Energy systems research in a world in transition: challenges for policy and research

Conference Report

Edited by William Burns and Jim Watson, UK Energy Research Centre

December 2016

Contact email:
ukercpressoffice@ukerc.ac.uk

ABOUT UKERC

The UK Energy Research Centre (UKERC) carries out world-class, interdisciplinary research into sustainable future energy systems.

It is a focal point of UK energy research and a gateway between the UK and the international energy research communities.

Our whole systems research informs UK policy development and research strategy.

UKERC is funded by The Research Councils UK Energy Programme.

For information please visit www.ukerc.ac.uk

Follow us on Twitter @UKERCHQ

Publication date: 19 December 2016

Table of Contents

1. ACKNOWLEDGMENTS 5

2. INTRODUCTION 7

3. KEYNOTE SPEAKERS 11

3.1. Plenary 1: Energy systems challenges 11
3.2. Plenary 2: What does good leadership look like across the energy system? 12
3.3. After-dinner speech 13

4. RESEARCH CHALLENGES AND OPPORTUNITIES 15

4.1. Energy security: beyond keeping the lights on 15
4.1.1. Differences between energy sources 16
4.1.2. Risks to security 17
4.1.3. The geography of energy security 18
4.1.4. Governance of energy security 18
4.1.5. Legacy infrastructures 19
4.1.6. Knowledge gaps: security implications of low carbon energy transitions 20
4.1.7. Recommendations 20
4.2. Resources for energy systems 21
4.2.1. Resource assessment 22
4.2.2. Making connections 23
4.2.3. Complexity, simplicity, politics 24
4.2.4. Recommendations 24
4.3. Energy innovation systems 25
4.3.1. Diversity in low carbon innovation 27
4.3.2. The role of policy and regulation 28
4.3.3. Beyond technological innovation 29
4.3.4. Recommendations 31
4.4. Making change happen: consumers, citizens, and practices 32
4.4.1. Motivations of energy users 33
4.4.2. From behaviour to practices 34
4.4.3. The value of data 34
4.4.4. Recommendations 34
4.5. Governance of energy systems transformation: emergence or design? 35
4.5.1. Complex systems, markets, and the state 37
4.5.2. Is the integration of governance and technical analysis too difficult? 37
4.5.3. Electricity and energy systems 38
4.5.4. Recommendations 39

5. MEETING THE ENERGY SYSTEMS CHALLENGE IN UK PUBLIC SECTOR RESEARCH 41
5.1.1. A CHANGING UK ENERGY RESEARCH LANDSCAPE 42
5.1.2. RECOMMENDATIONS 46
6. APPENDIX 1: SUMMARY OF RECOMMENDATIONS 52
7. APPENDIX 2: CONFERENCE PROGRAMME 57

1. Acknowledgments

UKERC sincerely thanks the conference steering group, sponsors, and partners, as detailed below. We also thank all speakers, chairs, rapporteurs, conference delegates, UKERC co-directors, and members of the UKERC Advisory Board.

Conference steering group

- Prof Jim Watson, UKERC (chair)
- Dr Mike Weston, UKERC
- Dr William Burns, UKERC
- Lindsay Wright, UKERC
- Jo Coleman, Strategy Development Director, Energy Technologies Institute
- Dr Jane Dennett-Thorpe, formerly Deputy Head of Science, DECC
- Prof Geoff Hammond, University of Bath
- Lacey-Jane Davis, University of Bath
- Roisin Quinn, Head of Energy Strategy and Policy, National Grid
- Nigel Fox, Stakeholder Strategy & Outlooks Manager, National Grid
- Dr Catherine (Frin) Bale, University of Leeds
- Dr Katy Roelich, University of Leeds
- Prof Catherine Mitchell, University of Exeter
- Richard Hoggett, University of Exeter
- Prof Jim Skea, Imperial College
- Dr Matthew (Matt) Hannon, Imperial College
- Prof Neil Strachan, UCL
- Liz Milner, UCL

Sponsors

- RCUK Energy Programme
- Whole Systems Energy Modelling Consortium (wholeSEM)

Partners

- DECC
- ETI
- IGov: new thinking for energy
- National Grid plc
- RCUK Energy Strategy Fellowship
- Realising Transition Pathways consortium

2. Introduction

Energy systems in many countries are undergoing rapid change. There are many reasons for this: the imperative of reducing greenhouse gas emissions, technological change and wider shifts in energy markets and governance. The UK is no exception. The need to meet statutory emissions targets has already initiated radical changes in the UK electricity sector. Heat and transport will also be affected if the transition to a low carbon energy system is to be successfully implemented. Continued progress will be far from easy. Reducing emissions will need to be compatible with other energy policy goals, particularly affordability, energy security and industrial development. Whilst there are many potential synergies between these goals, some will argue for trade-offs to be made – particularly in the short-term. Despite the reductions in costs of some low carbon technologies, the risks facing investors in the UK energy system have increased in the last two years. This is partly due to a series of UK government policy changes since the last election, compounded by the vote to leave the European Union. There is, therefore, a large amount of uncertainty about the future.

Against this background, the UK Energy Research Centre (UKERC) co-hosted a conference with a group of other research centres and stakeholders in March 2016. The main aim was to discuss future energy systems challenges for policy, research and practitioners; and to develop recommendations for energy systems research and decision-making in the UK. Although the conference was held before the vote to leave the EU on the 23rd June 2016, the conference steering group contend that the discussions and recommendations are still highly relevant.

The focus on energy systems was deliberate. 'Energy systems' is a term that is increasingly used in energy research and policy. The Research Councils UK Energy Programme has strengthened its funding in the area – with a new National Centre for Energy Systems Integration (CESI) to complement UKERC and other centres such as the WholeSEM energy systems modelling consortium. In parallel, the Energy Systems Catapult has been established by Innovate UK.

But definitions vary widely. They include different assumptions about boundaries – from a primary focus on energy networks to a wider focus that includes all components of energy supply and demand. They also range from technical definitions rooted in engineering to much broader interdisciplinary 'whole systems' definitions that also include economic, policy, social and environmental dimensions. The conference used this wider 'whole systems' definition, and brought together perspectives from engineering, natural science and social science to consider the challenges ahead.

Around 100 academics attended the conference, plus representatives from UK government, research funders and National Grid plc. Interaction was through themed parallel sessions, small group discussions and plenary sessions. This report summarises the presentations and discussions and a set of recommendations.

The six main recommendations from the conference are:

- More co-ordination and coherence of public funding for energy R,D&D is required, including the links between different institutions and programmes. Co-ordination is also required across government to meet strategic energy policy goals such as carbon budgets. It is essential that greater co-ordination does not undermine the independence of academic energy systems research, and leaves significant space for 'blue skies' research.
- It is unrealistic to expect a single vision or evidence base on the future vision or pathway for the UK energy system. Diversity is essential due to uncertainties about the technological, economic and other dimensions of change. It is also needed to take into account different disciplinary perspectives. However, the research community needs to do more to provide decision-makers with access to the academic evidence base. This includes identifying aspects of the UK energy transition where there is significant

consensus, providing accessible, rigorous reviews of the evidence base on particular questions, and providing energy system visions and pathways that include wider social and institutional dimensions of change.

- There is now significant energy systems research capacity in the academic community. However, there is a need to build on existing research to develop new models, tools and methods to understand the full complexity of these systems, and how they might change. Energy systems analysis also needs to engage more fully with the need for flexibility in decision-making given the rapid pace of change. The more co-ordinated approach to energy data that is now being pursued by the Research Councils is welcome, and is needed to support decision-makers as well as the research community.
- The energy systems research community have an important role to play in engaging diverse publics with the energy transition. This is required to ensure that this transition is more inclusive, to help other decision-makers understand public views, and to provide opportunities for publics to participate in the transition. Whilst a significant number of public engagement initiatives have already been implemented, including academic research, there is a case for a more strategic and comprehensive public engagement programme.
- Given the scale of the Global Challenges Research Fund, a strategic approach is required to identify priority research themes and questions, including how research on energy systems can contribute to achieving the Sustainable Development Goals (SDGs). This strategic approach should take into account the need to build capacity and skills in developing countries, and the potential scope for co-benefits of cleaner energy systems for other SDGs (e.g. those focused on health).

- The unfolding energy systems transition requires new skills, e.g. for designing, manufacturing and installing low carbon technologies. Energy systems research also requires new skills, including skills to carry out the interdisciplinary research that is needed to address real-world problems. Whilst the UK research community has built up substantial, world-class capabilities for such interdisciplinary research, a clearer career path is required for early career researchers.

This report was edited by William Burns and Jim Watson, based on contributions from session chairs and rapporteurs. The report and recommendations have taken into account the views of speakers and steering group members.

The remainder of the report is structured as follows: Section 3 summarises the presentations from the conference plenary sessions, which focused on energy systems challenges and leadership within energy systems. Section 4 discusses proceedings from the five thematic parallel sessions, each of which led to more specific recommendations. They focused on energy security; resources for energy systems; energy innovation systems; the roles of consumers, citizens, and practices; and governance of energy systems transformation. Section 5 examines the implications for energy systems research, based on plenary presentations and breakout discussion groups – and provides further context for the conference's main recommendations.

3. Keynote speakers

The conference included two plenary sessions that sought to highlight major cross-sector challenges. Substantive points made by our keynote speakers are briefly covered below.

3.1. Plenary 1: Energy systems challenges

Chair:

- Prof Jim Watson, UKERC Director

Rapporteurs:

- Dr Matthew (Matt) Hannon, Imperial College
- Dr Catherine (Frin) Bale, University of Leeds

Prof Arnulf Grübler, Acting Program Director, Transitions To New Technologies, International Institute for Applied Systems Analysis, Vienna

Arnulf Grübler made the point that we need to understand the energy system as interconnected. He referred to aspects of spatial/functional division, and resources/sectors (the latter exemplified by such terms as 'nexus'). His approach also included the fact that technologies are drawn from different sectors and systems architectures (e.g. ICT, and systems of production and use of innovation and technology). The user should not just be considered as the consumer of innovation but the generator of innovation. Overall, he felt the key challenge was how to integrate disciplinary-specific information to better understand linkages between production and use of knowledge.

Joan MacNaughton CB, Chair, WEC Trilemma & Member, UKERC Advisory Board

Joan MacNaughton reported on the findings of the World Energy Council (WEC) trilemma report, which was an assessment of 123 national policy strategies against dimensions of the energy trilemma (security, affordability and sustainability).[1] Sweden and Switzerland were the

[1] https://www.worldenergy.org/publications/2016/world-energy-trilemma-2016-defining-measures-to-accelerate-the-energy-transition/

leading countries (AAA-rated). What sets them apart is their very clear long term strategy, coupled to good processes to link up different policy agendas and to engage with key stakeholders and the public to generate buy-in. These two countries also hold periodic assessments that use feedback to tweak policies. The UK was fifth overall but went down from AAA to AAB due to a fall in the rating for affordability. While the UK was seemingly well-ranked, MacNaughton pointed out that data suffers a time lag and is a legacy from previous policy decisions. The key challenge for the UK was to move away from a 'tinkering' mind-set, with less micro managing from senior policy makers.

Phil Sheppard, Director, SO Operations, National Grid

Phil Sheppard focused on the real-time operations of the electricity network. He pointed out that UK electricity consumption had fallen by more than 15%, alongside a reduction in peak demand. He attributed the change to increases in efficiency and the economic downturn cutting demand. One of the major challenges was the changing characteristics of the network: renewables generation is impacting upon electricity system frequency. Another challenge lay with engaging consumers. Sheppard also pointed out that boundaries are becoming blurred between distribution network operator (DNO) and transmission network operator (TNO), as there is a move towards more distributed generation, (paradoxically) requiring much greater system-wide working and integration.

3.2. Plenary 2: What does good leadership look like across the energy system?

Chair:

- Jo Coleman, Strategy Development Director, ETI

Rapporteur:

- Dr William Burns, UKERC

Jonathan Luff, Co-Founder and Partner, Epsilon Advisory Partners

Jonathan Luff described his experience working as a consultant for Nest, the digital thermostat firm, describing how the company had framed its marketing around control and comfort, not the environment, cost, or efficiency. He said that electricity firms expect a customer click rate on emails below 0.5%, implying customer communication is failing. Nest, he said, had improved the email click rate to above 50%. One implication was that effective messaging about the energy transition need not be focused on energy per se.

Amy Mount, Senior Policy Adviser, Green Alliance

Amy Mount pointed to some broader debates that affect how we see energy systems change: including between those who emphasise planetary boundaries and those who think that new ways of finding prosperity should be identified. She argued that clean energy should be a central part of any long-term economic plan for the UK. She pointed out the whole system involves multiple levels which include public engagement. Furthermore, she made the point that leadership is not about management and control of the energy system.

Philip New, CEO, Energy Systems Catapult

Philip New argued that the UK government has been relatively far-sighted in supporting innovation; his concern was that relatively little of the investment was 'making it through'. He said that leadership is about placing a big bet – a big player can act to change the rules of the game. However, given limited capital, the Energy Systems Catapult[2] had to look at leadership in different ways – for example, in how it can enable others to succeed. He argued that small firms need support, while big firms will 'get on with it' themselves. Overall, he felt his key goal was to drive a stronger sense of consensus about the way forward for energy systems – how can everyone step into a bigger space, setting aside vested interests?

3.3. After-dinner speech

Laura Sandys, CEO, Challenging Ideas & Founder, POWERFULwomen

[2] https://es.catapult.org.uk/

Laura Sandys said that we had for too long framed the energy transition in terms of disaster: climate change. What was now needed was a statement of a clear and optimistic destination – politicians and the public need to be uplifted by what they are shaping and buying into. Although there were lots of great examples of a positive approach, there was a need to weave them into an integrated story that would draw-in new people with new thinking around a dynamic agenda. She felt the greatest need was to regain our passion and immediacy.

4. Research challenges and opportunities

This section discusses the outcomes of five conference sessions that focused on specific energy systems challenges. The first two of these sessions relate to national and international trends: How do we ensure the security of our energy system, and how will that change in future? What resources will our energy system require, especially if fossil fuels become less dominant as planned?

The remaining three themes are concerned with the challenges of implementing the low carbon transition: Who should deliver the low carbon innovation that is required to meet UK policy objectives, and how should it be supported? What is the role of people and communities: as consumers, citizens and practitioners? How should the transition to low carbon energy systems be governed, including the relative role of the state and markets?

4.1. Energy security: beyond keeping the lights on

Chair:

- Prof Jim Watson, UKERC

Rapporteur:

- Dr William Burns, UKERC

Energy security is a key government energy policy objective. It has risen up the policy agenda during the past few years for a number of reasons including an increasing need for energy imports as indigenous production declines; tighter margins between electricity supply and demand; and – until recent falls – increases in fossil fuel prices. Cyber security is, additionally, raised as a key risk as we transition to smarter energy systems.

According to the DECC Energy Security Strategy, published in 2012, 'when discussing energy security the Government is primarily concerned about ensuring that consumers have access to the energy services they need (physical security) at prices that avoid excessive volatility (price security).'[3]

Given how interdependent the UK energy system is with international trends, meeting energy security objectives requires an understanding of both global and UK-specific energy system changes.

The questions for this session included:

- What are the risks of energy security now, and how could these change? Which risks are likely to diminish, which are likely to emerge?
- Government and industry responses – are they fit for purpose, and how will they need to change in future as the system changes?
- Energy security for whom? What are the impacts of energy security risks and strategies on different energy system actors?
- Do our energy security strategies take a sufficiently system-wide approach – are they broad enough? Do these strategies strike the right balance between action on energy supply, networks, and demand?
- To what extent can we make security strategies compatible with those for low carbon, and other objectives – what are the trade-offs, what are the win-wins?

The session included three presentations: Keith Bell (University of Strathclyde) on the security of electricity systems; Amelia Hadfield (Canterbury Christchurch University) on European energy security and the Energy Union; and Paul Stevens (Chatham House) on oil and gas security. The presentations and discussion focused on a number of themes.

4.1.1. Differences between energy sources

First, the contributions to the session emphasised that energy sources and related infrastructures (e.g. for coal, gas and electricity) differ

[3] Department of Energy and Climate Change (2012) Energy Security Strategy. London: DECC.

significantly. Therefore the analysis of energy security needs to pay attention to their specifics as well as any interactions between them. For example, the UK electricity system balances supply and demand in real time. Greater security and resilience through storage is possible, as well as through spatial diversity of sources of generation. The close coupling of supply and demand mean that things can go wrong quickly if there is a significant disruption to that system. Gas and oil are significantly different. They include, for example, stocks and storage that can decouple supply and demand to some extent. The UK has a national gas grid, but not an equivalent network infrastructure for oil. This means that disruptions to gas and oil supplies would have different effects in practice: with gas being potentially more vulnerable if such disruptions were significant. It was also emphasised that discussions about gas and oil generally focus on the present and short-term future (though with some exceptions[4]). By contrast, discussions and analysis of electricity are more likely to focus on the medium- to long-term future as well as current security. If heat and transport are successfully decarbonised in future, this is likely to lead to closer coupling between those sectors and the electricity system – though the extent of electrification is highly uncertain, even if the UK's statutory climate change targets are met.

4.1.2. Risks to security

Second, the presentations focused on a range of potential risks to security. Whilst some of these were familiar, and are commonly discussed, others receive less attention in policy debates. For example, ageing domestic infrastructure such as the Forties pipeline is a potential risk to UK oil supplies. Yet, most of the discussion focuses on the increase in oil (and gas) imports over the past decade. Similarly, electricity supply disruptions are most likely to be due to faults on the electricity distribution network and, in most cases, the effects are local and can be fixed relatively quickly. This contrasts sharply with the focus on power generation capacity margins in much of the public discourse –

[4] For example, Ekins P. et al (2016) The future of natural gas in the UK. London: UK Energy Research Centre.

even though narrow margins have not generally been the cause of insecurity.

More than once, the speakers highlighted an important trade-off for policy makers and industry between spending more money on security (e.g. on more power plant capacity or gas storage) and what level of risk the government (and the public) are prepared to accept. This economic perspective emphasises that security is not simply a function of fuel or infrastructure availability, but also a function of the availability of finance or (in the case of final consumers) sufficient income to pay the bill. Spending more can increase security if consumers are willing to pay for it, but there tend to be diminishing returns.

4.1.3. The geography of energy security

Third, energy security can be analysed at different geographic levels. Whilst a lot of UK energy security discussions, like those in many other countries, are nationally focused, the speakers emphasised how interdependent UK energy security is with that of other countries – especially within the EU. Furthermore, it was argued that sharing of security with neighbouring countries could bring clear benefits in terms of sharing resources (for example, by distributing renewable electricity generation in the most economically advantageous locations) and reducing costs. To realise these advantages, greater levels of interconnection are likely to be required within the EU – in both electricity and gas. The Energy Union proposal from the European Commission has placed security at the top of the EU energy policy agenda. However, there is a lack of good, whole systems analysis of energy security at the EU level, including how this might change in future.

4.1.4. Governance of energy security

Fourth, governance arrangements for energy security matter, including roles and responsibilities for the security of national infrastructures (e.g. for electricity) and arrangements for sharing security or responses to disruptions between states. It was noted that the Energy Union vision of a collective approach to energy security is in tension with some of the shorter-term priorities of individual Member States as illustrated, for example, in different approaches to gas security. Similarly, while there have been long-standing arrangements under the IEA for emergency sharing of oil stocks in times of crisis, these do not work well. The equivalent EU system for oil has never been invoked. By contrast, it was argued in the discussion that some countries 'externalise' their security by relying on neighbouring countries. A good example is the German electricity system, which now has a large share of intermittent renewable generation.

4.1.5. Legacy infrastructures

Finally, there was a focus on the dynamics of change, and how legacy infrastructures and changes to the energy system as it decarbonises might affect security. As discussed previously, questions were raised about ageing national infrastructures such as offshore oil pipelines in the North Sea – and whether they will be reliable enough during the transition. A related point was made about the UK natural gas network which may eventually be redundant, but may also need some investment so that it is available during the transition away from gas towards low carbon heating systems. This expected decline was mirrored in Paul Stevens' talk by a challenge to the received wisdom that global oil demand will continue to rise. It may not rise in practice, and this may compound the problems faced by oil companies[5] and by oil exporting countries who are already under pressure due to the low prices that have been experienced recently.

The use of storage within the energy system is also changing fast. The UK's fossil fuel energy system includes a lot of storage, some of which is beginning to disappear. This includes coal stocks at power stations, oil stocks and gas storage capacity (which is dominated by the ageing Rough storage site). Collectively, these store much greater amounts of energy than electricity storage technologies, even if large-scale pumped hydro is included. This decline of storage may not mean a significant reduction in resilience, at least for the electricity systems. It was emphasised that

[5] Stevens, P. (2016) 'International Oil Companies: the Death of the Old Business Model' Energy, Environment and Resources Research Paper. London: Chatham House.

smarter grids may reduce costs by using assets more effectively, and allowing real time balancing of supply and demand without having as much spare capacity. This could also link to a greater use of demand side response or management, which is not yet well developed – especially at the domestic scale. As the National Infrastructure Commission argued, such smarter systems could also be complemented by interconnectors and electricity storage to deliver resilience at a lower cost than traditional approaches[6].

4.1.6. Knowledge gaps: security implications of low carbon energy transitions

Overall, the session demonstrated that there is a good level of understanding of many of the security risks faced by the current energy system, though clearly not what Donald Rumsfeld referred to as the ‘unknown unknowns’. However, some of these risks are less well appreciated and discussed than others in policy discussions – and to some extent in research too. When it comes to understanding the implications of the low carbon energy transition and the governance of that transition from an energy security perspective, there are more significant gaps. The measurement and assessment of energy security through this dynamic lens requires much more attention.

4.1.7. Recommendations

- The analysis of energy security needs to pay attention to the specifics of different fuels (materiality) as well as any interactions between them.
- There is a need for whole systems analysis of energy security at the EU level, including how the European energy system/systems may change in future.
- Researchers need to develop a greater understanding of the implications of the low carbon energy transition and the governance of that transition from an energy security perspective.

[6] National Infrastructure Commission (2016). Smart Power. London: NIC.

Accordingly, the measurement and assessment of energy security through a 'dynamic lens' requires much more attention.

4.2. Resources for energy systems

Chair:

- Prof Geoff Hammond, University of Bath

Rapporteur:

- Dr Mike Weston, UKERC

Currently, the UK's energy system is adequately resourced by fossil fuels. However, we will need to transition to low or zero carbon in the future. Energy demand could remain around the current level, but the transition will require some switching – for example, towards electricity for heat and transport. These changes will impact on our resource needs.

The low carbon energy technologies available to the UK include nuclear and various renewables. Each of these can have unwanted side-effects. For example, in the case of renewables, some may be constrained by the availability of materials such as rare earth metals.

This session sought to elucidate the key issues going forward on energy resources, their availability, and impacts for the UK. The following questions seeded the discussion:

- To what extent are energy resources limited both in the UK, and internationally? In the case of bioenergy, resource is uncertain, with estimated potential varying widely from 10-45% of total UK energy demand. Likewise, UK shale gas development is at a very early stage. Although the UK is one of the few countries in Europe where government wants to support shale gas, without a major programme of exploratory drilling, it is difficult to say what the UK resource will deliver. The fracking situation in the US is quite different from the UK, and is unlikely to serve as a model for a variety of technical, geological, and legislative reasons.

- Nationally, energy policy has moved from an emphasis on climate change towards affordability and energy security. What do we see as the most significant resource issues within this 'trilemma'? How should the UK balance the benefits and costs of these options?
- What do we need to say on the wider environmental issues, not just carbon emissions but also other policy issues such as land use and non-carbon emissions? For example, lifecycle assessments of solar photovoltaic (PV) show that the main environmental impacts arise from the aluminium frames, rather than the solar components.

The discussion included presentations from: Prof Mel Austen (UKERC Researcher & Head of Science, Plymouth Marine Laboratory), Prof Paul Ekins (Deputy Director, UKERC), and Dr Aled Jones (Director, Global Sustainability Institute, Anglia Ruskin University).

Discussions were primarily focussed on the knowledge needed to design renewable energy resource strategies for the UK, on the assumption that the current emphasis on finding and exploiting fossil fuels will diminish. Knowledge of fossil fuel reserves will need to be supplemented (or supplanted) at equivalent or even greater levels of granularity by understandings of the UK's renewable resources. A number of themes emerged in the discussions.

4.2.1. Resource assessment

It was argued by some participants that while there is a good deal of knowledge about the potential scale of biofuel resources, equivalent knowledge is lacking for renewable resources such as wind and tidal. This knowledge deficit is more pressing than might at first appear, as wind turbines are already a substantial feature of the offshore environment. Currently, we don't have enough understanding of the scale of the UK's renewable resource, its spatial distribution, and how it varies through time. This is important because renewable installations, such as wind farms and tidal barrages, draw on a resource that is limited: there is only a certain amount of wind or tidal energy available at any point in time.

Developing an understanding of the renewable resource is a complex problem. This is due to the fact that weather changes (with all the inherent unpredictability), renewable installations interact with one another and may have effects a long-way from their site (known as far field effects). There is little publically-available baseline data on weather patterns at the required level of detail. Accordingly, renewable facilities may be located in sub-optimal locations, suggesting substantial pay-off from better data.

4.2.2. Making connections

The major assumption in discussions was that energy, environment, and society are related and connections had to be taken into account to assess the realisable (rather than theoretical) resource available.
It was argued that analysis that takes into account multiple factors would allow more rational planning of renewable installations to minimise negative ecological damage and societal disruption, while maximising opportunities to use these resources. The entire supply chain might also fall within this analysis, including non-carbon waste, production standards, labour standards, and recycling. This analysis would draw on knowledge from engineering (costing the components), economics (markets), sociology (impacts on society) and environmental science (ecological aspects).

The dominant solution that was suggested to make such connections was mathematical modelling. However, it is difficult to connect ecological, economic and engineering models to understand, e.g., where wind farms, tidal barrages, etc., ought to be located.

One framing for the issue was through the idea of ecosystem services, and an endeavour to connect ecosystem models to energy models. This also remains a challenging task.[7] Efforts to reconcile different lines of evidence inside computer models, were matched by efforts to achieve the same more directly in people's minds, through the use of rhetoric,

[7] The ADVENT consortium on Addressing the Valuation of Energy and Nature Together, associated with UKERC, is developing approaches to link energy and ecosystem models.

narratives, and graphics that might trigger intuitive understandings by decision-makers.

This latter approach was exemplified by terms such as 'the nexus'. This is used to signify the connections between energy, water, and food, although other contributors to the session also identified skills, labour and expertise as important. The challenge for researchers was, however, to move beyond the point of saying there are connections to productive lines of analysis that could inform decision-making.

4.2.3. Complexity, simplicity, politics

A dominant assumption in discussions was that analysis of extra factors would be valuable in understanding energy resources. However, consideration needed to be given to the appetite for more detailed information among potential users of that analysis – and indeed, whether such added research would help to support the energy transition. For example, quantification of far field effects might, in theory, increase the risk of one offshore renewables installation suing one another for lost revenue.

It was pointed out that equivalent systems assessments of extracting and using fossil fuels (taking into account pollution other than carbon, road accidents, lung diseases, and economic, social and political effects such as incentivising corruption and gross inequality) are also required.

4.2.4. Recommendations

- Assessments of the UK's realisable renewables resources should be prioritised, drawing on a range of disciplines to develop integrated pictures that take account of economic, social, and environmental dimensions.
- Consideration should be given to how the various strands of information can be interpreted, represented and communicated. While modelling offers one potential integrating force, it is not the only one, and a rich picture might be produced by other means.

- The assumption that more and better data will speed low carbon transitions needs to be examined in particular cases as regards the potential customers for such data. As such, the role of models and data generation themselves as actors in the energy system should be considered.

4.3. Energy innovation systems

Chair:

- Prof Jim Skea, Imperial College

Rapporteur:

- Richard Hoggett, University of Exeter

To achieve the ambitious goals set out in the COP21 Paris agreement, improvements in current technologies and practices will be needed. Mid-century we may need to rely on existing technologies or reasonably foreseeable improvements and enhancements. In the second half of the century, the Paris agreement implies the development of negative emission technologies which are not yet available and which could imply new sustainability challenges.

Systems of innovation can be characterised by technologies, sectors or countries. In the last decade, there have been a number of initiatives designed to re-invigorate innovation processes in the energy sector and accelerate progress from basic science through to concept and market deployment. Examples include ARPA-E in the US; the absorption of the Risø labs into the Technical University of Denmark; and the Energy Technologies Institute and Low Carbon Network Fund in the UK. COP21 has inspired the Mission Innovation[8] initiative engaging 20 countries as well as the private sector Breakthrough Energy Coalition.

This session addressed the following questions:

[8] Since the energy systems conference was held, more details of individual country plans and the related, private sector Breakthrough Energy Coalition have been published: http://mission-innovation.net

- Do we need to expend more resources on energy R&D? Is Mission Innovation, for example, following the right approach? How do we not only spend more money, but spend it more wisely?
- What is the right balance between deployment support for near-market technologies and research support for more novel and potentially game-changing technologies? At what point should near-market technologies stand on their two feet?
- What institutional arrangements and practices can best accelerate the path from the laboratory to market deployment? Have initiatives like ARPA-E fulfilled their purpose?
- How can public sector interventions be designed to leverage private sector support? Can business-led initiatives such as the Breakthrough Energy Coalition act as game-changers?

This session included presentations from Charlie Wilson (University of East Anglia) who provided historical insights on energy innovation systems, and highlighted the global resurgence of interest and investment in energy R,D&D; Jeff Hardy (Ofgem) on the interactions between regulation and innovation, and how Ofgem seeks to ensure that their initiatives benefit consumers and responds to a rapidly changing energy system; and Jonathan Radcliffe (University of Birmingham) on innovation in energy storage technologies, and the risks of a public policy shift away from market incentives towards R&D support.

The presentations and discussion focused on a number of important themes, including the need to understand the differences between energy technologies and infrastructures from an innovation perspective; the important role of policy and regulation in supporting innovation; and the importance of a holistic view that considers social as well as technological innovation, and the relationship between them.

4.3.1. Diversity in low carbon innovation

In the opening talk of this session, Charlie Wilson emphasised three general insights from research with colleagues[9] that has drawn out lessons from a wide range of low carbon technologies. First, he emphasised that innovation systems approaches can help to explain the relative success or failure of directed innovation efforts by public policy. Second, accelerated innovation is most likely to occur when the technology is a ready substitute for existing technologies within the energy system. Third, diverse portfolios of smaller scale, modular and end use technologies are integral to climate change mitigation efforts, in addition to the larger scale technologies that often command attention in discussions about innovation.

It was noted that much of the focus within innovation systems tends to be on demand side or supply side technologies, but there are a range of technologies or infrastructures such as networks that are essential to energy systems which should also get attention. There are also significant scale and complexity differences between cleaner technologies: some are large and are often implemented in one-off capital-intensive projects (e.g. nuclear, CCS, etc.) whilst others are small, more modular and lend themselves to mass production (e.g. PV, storage). The relative size of any particular technology can have an impact on how innovation occurs; as well has having an implication on the sort of policy support that technology might need and the type of investor it might attract. For example, larger-scale technologies may take longer or can find it more difficult to get to market, so may need longer term or more support than smaller-scale technologies.

During the session, there was also some debate about whether there is a mismatch between two of the largest international innovation initiatives that were launched at the Paris climate change talks: the government-led Mission Innovation initiative and the private sector Breakthrough Collation. It was suggested that public sector funding is more focussed

[9] Grübler, A and Wilson, C (2014) Energy Technology Innovation: Learning from Historical Successes and Failures. Cambridge.

on larger-scale technologies, whereas the Breakthrough Collation may be focusing more on smaller scale technologies that could be attractive to consumers. It was also suggested that policy support should differentiate between the two, with public support and leadership being directed more towards larger-scale technologies, whilst for smaller scale consumer-focused technologies the policy emphasis could be on setting the right market conditions to enable private investors to support them. Whilst there was felt to be some logic and attractiveness to this contrast, it was felt that the evidence for it is not necessarily clear.

The session also considered whether there is a need for a different policy approach for technologies that do not fit neatly into a 'supply' or 'demand' category such as energy networks, storage and so on. These technologies and infrastructures play a critical role in energy systems, but they may be characterised by different innovation processes and could therefore need different kinds of policy support. Whilst it was argued that these technologies and infrastructures had not received the same policy attention, this particular session included an explicit focus on policy and regulatory support for innovation in both electricity networks and storage.

4.3.2. The role of policy and regulation

Policy and regulatory frameworks have an important influence on the pattern and direction of innovation, and were therefore discussed extensively during the session. It was noted that the emphasis on Mission Innovation – both globally and in the UK – may signal a shift in policy in favour of R,D&D spending, and away from support for technology deployment. In his talk, Jonathan Radcliffe suggested some reasons for this including cost (R,D&D is cheaper than support for deployment, which has also had significant impacts on consumer bills) as well as the short-termism of political cycles. With respect to storage in particular, it was argued that there is a lack of market support in the UK, which has led to some storage companies failing. The discussion also highlighted an important drawback of an emphasis on R,D&D. There is a significant risk that technologies will not be commercialised if there is no policy mechanism to support deployment – either through a carbon price or a more specific policy.

There was also a lot of discussion on how regulation could try to keep up with energy system change, particularly when change is rapid and profound. The challenge is that it needs do this whilst balancing the interests of current and future consumers, and ensuring the energy system continues to operate reliably. Examples from practice in Ofgem were given by Jeff Hardy, including through regulatory incentives for innovation, a project on flexibility and by embarking on a new horizon scanning process. A number of challenges for Ofgem were raised in the discussion. For example, there is a lot of interest in developing local energy projects and the extent to which current regulatory and market rules (which were developed with a very different energy system in mind) may need to change. Modifications to provide better incentives for storage technologies, including some tidal technologies, are also being considered. There were calls to review experience from regulatory schemes that have supported network innovation, particularly the Low Carbon Network Fund – to learn lessons and consider how non-licensed companies could get involved in future.

4.3.3. Beyond technological innovation

Much of the focus of the session was on technological innovation, but the growing importance of social innovation also came up in discussions. There was some consensus that social innovation is important area for innovation and innovation studies. An example is the development of new business models for energy, which some thought should be given more attention by the regulator. This led to a wider discussion about the different actors in the energy system, and the extent to which they will need to co-operate or compete.

There was also discussion about the social impacts that technologies could have. For example, would storage developments destroy other parts of the emerging demand side response market, or could some technologies reinforce a passive approach by consumers? To some extent, interactions of this kind were thought to be inevitable because different options to balance electricity systems (i.e. interconnectors, storage and demand side response) could be competing with each other. It was also highlighted that it is not clear that consumers will become more active as a result of the diffusion of demand-side innovations. Some of the solutions that are available can be automated and many consumers may prefer to avoid the 'hassle' of getting involved. Finally, it was noted that support for new end-use innovations may increase among consumers if wider co-benefits could be demonstrated. For example there are considerable local environmental and health benefits of electric vehicles, as their adoption would reduce particulate pollution in cities.

Perspective: Innovation and regulation: the role of Ofgem

Jeff Hardy, Ofgem

'Ofgem is the Office of Gas and Electricity Markets. Its principal objective when carrying out its functions is to protect the interests of existing and future electricity and gas consumers.

The energy sector is undergoing a profound and rapid transformation. This is being driven by technology (e.g. the falling costs of solar photovoltaics), behaviour (e.g. trends such as the sharing economy), policy and incentives (e.g. carbon budgets) and business models (e.g. local and community energy). These changes are in part driven by innovation. They will also require future innovation to integrate them into our energy system.

As a consequence, innovation in the energy system has the potential to bring great benefits to consumers. It can also bring risks. The role of the regulator is to balance delivering positive consumer outcomes with maintaining regulatory predictability.

To ensure that the balance is right it is crucial that Ofgem engages openly with stakeholders to identify regulatory barriers and opportunities. Its work on non-traditional business models[10], future of retail market regulation[11] and insights for future regulation[12], are examples of this.'

4.3.4. Recommendations

- Analysis and support for innovation needs to look across the whole energy system to include supply, demand and the infrastructure and networks that sit between the two.
- The scale of different technologies plays an important role within the innovation process and to some extent can shape where support might come from. Policy makers should take account of this when deciding how best to support innovation.
- Policy makers should give more consideration to how best to provide support across the whole innovation process. There are inherent risks in only supporting research and development if there are no policy mechanisms in place to support deployment.
- Policy and regulation needs to put in place mechanisms to keep up with the rapid pace of system change, and to adapt appropriately to it when evidence supports such adaptation.
- Innovation research, analysis and policy support needs to take account of social innovation; it is anticipated that this will grow in importance within energy transitions.
- In analysing different technological and social innovations there would be significant benefits in considering the wider co-benefits

[10] https://www.ofgem.gov.uk/publications-and-updates/non-traditional-business-models-supporting-transformative-change-energy-market
[11] https://www.ofgem.gov.uk/electricity/retail-market/market-review-and-reform/future-retail-market-regulation
[12] https://www.ofgem.gov.uk/news-blog/our-blog/call-engagement-insights-future-regulation

of different solutions, e.g. considering the carbon, environmental and health benefits of different low carbon transport options.

4.4. Making change happen: consumers, citizens, and practices

Chair:

- Prof Neil Strachan, Professor of Energy Economics and Modelling, UCL

Rapporteur:

- Lindsay Wright, UKERC

People and communities will be vital to the energy transition. But human responses are complex, hard to predict, and not always amenable to ‘nudges’. Given that we want to engage people with us as we move towards a decarbonised energy system, how can we better understand their roles, and accommodate human factors within our technology, modelling, scenario building, and policymaking? How can energy transitions take into account the different roles people play individually and collectively – as consumers, citizens and practitioners?

The aim of this session was to identify the insights and data that are currently available; to identify what we still don’t know; and to determine the kind of research we will need in five years’ time, to understand and foster changes in practices and behaviours.

Critical questions included:

- What lessons and evidence exist to inform start-ups developing products that are designed to influence energy use by individuals and communities?
- What publically-available primary data do we have on how practices and behaviours change? Is it possible to connect, say, Oyster (London public transport), walking (phone GPS), driving and taxi

use data? How do interventions such as Hive, Zipcar, and Uber impact energy consumption, if at all?

- Is a data-driven approach feasible? Are there ‘generalizable’ behaviours or practices that can be characterised and influenced? How ought we to segment, and prioritise, particular groups of people for intervention?
- How can citizens be more fully engaged in energy decision-making at national and local levels? What do we know now that could be used for decision-making immediately, and what do we need to know?

The session included presentations from Dr Catherine (Frin) Bale (University Academic Fellow, University of Leeds) and Prof Benjamin Sovacool (Professor of Energy Policy, University of Sussex).

4.4.1. Motivations of energy users

There was substantial discussion about the motivations of energy users (variously termed consumers, customers, and citizens) – and how these might be changed, e.g., to cut energy demand. It was said that the types of consumers in the energy system could be changing, for example, the emergence of ‘prosumers’ who produce electricity as well as consume it. Equally, it was said that consumers were not particularly active participants in the system, and might become less active; no consensus was reached in discussions as to the status of consumers as active participants.

It was also said that different energy users make decisions on complex criteria that are not just about cost-optimisation; there is a need to move beyond economic frameworks for evaluating costs and benefits. Energy users have complex motivations that are hard to model, are difficult to isolate, and are dynamic. These insights had implications for modelling – which was currently unable to take account effectively of behaviour.
The consumer focus chimed with the Energy Systems Catapult’s stated intention to prioritise ‘consumer insights: methodologies and tools to

ensure end-user behaviour is factored into energy system analysis and product development'.

4.4.2. From behaviour to practices

A countervailing view held that the behaviour of individuals, citizens, societies, social groups or even sociotechnical systems is incidental to understanding the human factor in the energy system. Rather, we ought to focus our attention on the idea of practices (e.g., cleaning, cooking, or driving a car), and explore how these develop, change, and transmit themselves.

The idea of consumer behaviour is a dominant framing in discussions of change in the energy system. It is an easy-to-grasp framing, but it probably offers an incomplete understanding of how people affect change in energy systems. Other units of analysis such as the idea of practices, which look beyond the individual, ought to be brought to bear on real-world issues in government departments and firms, with the aim of producing a richer account of energy systems.

4.4.3. The value of data

The potential value of big data was raised, as there is a good deal of data already available on consumer behaviour – and potentially significant extra volumes that could be obtained from firms (subject to confidentiality agreements). But it was also said that blanket calls for analysis of data might not be productive.

There was a need to find ways for researchers to work with companies that are generating large amounts of relevant data, such as Hive and Uber (as well as public sector data generators such as Transport for London) – and to do so in a way that allows for commercial and individual confidentiality. There are probably opportunities for mutual learning in this field across academic, government, and business sectors.

4.4.4. Recommendations

- Firms generating large amounts of relevant data, such as Hive and Uber (as well as public sector data generators such as Transport for

London) should work with researchers to analyse these data for insights on behaviour relevant to energy use.

- Other units of analysis besides behaviour, such as the idea of practices, which look beyond the individual, ought to be brought to bear on real-world issues in government departments and firms, with the aim of producing a richer account of energy systems.

4.5. Governance of energy systems transformation: emergence or design?

Chair:

- Nigel Fox, National Grid plc

Rapporteur:

- Dr Mike Weston, UKERC

The transition to a low carbon, sustainable energy system does not only mean changes to resources, technologies and infrastructures. It is already clear that changes in governance, institutions, policies and regulations will also be required.

At the moment, decision-making within the UK energy system is characterised by a mixture of markets and regulation. The extent of government intervention in markets has increased in recent years, and this has led to a debate about the desirability of more co-ordination or a return to a more market-led approach.

This session sought to identify what knowledge we have about how the governance of the UK's energy system is already changing, and how governance arrangements could change in future.

Critical questions included:

- What are the common problems of coordination, investment and management across the energy system – and what are the solutions?

- To what extent is more co-ordination – or even planning – required as part of the transition to a low carbon energy system?
- How could alternative ownership models solve the problems we face, and what other problems and solutions might different ownership models produce?
- What is the role of institutions at different scales in energy system governance, and how might the balance change between European, national, devolved and local institutions?

The session featured presentations from Duncan Botting (Managing Director, Global Smart Transformation Ltd & Member, IET Energy Policy Panel), Prof Frank Geels (Professor of System Innovation and Sustainability, University of Manchester), and Prof Catherine Mitchell (Professor of Energy Policy, Exeter).

Two recent reports, the National Infrastructure Commission's *Smart Power* report[13] and the report of the Future Power Systems Architecture project[14], framed many of the discussions about the need to transform the electricity system to avert substantial technical problems which could arise over the next decade.

A range of upcoming developments lie behind these calls for change, which include a rising contribution from intermittent renewable sources of electricity; decentralisation; greater use of interconnectors, smart meters, and storage; and the potential electrification of transport and heating.

The discussion was concerned with deepening analysis of the governance of the changing energy system, and how academic knowledge could inform future change. There was no single viewpoint within the

---

[13] National Infrastructure Commission (2016). Smart Power. London: NIC.
[14] The final report was published by the IET and the Energy Systems Catapult in July 2016. Institution of Engineering and Technology and Energy Systems Catapult (2016) Future Power Systems Architecture. Report commissioned by the Department of Energy and Climate Change. London: IET.

discussions. The following subheadings capture the major lines of argument, and briefly outline their implications.

4.5.1. Complex systems, markets, and the state

There was frequent reference in the discussions to the complexity of the energy system, with arguments that ranged freely across the philosophical and political landscape, referencing ideas about complex systems, markets, and the state. There was no single language among academic experts to talk systematically about the governance of the energy system.

One marker in discussions appeared to be around the idea of the energy system being 'complex' – intended in the formal sense: a system in which behaviour cannot be predicted, and displaying emergent properties that are greater than the sum of the parts.

This viewpoint implies the need to maintain flexibility to exploit new developments (and to mitigate the effects of negative developments), tempered by humility around our ability, even in principal, to shape the energy system.

This contrasted with the view that the energy system is complicated, but ultimately understandable given enough effort (possibly by new forms of data handing and smart systems); and therefore that it can be designed, and undergo substantial rapid change with predictable (in theory) effects.

A third range of views concerned the value of the market. It was argued that if value streams were well designed, then the market will deliver. On the contrary, others argued that markets would be unable to deliver the required changes, implying the need for a more centrally-directed model of governance.

4.5.2. Is the integration of governance and technical analysis too difficult?

It was said, jokingly, by an engineer that 'policy will outvote physics'. In other words, it is a commonplace that the energy system is more than just pipes and wires, engaging complex relationships between people and machines (a socio-technical system).

However, despite their importance, many of the sociological, institutional and political issues end up being excluded from technically-oriented analysis and placed in the too-complicated box, or considered matters of personal viewpoint rather than amenable to rational, expert, analysis.

They often become implicit assumptions, at least in more technically-oriented analysis of change. However, this contrasts sharply with social science energy research where such issues are often the main focus. Insights from research in political and social science, comparative studies of energy systems in different countries, and well-constructed analysis of the views and behaviours of citizens, all contribute significantly to knowledge and evidence.

Bringing all these elements into discussions productively is not easy, but there was consensus across the disciplines from engineering and social science, that substantial value would derive from developing a richer picture of the energy system and how it could change.

Integration of insights from social and political science into engineering analysis of energy systems is important. There is a need for greater efforts to work out how this can be done, such as through modelling. This was not a call for further interdisciplinary research, but rather consideration of how insights from the various fields of knowledge could be usefully integrated to assist strategic policy design.

4.5.3. Electricity and energy systems

Whilst this session was concerned with the entire energy system, discussions overwhelmingly focused on the electricity network. Given the potential electrification of heat and transport, electricity could come to dominate the energy system, but that is not the case now, and might not be in the future.

At present, there are large differences between the governance of the electricity system and other parts of the energy system. Electricity is heavily regulated with extensive governance already in place. Heat is in the opposite position, lacking governance. Petroleum is taxed, but it was argued that it lacks a national governance structure. The materiality of each vector is strikingly different. Furthermore, there is insufficient governance analysis of the potential interactions and integration of these various systems.

Perspective: How to achieve the energy system I would like

Catherine Mitchell, University of Exeter

'I would like the global energy system to move from its current dirty state to become a sustainable, secure and affordable energy system based primarily on renewable energy, energy efficiency and smart operation. In order for this to occur, the governance system has to change so that the things that we want to have happen can make money, and the things we do not want to have happen are not incentivised. A sustainable energy system requires having bottom-up optimisation, being customer and demand-focused, and being flexible and integrated between electricity, heat and transport. Whilst the system is very different from what we have now, it reflects changing, decentralising technologies, and social preferences.'

4.5.4. Recommendations

- There is no single language among academic experts to talk systematically about the governance of the energy system – discussions, therefore, ought to recognise that a single voice is unachievable. However, it is possible to gain a greater understanding of the differences and areas of agreement.

- Integration of insights from social and political science with engineering analysis of energy systems is important. There is a need for greater efforts to work out how this can be done productively, such as through modelling.
- The materiality of each energy vector is strikingly different. Researchers ought to devote more of their focus to governance analysis of the potential interactions and integration of the various vectors and systems.

5. Meeting the energy systems challenge in UK public sector research

Chair:

- Dr Jane Dennett-Thorpe, formerly Deputy Head of Science, DECC

Rapporteur:

- Dr Matthew (Matt) Hannon, Imperial College

Significant shifts are occurring in the way UK Government approaches and funds research and innovation, including research on energy systems. These include the follow-up to the Nurse Review, the formation of UK Research and Innovation (UKRI), plans for stronger co-ordination of public sector funders of energy R&D, and the founding of the Energy Systems Catapult.

The second day of the conference started with three presentations that provided an overview of some of the changes that are affecting the energy research landscape. The speakers were: Dr Paul Durrant (Head of Innovation Policy, Department of Energy and Climate Change); Dr Kathryn Magnay, (Head, RCUK Energy Programme) and Dr Alan Pitt (Deputy Director, Science Capability, Energy & Climate Change, Government Office for Science). The speakers were followed by breakout groups to discuss important themes that have emerged from the conference, and to develop recommendations for researchers, funders, and decision-makers.

Key questions for the second day included:

- What impact will the Nurse Review, and the formation of UKRI, have on funding for energy systems research?
- What within existing structures is working well – and what could be improved?
- How should academia work with industry and government? What structures and communication channels need to be reinforced?

5.1.1. A changing UK energy research landscape

Recent Developments in the UK research landscape have been discussed in detail elsewhere, particularly in an Energy Research and Training Prospectus produced by Professor Jim Skea and his team in 2013.[15] This discussion will not be reproduced here in full, but the conference presentations helped to provide an overview of some more recent developments, and the roles of different institutions and programmes. The latest official statistics on UK government funding of energy research, development and demonstration (R,D&D), and a comparison with several other OECD counties, are provided in Figures 1 and 2.

Three observations are particularly notable from these statistics. First, UK energy R,D&D spending is relatively low when compared to spending in other OECD countries.

Second, levels of spending have varied widely. Spending fell at the time of a return to low oil prices and industry privatisation in the 1980s, and then rose again as oil prices and the salience of climate change increased in the mid-2000s.

Third, the pattern of spending is now much more diverse than it was in the 1970s and 1980s. UK funding now supports a diverse portfolio of technologies (including research on energy systems), whereas it was previously dominated by spending on nuclear technologies. As Jim Skea's report emphasised, patterns of public spending are not the same as those in the private sector. Spending by the latter is dominated by research on fossil fuels.

15 https://workspace.imperial.ac.uk/rcukenergystrategy/Public/reports/Final%20Reports/RCUK%20Brighter%20energy.pdf

Figure 1. UK Energy RD&D Spending (1974-2013). Source: IEA.

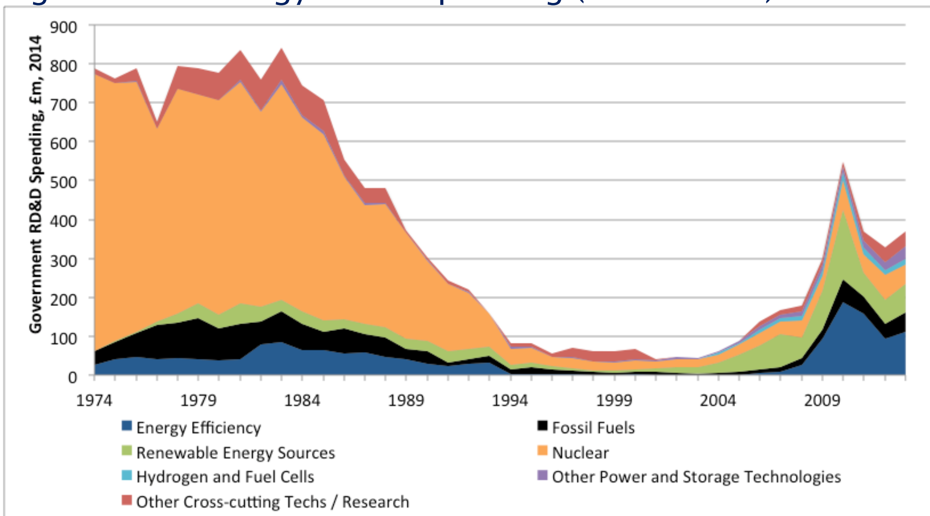
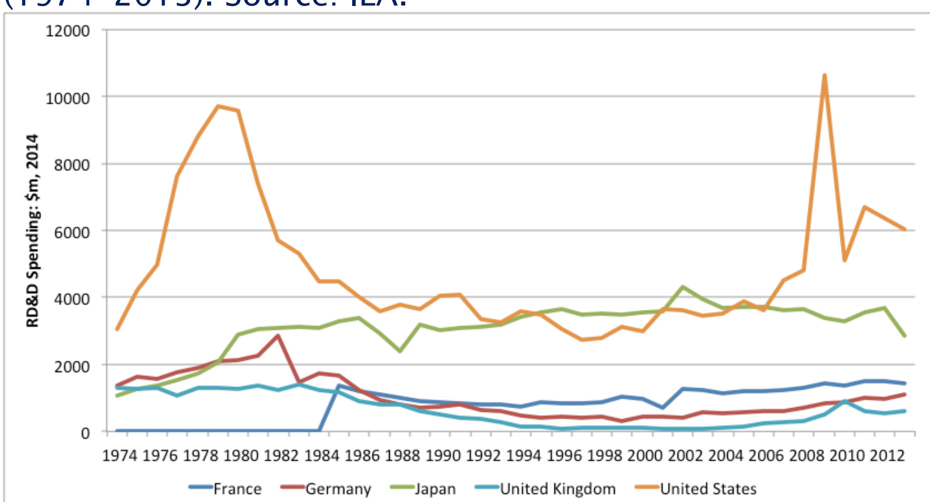


Figure 2. RD&D Spending in the US, UK, Japan, Germany and France (1974-2013). Source: IEA.



Publically-funded energy research is carried out in both universities and firms, with government funding coming in four streams: (1) Research Councils, which mainly fund universities; (2) Innovate UK, which is mainly focused on funding firms; (3) Public-private partnerships such as the Energy Technologies Institute (founded in 2007) and the Energy Systems

Catapult (established in 2015); and (4) direct funding via central government departments. The UK does not have a national energy laboratory that is comparable to those found in Germany, the USA, and other countries. However, it does have institutions and centres such as the ETI and UKERC that were deliberately created to fulfil some of the roles of national labs.

The following trends and ideas were raised by speakers and members of the audience during discussion:

- There is a renewed focus on energy innovation within government, coupled with a desire for a stronger role for competitive markets (particularly in the electricity sector) by the mid-2020s. Public funding for energy R,D&D is due to double during the current Parliament – from £200m in recent years to £400m by 2020. This has been partly driven by the UK's membership of Mission Innovation, a coalition of 21 countries that made similar pledges at the climate change talks in Paris in November 2015.[16]
- There is a desire to develop a more tightly coordinated innovation programme across the funders. Whilst the institutions that support and carry out publicly funded energy R,D&D are subject to loose co-ordination through the Low Carbon Innovation Co-ordination Group (LCICG), there are plans to replace the Group with stronger co-ordinating arrangements in the near future.[17] For one speaker, the ideal would be a single innovation research plan, with each body feeding into its structure and content. There is also a desire to coordinate energy R,D&D internationally, e.g. through the SET Plan within the European Union, and Mission Innovation.

[16] A summary of the UK's plans is available on the Mission Innovation website. The planned doubling of UK energy R,D&D is largely due to a £250m programme on small modular reactors: http://mission-innovation.net/participating-countries/#UnitedKingdom

[17] A new Energy Innovation Board, chaired by the government Chief Scientific Advisor, was announced in Autumn 2016: https://www.gov.uk/government/groups/energy-innovation-board

- Within more directed energy R,D&D programmes funded by government, there will be a tighter focus on a smaller number of specific energy R,D&D areas, clustered around six themes: (1) renewables; (2) nuclear; (3) built environment; (4) smart systems and system integration; (5) industrial carbon capture and storage (CCS) and energy efficiency; and (6) cross-cutting issues, with a focus on helping smaller companies and entrepreneurs.
- Research, development and demonstration of energy systems (rather than just individual technologies) is an important priority. As well as being one of the six themes for publicly funded R,D&D, energy systems research also needs to be strengthened within the RCUK energy programme. This includes increasing research on interactions between energy supply and demand (though a new National Centre for Energy Systems Integration), research on systems enablers such as new materials, and understanding of how individual technologies can be integrated. It is also important to draw in advances from other fields (e.g. maths, physics and chemistry), and understand in more detail how the energy system is related to other sub-systems (e.g. economic, environmental, political).
- There are potential downsides of this more co-ordinated approach. It was emphasised that there is a need to strike a balance in Research Council funding between managed research programmes and space for research that is driven by the interests of the academic community through responsive mode.
- There will be an increase in development research managed by RCUK on clean energy. Funding for the new £1.5bn Global Challenges Research Fund is coming from the DFID budget, and will be subject to Official Development Assistance (ODA) rules. It will therefore become essential that researchers consider the value of their work for a developing world context.

- There continues to be a strong emphasis on impact. Encouragement will be lent to sophisticated and in-depth discussion between academia and government. Government need to articulate their needs better, and academia needs to tailor their work to generate more impact.

5.1.2. Recommendations

The breakout groups came up with a wide range of recommendations for future energy systems research, and the relationship between research and decision-making. This section discusses the key points under six themes, and puts forward some overall recommendations (highlighted in bold).

Co-ordination of publicly funded research and policy

It was emphasised that energy systems transitions require support for a portfolio approach to research that includes both early stage and near market technologies; and a combination of directed and 'blue skies' research. A major issue for the UK is the multiple funding bodies, agencies and institutions involved in energy systems R,D&D. This makes for a confusing and complex landscape. More co-ordination and a better understanding of the roles and interactions of these institutions is required. Furthermore, influencing change in energy systems is not just a task for the government departments responsible for energy policy and research. Energy systems are complex, and cut across many departmental remits. Further co-ordination of policy is therefore required to develop overall strategic approaches to meeting policy goals such as statutory carbon budgets.[18]

Recommendation: More co-ordination and coherence of public funding for energy R,D&D is required, including the links between different institutions and programmes. Co-ordination is also required across government to meet strategic energy policy goals such as carbon budgets. It is essential that greater co-ordination does not undermine

[18] Since the conference was held, the 5th carbon budget (2028-32) has been approved by both Houses of Parliament.

the independence of academic energy systems research, and leaves significant space for 'blue skies' research.

The research-policy interface

There was a lot of debate about how to build more effective links between the substantial evidence base on energy systems that is being developed by the academic community; and decision-makers, particularly within government.

There were calls for the academic community, perhaps led by UKERC, to develop a stronger vision for the future of the energy system. It was argued that such a vision would be necessarily long-term, but would also need to be consistent with short- to medium-term pathways. There are, of course, a wide range of existing visions, scenarios and pathways that have been produced by academic research and by industry and public sector organisations. Some argued that the academic scenarios and visions are too diverse – and that it would be preferable for some consensus to be formed about a particular vision for the future of the energy system. Others disagreed strongly, and argued that it was important to recognise that visions of the future differ – for example, because of different objectives, disciplinary perspectives, and large uncertainties in the future evolution of the technologies and other components of energy systems.

Furthermore, some delegates pointed out that visions of energy systems change are often rather narrowly framed – and focus too much on technologies and costs, and do not spend enough time describing and analysing the potential social, institutional and wider dimensions of change.

There was, however, more agreement that the research community could do more to identify areas of consensus and disagreement within this diverse evidence base, and 'least regrets' actions. Examples that are often emphasised include the importance of energy efficiency and the central role for carbon capture and storage in many energy scenarios that meet statutory climate targets. To some extent, UKERC and other energy systems centres perform this role. For example, UKERC's Technology and Policy Assessment team conduct systematic evidence reviews on contested energy topics. However, more could be done to help decision-makers understand the evidence base, to ensure that future visions and scenarios are broad enough, and to explore the use of new methods and tools (see next section below).

Recommendation: It is unrealistic to expect a single vision or evidence base on a future vision or pathway for the UK energy system. Diversity is essential due to uncertainties about the technological, economic and other dimensions of change. It is also needed to take into account different disciplinary perspectives. However, the research community needs to do more to provide decision-makers with access to the academic evidence base. This includes identifying aspects of the UK energy transition where there is significant consensus, providing accessible, rigorous reviews of the evidence base on particular questions, and providing energy system visions and pathways that include wider social and institutional dimensions of change.

Models and tools to support decision making

Not surprisingly, there was a lot of discussion of the need for more research to understand energy systems, their interactions and how they could change in future. Several suggestions were made for areas where more independent, academic research is needed including: understanding of interdependencies and interactions between different energy vectors and sub-sectors; the potential economic and emissions reduction opportunities of particular technologies (rather than leaving such macro-economic appraisals to consultancies); energy system uncertainties and the robustness of particular conclusions to potential changes in technology, prices, and business models; the business and economic case (or lack of it) for greater energy systems integration; and evidence reviews that focus more specifically on the appraisal of specific technologies, their advantages and impacts.

A number of attendees emphasised the importance of flexibility in the face of uncertainty. Therefore tools and methods are required to support decision-making that take into account learning and feedback on the actual performance of energy technologies and systems. Such methods also include processes to ensure that a wide range of views are taken into account, which may help to avoid or minimise stranded assets.

The organisation and curation of research data was also discussed. Some argued that there should be a single Research Council data repository for energy research. The UKERC Energy Data Centre could be developed further to fulfil this role, for example. There is also the relatively new Research Fish system developed by the Research Councils for recording outputs and other impacts from research grants. This does not include outputs from projects supported by other funders.

Recommendation: There is now significant energy systems research capacity in the academic community. However, there is a need to build on existing research to develop new models, tools and methods to understand the full complexity of these systems, and how they might change. Energy systems analysis also needs to engage more fully with the need for flexibility in decision-making given the rapid pace of change. The more co-ordinated approach to energy data that is now being pursued by the Research Councils is welcome, and is needed to support decision-makers as well as the research community.

Social and public engagement

There was agreement that the academic community should have a role in engaging the public (or, more accurately, multiple ‘publics’) in discussions about energy systems transitions. As noted earlier, a potential component of this engagement process is the need to understand the social dimensions of energy transitions more fully. It also means doing more participatory research, for example, to understand the adoption of new technologies or to explore what kinds of energy system change are more or less likely to have public support.

Public engagement research is now an important part of the energy research community. Some of this research is focused on the energy system as a whole, rather than on individual technologies or projects[19].

[19] For example, UKERC research led by Jason Chilvers is conducting and evidence review of different forms of public participation in energy systems in the UK: http://www.ukerc.ac.uk/programmes/decision-making/systemic-decision-making.html

However, activities by that research community to help diverse publics understand and engage with potential changes to energy systems are relatively modest. Significant resources would be required to undertake a more strategic and comprehensive programme of research and other activities to involve publics in decision-making about energy system change.

Recommendation: The energy systems research community have an important role to play in engaging diverse publics with the energy transition. This is required to ensure that this transition is more inclusive, to help other decision-makers understand public views, and to provide opportunities for publics to participate in the transition. Whilst a significant number of public engagement initiatives have already been implemented, including academic research, there is a case for a more strategic and comprehensive public engagement programme.

Energy systems in developing countries

The previous discussion about the new Global Challenges Research Fund (GCRF) led to suggestions about the relative importance of energy systems research that focuses on developing countries. It was argued that individual academics and institutions are best placed to develop the relationships with colleagues in developing countries to carry out such research. However, it was also suggested that, given the scale of the GCRF, a more strategic and co-ordinated approach is required. This should include more engagement with the Department for International Development (DFID); consideration of the interactions of energy research with domains where there might be co-benefits from more sustainable energy systems (e.g. health and local environmental impacts); and a focus on the development of capabilities and skills in developing countries as well as the deployment of technologies.

Recommendation: Given the scale of the Global Challenges Research Fund, a strategic approach is required to identify priority research themes and questions, including how research on energy systems can contribute to achieving the Sustainable Development Goals (SDGs). This strategic approach should take into account the need to build capacity and skills in developing countries, and the potential scope for co-benefits of cleaner energy systems for other SDGs (e.g. those focused on health).

Skills and career development

Finally, a number of points were made about skills and careers to support the transition to a more sustainable energy system. The changes that are already beginning to take place illustrate the need for new skills in implementation, for example, in carrying out whole house retrofits to achieve significant gains in energy efficiency.

Within energy systems research, interdisciplinary capabilities are particularly important. Whilst a lot of progress has been made to develop these capabilities, more could be done to bring in and/or integrate perspectives from other disciplines – whether they are technical (e.g. to better inform systems models) or from the social science (e.g. to better understand distributional implications of energy transitions). There is also a need to think more systematically about career paths for interdisciplinary energy systems research. Such career paths face the familiar challenge of cutting across established disciplinary funding, teaching and promotion structures. Research centres such as UKERC, WholeSEM and university energy research centres often provide a 'home' for interdisciplinary careers, but this provides a limited career path – particularly beyond the PhD.

Recommendation: The unfolding energy systems transition requires new skills, e.g. for designing, manufacturing and installing low carbon technologies. Energy systems research also requires new skills, including skills to carry out the interdisciplinary research that is needed to address real-world problems. Whilst the UK research community has built up substantial, world-class capabilities for such interdisciplinary research, a clearer career path is required for early career researchers.

6. Appendix 1: Summary of recommendations

Energy security: beyond keeping the lights on

- The analysis of energy security needs to pay attention to the specifics of different fuels (materiality) as well as any interactions between them.
- There is a need for whole systems analysis of energy security at the EU level, including how the European energy system/systems may change in future.
- Researchers need to develop a greater understanding of the implications of the low carbon energy transition and the governance of that transition from an energy security perspective. Accordingly, the measurement and assessment of energy security through a 'dynamic lens' requires much more attention.

Resources for energy systems

- Assessments of the UK's realisable renewables resources should be prioritised, drawing on a range of disciplines to develop integrated pictures that take account of economic, social, and environmental dimensions.
- Consideration should be given to how the various strands of information on energy resources can be interpreted, represented and communicated. While modelling offers one potential integrating force, it is not the only one, and a rich picture might be produced by other means.
- The assumption that more and better data will speed low carbon transitions needs to be examined in particular cases as regards the potential customers for such data. As such, the role of models and data generation themselves as actors in the energy system should be considered.

Energy innovation systems

- Analysis and support for innovation needs to look across the whole energy system to include supply, demand and the infrastructure and networks that sit between the two.
- The scale of different technologies plays an important role within the innovation process and to some extent can shape where support might come from. Policy makers should take account of this when deciding how best to support innovation.
- Policymakers should give more consideration to how best to provide support across the whole innovation process. There are inherent risks in only supporting research and development if there are no policy mechanisms in place to support deployment.
- Policy and regulation needs to put in place mechanisms to keep up with the pace of rapid system change, and to adapt appropriately to it when evidence supports such adaptation.
- Innovation research, analysis and policy support needs to take account of social innovation; it is anticipated that this will grow in importance within energy transitions.
- In analysing different technological and social innovations there would be significant benefits in considering the wider co-benefits of different solutions, e.g. considering the carbon, environment and health benefits of different low carbon transport options.

Making change happen: consumers, citizens, and practices

- Firms generating large amounts of relevant data, such as Hive and Uber (as well as public sector data generators such as Transport for London) should work with researchers to analyse these data for insights on behaviour relevant to energy use.
- Other units of analysis besides behaviour, such as the idea of ‘practices’ (which look beyond the individual) ought to be brought to bear on real-world issues in government departments and firms, with the aim of producing a richer account of energy systems.

Governance of energy systems transformation: emergence or design?

- There is no single language among academic experts to talk systematically about the governance of the energy system – discussions, therefore, ought to recognise that a single voice is unachievable. However, it is possible to gain a greater understanding of the differences and areas of agreement.
- Integration of insights from social and political science with engineering analysis of energy systems is important. There is a need for greater efforts to work out how this can be done productively, such as through modelling.
- The materiality of each energy vector is strikingly different. Researchers ought to devote more of their focus to governance analysis of the potential interactions and integration of the various vectors and systems.

Meeting the energy systems challenge in UK public sector research

- More co-ordination and coherence of public funding for energy R,D&D is required, including the links between different institutions and programmes. Co-ordination is also required across government to meet strategic energy policy goals such as carbon budgets. It is essential that greater co-ordination does not undermine the independence of academic energy systems research, and leaves significant space for 'blue skies' research.
- It is unrealistic to expect a single vision or evidence base on the future vision or pathway for the UK energy system. Diversity is essential due to uncertainties about the technological, economic and other dimensions of change. It is also needed to take into account different disciplinary perspectives. However, the research community needs to do more to provide decision-makers with access to the academic evidence base. This includes identifying aspects of the UK energy transition where there is significant

consensus, providing accessible, rigorous reviews of the evidence base on particular questions, and providing energy system visions and pathways that include wider social and institutional dimensions of change.

- There is now significant energy systems research capacity in the academic community. However, there is a need to build on existing research to develop new models, tools and methods to understand the full complexity of these systems, and how they might change. Energy systems analysis also needs to engage more fully with the need for flexibility in decision-making given the rapid pace of change. The more co-ordinated approach to energy data that is now being pursued by the Research Councils is welcome, and is needed to support decision-makers as well as the research community.
- The energy systems research community have an important role to play in engaging diverse publics with the energy transition. This is required to ensure that this transition is more inclusive, to help other decision-makers understand public views, and to provide opportunities for publics to participate in the transition. Whilst a significant number of public engagement initiatives have already been implemented, including academic research, there is a case for a more strategic and comprehensive public engagement programme.
- Given the scale of the Global Challenges Research Fund, a strategic approach is required to identify priority research themes and questions, including how research on energy systems can contribute to achieving the Sustainable Development Goals (SDGs). This strategic approach should take into account the need to build capacity and skills in developing countries, and the potential scope for co-benefits of cleaner energy systems for other SDGs (e.g. those focused on health).

- The unfolding energy systems transition requires new skills, e.g. for designing, manufacturing and installing low carbon technologies. Energy systems research also requires new skills, including skills to carry out the interdisciplinary research that is needed to address real-world problems. Whilst the UK research community has built up substantial, world-class capabilities for such interdisciplinary research, a clearer career path is required for early career researchers.

7. Appendix 2: Conference programme

Day 1

10.00 Registration & coffee
10.30 Plenary: Energy systems challenges
12.00 Lunch
13.00 Parallel sessions:

- Governance of energy systems transformation: emergence or design?
- Energy security: beyond keeping the lights on
- Making change happen: consumers, citizens, and practices

14.30 Coffee break
15.00 Parallel sessions:

- Energy innovation systems
- Resources for energy systems

16.30 Plenary: What does good leadership look like across the energy system?
17.30 Break
18.00 Poster session and drinks reception
19.00 Formal Hall

Day 2

8.00 Breakfast
9.00 Plenary: How can we fund energy systems research and innovation?
9.45 Break-out groups
10.45 Coffee
11.00 Plenary: Synthesis of discussions
12.00 Lunch
13.00 Close of meeting