material systems. CESI was primarily a computer modelling exercise, implemented through trials based on 'demonstrator' sites.

Design challenges for integrated models

Each model is designed according to a particular purpose, within a particular scope and aims to satisfy policy goals. For instance, planning models might ask which energy supply technologies should be invested in to meet future energy demand. Planning needs to meet certain objectives set by the modeller – for example, lowest economic cost – for 'optimising' the integrated system. Such longer-term objectives are not feasible for detailed operational models that try to understand the integrated energy system on a more or less real-time basis (for instance, every half an hour, as mentioned above). These are simulation models of physical systems that tend to explore the behaviour of an approximate 'real' integrated energy system – such as its pressures, voltages, currents and demands. Operational models can also partly incorporate end-user routines when approximating energy system behaviour, while planning models tend not to operate at this level of detail, such as when it comes to people changing their energy use practices.

The aim of CESI modelling was described as being to devise a 'suite' or 'framework' of models by looking for methods to enable distinct models to communicate; however, modellers commented on the lack of clarity on agreed terminology. This 'suite' or 'framework' would, in turn, allow for whole-system analysis of integrated energy systems, where each model only shows an element of that integrated whole. As an ESI modeller illustrates the lack of an accepted language for achieving ESI, in turn indicating that ESI modelling is not a straightforward ambition:

> I think we understand that there's a suite, we spoke a while in the last meeting and the meeting before that, what word we should be using: framework, architecture, or suite? I think I kind of like suite because it, the idea this kind of suite of models that do interlink, soft links, hard links, whatever there might be.

Among the challenges to integrating models was the divergence in detail and time-demands – very detailed models might give accurate outcomes but have extremely large computing power demands, or take days or even weeks to produce results, while summarising models, without the detail, could be quick (and dirty, as it were). The interviewee above emphasised the value of models that could be easily used by other modellers, by incorporating 'really quick assumptions', for example. With multiple models that are all potentially useful, especially for ESI, this creates further challenges.

These different designs had material impacts on what the models could know about energy systems themselves (Silvast et al. 2020). On numerous occasions, the ethnography observed that the kind of model that a scientist used shaped the areas of concern that they articulated in relation to energy demand dynamics, supply dynamics, energy future, technological detail or other related issues. For example, a simulation modeller spoke of the intricacies of energy integration in networked systems and the differences between simulated and 'real' systems; a building modeller discussed the future of sustainable housing as envisioned by the models and an agent-based modeller introduced polycentric visions of energy systems where consumers become active 'prosumers' who generate and trade their own energy in interaction with other similar 'agents'.

While models incorporate a number of constraints, models represent a simulated world and, therefore, are only able to reflect a limited range of physical constraints similar to laboratory experimentation (Dodgson, Gann, and Salter 2007). Modelling clearly relies on a degree of imaginative reach, but while models can be thought of conceptually as able to simulate anything, in practice, models are constrained by their own assumptions and purposes, which could shape what integrated energy will look like in the future, an issue that is acknowledged in the modelling scholarship (e.g. McDowall 2014; Mcdowall et al. 2014; Li, Trutnevyte, and Strachan 2015).

How are system models thought to aid communication between science and policy?

A general concern of energy modellers is that their models are 'useful' (Aykut 2019; Hawker and Bell 2020). The CESI project has received industry funding and was inherently an applied engineering project with an industrial board providing direction and advice. The ESI scientists wanted explicitly to influence policy decision makers. For this purpose, the prime quality of a model was not necessarily accuracy but usefulness. One of the interviewees who had regularly participated in regional political working explained that models need to be fit for purpose and are for 'making better decisions around things'. This raises questions around what makes a model useful, for whom, and how scholarship can understand the relationship between a model's usefulness and its scientific 'quality' (i.e. its epistemological and non-epistemological values – see Silvast et al. 2020). First, ESI researchers are aware of the social, economic and political context of their work, though many of these contexts are difficult to incorporate in any useful modelling process. It is one thing to 'validate' a model by conducting experiments in a laboratory or against other model results and methodologies. But how can ESI modellers know when their models are fit for purpose for making better decisions?

A separate workshop organised by one of the project participants and including several CESI members (Dent et al. 2019) discussed the planning of complex infrastructures of the future. A network was formed around interdisciplinary research that would not only research new state-of-the-art techniques of modelling, but also more particularly, modelling that would support decision making, including policy, industry and the research community. To do this, translating modelling practice into applications in new areas is necessary. In one of their key recommendations, the authors state the value and the interactivity of the policy-science interface:

> analysis outputs must be presented in such a way that decision makers have a proper appreciation of what the analysis has to say about the real system under study, and conversely in order to deliver useful analysis the analysts must have a proper appreciation of the interest of decision makers. (Dent et al. 2019, 1)

In other words, the effort of modelling should be consistent with the policy decision for which it is designed.

The modellers interviewed were (predominantly junior) academic researchers who designed computer models, and like many other designers, drew from their common sense to understand the needs of the end-users ('decision makers') of technological tools broadly rather than specifically. As STS scholarship suggests, this embracing of a decision maker's needs resembles strategic impactful research in many areas, such as smart energy futures, where the boundaries between pure research and societal relevance start to intertwine (Jalas et al. 2019). Researchers in these kinds of projects need to fulfil two overlapping roles: providing insights into societal challenges, such as sustainability, and offering visions to address these challenges, such as smart grids for sustainable energy futures. The way in which scientists make themselves 'useful' to political and practical contexts requires moving between science, politics and business and recognising how or even if, these 'boundaries' are crossed.

In the fieldwork, none of the interviewed academics saw problems in using their academic knowledge for decision making, whether in the policy sense or in an industrial application context. However, this policy relevance also had a specific practical limitation: it should not be mistaken for advocacy for a political standpoint on how energy systems should be planned and managed.

How can ethnographic research methodologies in Science and Technology Studies (STS) address these issues?

There have been repeated calls for more emphasis on social science research in energy studies (Sovacool 2014; Foulds and Christensen 2016; Sovacool et al. 2020) and for the value of ethnographic methods and anthropological analysis (Wilhite 2005; Abram, Winthereik, and Yarrow 2019). These approaches were particularly appropriate for this research, being open for the recognition of diversity in the aims and purposes of computer models, the difference between modelled knowledge and experimental knowledge, as well as the need to address modelling uncertainty and more broadly visions of energy futures. Studying the modelling process and interrogating what modelling means to model designers demonstrated the simultaneous challenges of scientific, economic and political aims of models, simulations and scenarios.

More particularly, work on the perennial challenge of aligning qualitative and quantitative approaches led the authors to argue within the CESI project that our aim should not be to incorporate qualitative methods and knowledge into computerised models, but to find ways to complement approaches that are based on quite different epistemological claims. The ethnographic approach enabled us to observe how knowledge was being characterised, and how certain kinds of information were considered valid, while others were unavailable for modelling. Despite this, the authors also observed that the ambition of incorporating 'social knowledge' or 'expertise' into system modelling endures, and can remain despite the demonstration that social knowledge is of a different order to physical or material data. In this, the article merely has to note that the scientific method that lies behind computational system modelling is a universalising method and leads people to assume that it can incorporate all forms of knowledge, even when that is demonstrably not the case. Hence one conclusion is that the method of computational modelling is one that does not readily address its own limitations, but conceptualises them under a rubric of insufficient data, or flattens different epistemologies into singular quantities (e.g. 'uncertainty').

These flattenings matter, to the extent that ESI envisages an energy system that can be managed according to its own principles, leaving very little room for issues or practices that do not conform to its totalising approach. This is a paradox; however, since most of the participants in ESI research and discussion were particularly concerned with the significance of policy, the workings of markets, and the conditions under which energy is both generated, shared and used. Dividing modelling into operational models and planning models was done under the assumption that these practices were politically and commercially unaligned, based on a series of tacit assumptions about the direction of political and economic travel. Some of the energy modellers were explicitly committed to energy justice goals, applying findings and methods to schemes to combat energy poverty, or advancing inclusive energy market mechanisms (such as community-based aggregators or community-energy microgrids).

In other words, one might suggest that the politics of energy modelling were shifted into the application of the models, and out of the modelling process itself. Having said this, however, through a series of project workshops it became clear that modellers did, in fact, recognise that the choices they made in designing and using models – such as setting threshold values, choosing criteria, setting probability limits or externalising particular factors – were inherently ethical choices. One modeller who attempted to argue that there were no ethics in physical system models was roundly taken to task in a project meeting (and not by the social scientists present). Yet how to acknowledge these judgements, how to make them available for consideration or how to keep them explicit and apparent in the progress of models from theory to practice to policy remained unresolved questions.

In a context where many aspects of energy systems are changing rapidly, it appeared that the challenge of modelling changing scenarios was sufficiently demanding to push ethical and political questions into the shadows. Despite this, the project of ESI itself highlights the need to incorporate areas into modelling that are conventionally outside of its scope: such as modelling of consumption practices, policy and political negotiation or political processes.

The participatory workshop we have referred to in this paper as an element of the mixed ethnographic methods was revealing in several ways. Primarily, it was an opportunity for collective reflection on the general aims of ESI, and for participants to discuss and reflect on their motivations, their understandings of central concepts and approaches. This, and in more focused interviews, was the occasion for explicit discussion of otherwise largely tacit questions, and illustrated on the one hand how far these concerns were held apart from the direct modelling activities, and on the other how difficult it is to articulate broader social concerns through the medium of energy system modelling, despite the clear engagement that most of the modellers had with these central concerns. In asking, what ESI is for, the workshop elicited that answers went well beyond technical concerns about optimisation or efficiency, opening up widespread dissatisfaction with the assumptions behind the kind of generalising definitions cited above (O'Malley et al. 2016). Instead, participants conceptualised ESI as an exercise in coordination (rather than optimisation).

It may be no surprise that engineers and ESI modellers tend to envisage a system as controlled and organised and have difficulty in articulating the forms of governance that would ensure that such systems are accountable or to whom accountability should be afforded. Discussions about the risks of centralised control tended to slide rapidly into questions of system safety and security, with questions of political risk underemphasised. Among a group of researchers with expert knowledge of the operation of energy systems, including the role of key political actors including regulators, governments, agencies and operators, it was notable that political debate was largely avoided. Yet a key goal of ESI is decision-support for policymaking. Ethnographic research enabled us to create an occasion with sufficient trust and engagement to enable us to bring to light this central paradox at the heart of ESI.

Conclusions

Our empirical research answers the three research questions, and through this, contributes to the previous studies of ESI in particular and STS and social science of modelling. Firstly, our research confirms the previous suggestions in STS literature (Knuuttila, Merz, and Mattila 2006; McDowall 2014; Aykut 2019) that the ESI researchers conceptualise ESI in relation to social, economic and political contexts of their modelling work. In this respect, ESI should not imply prescriptions on a single ownership of utilities or a return to the days of centralised planning. Certain ESI scholars (Taylor and Walker 2017) advocate a Systems Architect role to resolve this tension, whom they imagine as a 'facilitator' between bottom-up regional energy networks and top-down systems views who would have non-political and non-commercial views on energy issues. The ESI efforts that we studied are, though, very concerned with influencing policy and note that complex interacting energy systems are 'strongly coupled with society' (Taylor and Walker 2017, 3).

At the same time, there was a clear acknowledgement that the process of designing and developing models entailed choices that were both analytical and ethical. Choosing what to include and what to ignore as relevant factors in modelling were recognised to entail matters of judgement. Participants recognised that citizens are often overlooked as energy system actors by institutions such as governments or financial market actors, and by equipment and asset designers. Questions of system control were recognised as fraught with political risk but were set aside as issues for future or further research alongside socio-legal or energy-law scholars.

In response to the second question, issues that touch on both science and policy around energy systems were the motivation for ESI yet were underemphasised in project work. The previous literature has not emphasised the implications of ESI modelling in research practice. This work relied largely on conventional practices of modelling, with efforts directed at combining analytical outputs from different models across different sectors and disciplines. Adapting models to use similar or common input data, for example (such as weather data or demand data) was one aspect of this approach, while another was to use simplified outputs from one set of models as inputs to another (such as using 'surface response' models). Models themselves were recognised as partial, such that integration could lead to the introduction of inaccuracies and uncertainties. Here, the researchers were again concerned that the results of the ESI process should not be misread or mistaken, for example by being taken as an argument for a return to nationalised systems. Nor should they be understood as predictions for infrastructure planning, being unable adequately to account for future uncertainties. Further calls for collaboration with policy makers were made, although we note that the identification of policy makers or decision makers remained unclear – and we deduced that the terms 'policy maker' and 'decision maker' meant different things to different participants. This will be the subject of future research on the figure of the decision maker in ESI.

On the third and final question, this article complements an increasing body of literature on the role of social sciences and humanities in addressing energy issues (Sovacool et al. 2020) and distinguishes this role in anthropological and ethnographic scholarship (Wilhite 2005; Abram, Winthereik, and Yarrow 2019). It complements the existing literature by showing that mixed ethnographic methods enable researchers to build relations of trust with research participants that enable discussion of sensitive topics such as the risk and politics of energy modelling approaches. These methods also highlight the institutional contexts in which the activities take place and the assumptions, context and concepts that otherwise remain implicit. In observing and participating in informal discussion around formal project activities the authors were able to identify the social and environmental matters of concern that both motivated and worried the participants and show how little modelling methods either acknowledged or addressed those matters.

Our research highlights several paradoxes and dilemmas for ESI that frame the modelling process. One apposite observation is that the purpose of ESI remains debateable. This is not to say that the value of ESI is doubted, but that the precise use and future applications of ESI remain open. Whether

ESI is about ownership of systems, coordination of systems or better understanding increasingly interconnected systems is a matter of discussion. How ESI will be used – i.e. what questions could be posed to an integrated model of diverse energy infrastructures – is still open. The same applies to the question of who the decision makers are that ESI models could support, or what kind of decision-support is advisable or appropriate using ESI models. While modelling for decision-support is taken as a given good, the ethics of appropriate use of models by policy and decision makers are contested, and further research would be advisable to address these issues in more detail.

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References

Abeysekera, M., J. Wu, and N. Jenkins. 2016. "Integrated Energy Systems: An Overview of Benefits, Analysis, Research Gaps and Opportunities." HubNet Position Paper Series.

Abram, S., B. R. Winthereik, and T. Yarrow. 2019. *Electrifying Anthropology: Exploring Electrical Practices and Infrastructures*. London: Bloomsbury.

Aykut, S. C. 2019. "Reassembling Energy Policy." *Science & Technology Studies* 32 (4): 13–35.

Borup, M., N. Brown, K. Konrad, and H. Van Lente. 2006. "The Sociology of Expectations in Science and Technology." *Technology Analysis and Strategic Management* 18 (3–4): 285–298.

Cetina, K. 1995. "Laboratory Studies: The Cultural Approach to the Study of Science." In *Handbook of Science and Technology Studies*, edited by S. Jasanoff, G. Markle, J. Peterson and T. Pinch, 140–166. Thousand Oaks, CA: SAGE Publications.

Dent, C., A. Anyszewski, T. Reynolds, G. Masterton, H. Du, E. Tehrani, K. Lovell, and G. Mackerron. 2019. "Planning Complex Infrastructure under Uncertainty – Network Final Report." https://www.repository.cam.ac.uk/handle/1810/293301.

Dodgson, M., D. M. Gann, and A. Salter. 2007. "The Impact of Modelling and Simulation Technology on Engineering Problem Solving." *Technology Analysis and Strategic Management* 19 (4): 471–489.

Doing, P. 2008. "Give me a Laboratory and I Will Raise a Discipline: The Past, Present, and Future Politics of Laboratory Studies." In *The Handbook of Science and Technology Studies*, edited by S. T. S. In E, J. Hackett, O. Amsterdamsa, M. Lynch and J. Wajcman, 279–295. Cambridge, MA: MIT Press.

Edwards, P. N. 2010. *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*. Cambridge, MA: MIT Press.

Foulds, C., and T. H. Christensen. 2016. "Funding Pathways to a Low-Carbon Transition." *Nature Energy* 1 (7): 1–4.

González, I. H., P. R. Castello, A. Sgobbi, W. Nijs, S. Quoilin, and A. Zucker. 2015. *Addressing Flexibility in Energy System Models*. Luxembourg: European Commission Joint Research Centre.

Hawker, G. S., and K. R. Bell. 2020. "Making Energy System Models Useful: Good Practice in the Modelling of Multiple Vectors." *WIRES Energy and Environment* 9 (1): e363.

Ialenti, V. 2020. "Spectres of Seppo: The Afterlives of Finland's Nuclear Waste Experts." *Journal of the Royal Anthropological Institute*.

Jalas, M., M. Rask, T. Marttila, and T. Ahonen. 2019. "Futures Work as a Mode of Academic Engagement." *Science & Technology Studies* 32 (3): 44–61.

Jenkins, D. 2018. "Integrating Building Modelling with Future Energy Systems." *Building Services Engineering Research and Technology* 39 (2): 135–146.

Knuuttila, T., M. Merz, and E. Mattila. 2006. "Editorial: Computer Models and Simulations in Scientific Practice." *Science Studies* 19 (1): 3–11. https://sciencetechnologystudies.journal.fi/article/view/55199.

Kroposki, B., B. Garrett, S. Macmillan, B. Rice, C. Komomua, M. O'Malley, and D. Zimmerle. 2012. "Energy Systems Integration: A Convergence of Ideas (No. NREL/TP-6A00-55649)." National Renewable Energy Lab. (NREL), Golden, CO (United States).

Li, F. G. N., E. Trutnevyte, and N. Strachan. 2015. "A Review of Socio-Technical Energy Transition (STET) Models." *Technological Forecasting and Social Change* 100: 290–305.

Mancarella, P. 2014. "MES (Multi-Energy Systems): An Overview of Concepts and Evaluation Models." *Energy* 65: 1–17.

McDowall, W. 2014. "Exploring Possible Transition Pathways for Hydrogen Energy: A Hybrid Approach Using Socio-Technical Scenarios and Energy System Modelling." *Futures* 63: 1–14.

Mcdowall, W., E. Trutnevyte, J. Tomei, and I. Keppo. 2014. "UKERC Energy Systems Theme Reflecting on Scenarios." (UKERC Report), 109. London: UK Energy Research Centre (UKERC). http://www.ukerc.ac.uk/publications/ukerc-energy-systems-theme-reflecting-on-scenarios.html.

O'Malley, M., B. Kroposki, B. Hannegan, H. Madsen, M. Andersson, D. William, M. F. McGranaghan, et al. 2016. "Energy Systems Integration: Defining and Describing the Value Proposition." Nrel/Tp-5D00-66616. Golden, CO (United States). http://www.osti.gov/servlets/purl/1257674/.

Parker, W. S. 2006. "Understanding Pluralism in Climate Modeling." *Foundations of Science* 11 (4): 349–368.

Pollock, N., R. Williams, and R. Procter. 2003. "Fitting Standard Software Packages to non-Standard Organizations: The 'Biography' of an Enterprise-Wide System." *Technology Analysis & Strategic Management* 15 (3): 317–332.

Ryghaug, M., and T. M. Skjølsvold. 2010. "The Global Warming of Climate Science: Climategate and the Construction of Scientific Facts." *International Studies in the Philosophy of Science* 24 (3): 287–307.

Schot, J., and F. W. Geels. 2008. "Strategic Niche Management and Sustainable Innovation Journeys: Theory, Findings, Research Agenda, and Policy." *Technology Analysis & Strategic Management* 20 (5): 537–554.

Silvast, A. 2017. *Making Electricity Resilient: Risk and Security in a Liberalized Infrastructure*. London: Routledge.

Silvast, A., E. Laes, S. Abram, and G. Bombaerts. 2020. "What do Energy Modellers Know? An Ethnography of Epistemic Values and Knowledge Models." *Energy Research & Social Science* 66: 101495.

Sovacool, B. K. 2014. "Diversity: Energy Studies Need Social Science." *Nature* 511: 529–530.

Sovacool, B. K., D. J. Hess, S. Amir, F. W. Geels, R. Hirsh, L. R. Medina, C. Miller, et al. 2020. "Sociotechnical Agendas: Reviewing Future Directions for Energy and Climate Research." *Energy Research & Social Science* 70: 101617.

Sundberg, M. 2006. "Credulous Modellers and Suspicious Experimentalists? Comparison of Model Output and Data in Meteorological Simulation Modelling." *Science & Technology Studies* 19 (1): 52–68. https://sciencetechnologystudies.journal.fi/article/view/55202.

Taylor, P., and S. Walker. 2017. "The Role of the System Architect." National Centre for Energy Systems Integration (CESI). https://blogs.ncl.ac.uk/cesi/files/2017/09/The-Role-of-the-System-Architect-CESI-Publications-CESI-TF-0006-02.pdf.

van der Vleuten, E. 2004. "Infrastructures and Societal Change. A View from the Large Technical Systems Field." *Technology Analysis & Strategic Management* 16 (3): 395–414.

Widl, E., T. Jacobs, D. Schwabeneder, S. Nicolas, D. Basciotti, S. Henein, T.-G. Noh, O. Terreros, A. Schuelke, and H. Auer. 2018. "Studying the Potential of Multi-Carrier Energy Distribution Grids: A Holistic Approach." *Energy* 153: 519–529.

Wilhite, H. 2005. "Why Energy Needs Anthropology." *Anthropology Today* 21 (3): 1–2.