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Energy and Complexity – The Way Forward

Workshop Report

5th July 2012, Exam Schools, University of Oxford
REF UKERC/MR/MP/2012/004

Edited by Timothy Cooper and Lucy Mahoney from the UK Energy Research Centre Meeting Place together with the workshop Steering Committee.

This document is a report by the organiser of a technical meeting set up as part of UKERC's research programme. It is believed to be an objective record of the meeting but has not been separately reviewed by the participants.

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Contents

Overview

This report details the outputs of a one-day workshop presenting the state-of-the-art of complexity science approaches to addressing energy challenges, held in Oxford in July 2012. The event sought in particular to draw insights and lessons from four major EPSRC projects for future energy research and decision-making. Presentation hyperlinks have been inserted where available. Although no strict definition was given during the workshop, complexity science was generally interpreted as the study of systems with many interdependent components.

Executive Summary

1. Complexity science needs to be better understood by researchers, politicians, policy makers and industry. Complexity science as a taxonomy needs better definition.
2. Computer scientists, mathematic and energy specialists should be clearer and more proactive in obtaining funding. European funding for complex projects as well as UK funding for smaller and larger projects should be obtained through cross-disciplinary cooperation.
3. As new models are developed, consolidation and integration need to be thought about, as well as application of complexity techniques to new areas
4. It is important to manage and share data across multiple disciplines and research groups. Especially with the increase of data from smart meters/smart grids.
5. Complexity science is likely to be needed in order to address complex behavioural questions.

Scene Setting Presentations: Sharing learned experiences

Chair: Stephen Peake (Open University)

1. **Energy decision-making for cities, presented by Nick McCullen (University of Leeds) and Tao Zhang (University of Nottingham)**

(click here for presentation)

Smart grids are highly interesting but customers must be at the heart of any modelling-based research. Economic modelling or engineering-based models are sadly not ideal for revealing how customers will react to real-life situations. It is therefore important to ensure that social scientists are involved as the field evolves. Developing network models depends on obtaining valid data from surveys about who is being influenced by whom, but this is difficult to collect reliably. Establishing who has been talking to people about energy, and also whether people are actually influenced by new information, are both exceptionally challenging. At present most studies merely ask customers who they are “most likely to listen to”.

2. **Preventing wide-area blackouts through adaptive islanding of transmission networks, presented by Janusz Bialek (Durham University)**

(click here for presentation)

In recent years we have witnessed an unusually high rate of power system blackouts and disturbances in Europe and US/Canada. They seem to indicate that the twin drivers of: a) commercial pressures for better utilisation of transmission and distribution networks, and b) increased penetration of Distributed Generation (DG), tend to reduce security margins and lead to a higher probability of blackouts. This interdisciplinary project, involving power engineering, graph theory and operational research, investigates methodologies to limit the occurrence and cost of blackouts through preventive splitting of large networks into islands when a cascade fault is imminent.

From a mathematical point of view, grid reactances give rise to a new metric structure on the grid that allow one to analyse the problem of islanding in the mathematical context of much studied isoperimetric problems. The main tool has been spectral analysis of the discrete weighted Laplace operator, Ddiscrete version of calculus and discrete Morse theory has been applied to capture the information about the power flows, to develop alternative techniques for identifying balanced islands, and to assess the effect of disconnecting an island on the rest of the network.

As an alternative approach to preventive islanding, mixed-integer optimisation techniques have also been employed.

3. **SCALE (Small Changes Lead to Large Effects), presented by Minette D'Lima (UCL) and Joan Serras (UCL)**

(click here for presentation)

Some effects are not immediately susceptible to government modelling (e.g. models of complex systems), it is therefore important to think more critically about which aspects of the outputs relate to the real world and which are simply characteristics of the model itself. One finding of this study was the assumption that larger cities will always have lower transport cost is not necessarily true. The transport land-use modelling project only examined work-related commuting, since this is easier to model, but other trips are also important as they in themselves help to inform the commuters’ daily choices. Cultural and psychological factors that normalise the use of cars for shopping, leisure and multiple trips often lead people to perceive the inherent cost of driving as less than that of walking, for example.

4. **Complex Adaptive Systems, Cognitive Agents and Distributed Energy (CASCADE), presented by Liz Varga (Cranfield University) and Rupert Gammon (De Montfort University)**

(click here for presentation)

CASCADE uses agent-based modelling but not network-based modelling, since the former can show heterogeneity closely and smartly, and can be set up in different scenarios. Whilst an understanding of demand-side responses in the domestic sector can be derived through a study of price signals, industry activity is more challenging to monitor, since energy is typically obtained on a contractual basis by this sector. Uncertainties remain over the nature of the relationship between the demand profile and the energy mix. CASCADE work suggests that the former often constrains the latter, since changes in demand will result in particular plants being turned on or off depending on precise needs. However, the relationship will also be influenced by the nature of the energy supplies that are available at any given time (one example being the intermittent nature of wind energy).

Knowledge Café 1

The aim of the first knowledge café was to discuss research gaps and overlaps between complexity science techniques, and their application to specific issues. Participants selected three questions they wanted to address.

The questions discussed were:

1. How can we validate complexity science models and improve the reliability of the research outputs?
2. How can we integrate different models?
3. What sources of data are available? How can we share/manage data?
4. How can complexity science be used to address energy challenges related to resilience?
5. How can complexity science be used to address energy challenges related to behaviour (organisations and individuals)?
6. How can complexity science be used to address energy challenges related to transport?
7. How can complexity science be used to address energy challenges related to Smart Grids?

Feedback from each question is summarised below:

Q1. How can we validate complexity science models and improve the reliability of the research outputs?

- Participants acknowledged that it might never be possible to validate complexity science models, owing to the nature of the systems that are being studied. Even if validation remains impossible, models provide a valuable insight into complex systems.
- Often the assumptions used in complexity science models are not clearly articulated. For politicians to make decisions, assumptions need to be made much clearer.
- The concept of validity itself can be defined in many ways; it is therefore important to ask whether producing complexity science models whose outputs are verifiable is necessarily desirable. So long as assumptions are clarified, models can still be very useful decision-making tools.

Q2. How can we integrate different models?

- To answer this question it is first necessary to establish precisely what is meant by the term “models”. Models used by social scientists differ greatly from those used by economists, for example. Perhaps one strategy for integration would involve using the outputs of one type of model as the inputs for another.

- It is also important to ask why integrating different models is desirable. Who would ultimately benefit? To use models to their full potential it is first necessary to understand the advantages and disadvantages of each. There may be some cases however where integration is beneficial, such as where static models are integrated with dynamic ones.
- Often there are large issues surrounding how integration would be achieved in practice (relating for instance to time-scale and disciplinary conflicts), and even then it is not certain that integration will actually yield any new insights. Might integration simply end up generating over-complexity?

Q3. What sources of data are available? How can we share/manage data?

- Many participants felt it important in the future to use research councils to provide better access to data, and also for academics to share their data more freely themselves, for instance through open data access websites.
- The sharing of data might be encouraged by enabling direct citations of data sources to be made in journal articles, so that the people involved in data collection can be easily and directly acknowledged.
- The discipline should actively seek to engage people from government (for instance DEFRA), since they can help obtain the right type of data.
- It is also critical to keep available data sets as up-to-date as possible by talking to research councils; the EPSRC for instance has large swathes of data available from past projects.
- The most frequently data sources used by the event participants are available from Appendix A.

Q4. How can complexity science be used to address energy challenges related to resilience?

- This is a complex question – ultimately complexity science is still relatively immature, and not everyone will recognise it as the best approach for a given resilience problem, since there is little interdisciplinary agreement.
- In addition, time-scale is important; short-term resilience will involve mitigating problems and finding solutions, whereas long-term resilience will involve enhancing the overall adaptability and flexibility of the energy system.
- There are a number of different definitions of complexity science and resilience themselves, and this will lead to a diversity of approaches that use different tools and frameworks.

- It is important to try and understand the potential for emerging approaches. The relative merits of engineering resilience and human resilience must also be weighed up more effectively.

Q5. How can complexity science be used to address energy challenges related to behaviour (organisations and individuals)

- Firstly, it is necessary to identify what the relevant challenges are, and then to ask whether complexity science will actually be useful.
- The most critical challenges would seem to reside at the interface of technology and behaviour. How can research influence behaviour, and what are the best incentives to deploy?
- The strength of many complexity science models resides in their potential to predict the response of a whole system, but access to more data is required to fulfil that potential successfully.
- Critical energy challenges that complexity science can inform include better incentivising behavioural change. Research should seek to introduce simple measures that people can understand and respond to effectively.

Q6. How can complexity science be used to address energy challenges related to transport?

- With respect to domestic vehicle use and the need to move away from widespread societal reliance on fossil-fuel propulsion, complexity science can help illuminate the trade-offs between petrol or diesel and electric vehicles. Since it seems that the present electric grid infrastructure is insufficient to facilitate charging of cars “at home”, perhaps people could swap batteries at new versions of petrol stations?
- On the issue of cycling, it is clear that huge changes are required in planning.
- It is obviously critical to understand not just how people use their cars but also why people use them. Good solutions are emerging from complexity science but at present these seem merely hopeful.
- Technical discussions should be oriented towards establishing not just how transport will evolve in the future, but also how this will impact upon the power sector.
- Complexity science can address challenges by bridging the barriers that presently exist between different sectors, disciplines, players and stakeholders.

Q7. How can complexity science be used to address energy challenges related to Smart Grids?

- To answer this question it is necessary to establish exactly what is meant by complexity science, and indeed by smart grids.
- Another key question is to ask what the function of smart grids should actually be. Unfortunately, it is very hard to predict what society will want in the future, or what will be popular.
- Tipping points also need to be better understood; smart grids require interaction between different layers; if one layer goes wrong it can bring down other layers.

Panel Discussion: Energy Challenges in Complex Systems

Chair: Tim Foxon (University of Leeds)

Following the morning sessions, a panel discussion was staged to address the following three key questions:

1. What key insights or lessons do the four EPSRC projects offer, and for whom?
2. What are the main challenges in understanding energy systems that we could tackle with the tools of complexity science?
3. What areas are priorities for research?

The session was then followed by a wider discussion.

Stephen Peake (Open University)

- Policymakers might be considered as designers in a complex system, since policy creates an operating space for different options to be tried out.
- There are fantastic data sets being generated from Smart Meters that will enable us to better understand the problems faced in society.
- Whilst a large number of models have been discussed, the discipline must think hard about whether settling on fewer representations of these might be desirable. Policymakers, and therefore society, may ultimately benefit more from being shown just a few models, or the combined outputs of several, as opposed to being bombarded with hundreds of different permutations.
- Research priorities – instrumenting models and conducting real experiments. Policy-makers and scientists need to work more closely together.

Andrew Richards (National Grid)

- The ultimate aim should be to ensure that energy supply and energy demand are the same. This is an extremely complex task however, and it is not entirely clear whether those involved at different points understand just how complex things actually are at the overall level. The CASCADE project, for example, offers us a great model at the distribution level, but what about other levels?
- The energy market has rules, but rules do not always achieve what they were designed to. There are constraints, but the market does not know about these, so the task is to devise feasible solutions to reach the desired end state.
- Customers often act in ways that would not be considered as "rational" by modellers, yet most of the time overall behaviour and demand are predictable. Therefore, it is important to ask whether things will necessarily be easier if smart grids are introduced.

Joe Ravetz (University of Manchester)

(click here for presentation)

- It is crucial to ask what complexity science research is ultimately for. Is the relevant audience the policy-making community, wider stakeholders, infrastructure providers or other groups?
- A huge number of wider issues impact on energy stakeholders and energy policy. It is therefore critical to develop a more nuanced understanding of the varying kinds of complexity that exist in different situations.
- Moreover, it would be useful to have a clearer idea of the different benefits that complex science knowledge can actually have. Does such knowledge really help to build bridges between disciplines, for instance?
- There should also be a normative dimension to complexity research; the field should not just be about promoting particular technologies that will then slot into society.

Jim Skea (RCUK Energy Programme Strategy Fellow)

- The entire research community is facing profound funding challenges in these present times of austerity. Against this backdrop, is there a coherent idea that can be presented to a set of funders as the central organising principle of complexity science?
- There are common methodologies around complex systems and coherent networks around behaviours, but the fundamental challenge is to put forward

a coherent idea underpinning the field as a whole. What is the purpose of this discipline?

- Perhaps complexity science needs a champion to put forward ideas and to build strong networks that will develop opportunities for the disciplines to expand.

Wider Discussion

Methodological Challenges

- At a fundamental level this discipline seeks to understand systems that are complex both because of the nature of linkages between variables, but also because they involve human choices that are not predictable. Even as models get more complex and increasingly prove their predictive power however, it will be crucially important to ask whether the outright prediction of human systems is even desirable. Perhaps the aim should not be to seek predictive power, but instead to embrace models for cognitive and anticipatory power.
- Modellers need good data to facilitate the formulation and calibration of their models. Yet researchers are constantly confronted with barriers around the availability of data. Putting more pressure on the government and other data holders is therefore a priority area.
- However, the way in which data are ultimately used must also be thought through carefully, since it is often highly detailed at the household level, raising possible issues around privacy.
- A further issue that must be dealt with concerns the term complexity itself. The discipline must seriously ask itself whether this term merely refers to everything that is not fully understood yet. If the answer is yes, then is complexity science really a standalone discipline at all?

Understanding Behavioural Change

- There are a large number of challenges that require further thinking about and modelling of changes in consumer behaviour; arguably this is therefore an area where research councils could be persuaded of both the intellectual and policy importance of further research. Many of the relevant research councils have acknowledged that they have not done enough in the past on energy demand; therefore there is scope for people to pursue funding for complexity science research in this area.
- A huge question that remains unanswered concerns how best to transform niche behavioural changes into mainstream behavioural changes. It is

certainly clear that such transformations can happen, and indeed the private sector is very interested in monitoring consumption patterns to see what triggers them. However, does the research community direct enough of its funding and energy in this direction?

- More funding arguably is needed, and there are many possible areas to explore; for example it might be fruitful to explore how synergies form, evolve and create their own dynamics.
- People arguably tend to change behaviour according to social norms, and therefore there needs to be a critical mass before change becomes mainstream, but what generates this cascade? Perhaps this dynamic is not really the sort of thing that can be modelled in the traditional sense?

Enhancing Interdisciplinary Collaboration and Communication

- Economists presently think that complexity science is not useful as it does not yield “perfect knowledge”, and seem to believe that those who do study complexity do not understand other areas. This misconception needs to be addressed.
- There is real scope for complexity science to build new methods and apply tools to many other areas. Addressing energy challenges in complex systems is a good starting point in this respect and will help give people a better understanding of how complexity science actually works.
- As the discipline matures it must develop a common language with other disciplines.
- Providing greater levels of renewable energy, reducing overall energy use, reducing dependency on fossil fuels, moving away from cars – these are all enormous challenges and at present modelling is the only tool available to help forecast what is likely to happen before it does happen. This argument needs to be made better when presenting ideas to research departments in the private sector; they must be better persuaded that complexity science is directly related to the challenges that they will face over the coming years.

Knowledge Café 2

This second knowledge café aimed to address the questions of how best to enhance the quality of collaboration and communication, both among researchers themselves and between the research community, policy-makers and other stakeholders. The participants selected two questions they wanted to address.

The questions discussed were:

1. What needs our immediate attention going forward?
2. How might we better link the energy and complexity science communities? What linkages are there currently – or where has this information been compiled?
3. Who else so we need to engage, who is missing from this group? How should these individuals/organisations be engaged and who should do it?
4. What recommendations should we make for future funding initiatives?
5. How can we effectively interpret the research outputs and disseminate them to non-technical policy/decision makers in the energy market? What is the coherent message?

Feedback from each question is summarised below:

Q1. What needs our immediate attention going forward?

- Data collection is important; it needs to be documented in a standardised way so that it can be more easily used in conjunction with other sources.
- The discipline should promote what it has already achieved more vigorously, so as to find more people who would like to use its tools and techniques.
- Often missing in existing research and models is a consideration of the rebound effect. This should be addressed immediately.

Q2. How might we better link the energy and complexity science communities? What linkages are there currently – or where has this information been compiled?

- It is necessary to define what is meant by the energy community and the complexity science community. Both contain groups of researchers who would define their work as "hard" – such as mathematical modellers – and groups of researchers who would define their research as "soft" – such as those who look at issues from an interdisciplinary perspective. Perhaps a fruitful way forward would be to develop projects, which require both hard and soft types of research, thereby bringing these communities together.

- Better links do not necessarily have to be new links. Researchers should aim to use existing links more effectively through CDT students, matching disciplines and joint supervision. CDT students will then not only get to experience an interdisciplinary setting from an early stage in their careers, but other academics will also get to understand each other's work better.
- Both communities should set out their key research questions and capabilities more clearly. What can realistically be achieved with complexity science and what are the big energy challenges that need to be addressed?

Q3. Who else so we need to engage, who is missing from this group? How should these individuals/organisations be engaged and who should do it?

- Other groups who should be engaged include some areas of industry (architects etc.), scientists, policy-makers and the right kind of economists. These actors need to be better convinced of the benefits of being engaged; research should more clearly identify where complexity science will serve a useful function for them.

Q4. What recommendations should we make for future funding initiatives?

- Future funding proposals should think very carefully about whether or not complexity is the best word to describe the type of research being carried out.
- A greater focus on system linkages and the human dimensions of complexity is arguably likely to prove both intellectually and politically relevant; funding applications in these two areas should therefore be encouraged. The second of these avenues in particular would also provide an opportunity for complexity science to engage more productively with social scientists.
- Whilst it is arguable that large funding proposals may lead to better synergy, it is also possible that a large number of small proposals may be equally useful. For instance, at present if mathematicians want to be included in research, but there is only a small budget, they will effectively be excluded. A range of different grant sizes should therefore be made available.
- Understanding where demand for energy comes from, and how people make their decisions on a day-to-day basis is not an area funded through our research councils; better collaboration is therefore needed.
- In addition, the overall outlook of complexity science is probably too UK-centric; the discipline must therefore look for linkages and funders outside of the UK.

Q5. How can we effectively interpret the research outputs and disseminate them to non-technical policy/decision makers in the energy market? What is the coherent message?

- The research community needs to better understand the difference between policy-makers and politicians.
- Politicians need to understand matters so that they can transfer knowledge to the public. Engaging them in debates over uncertainty is therefore likely to prove unproductive, since they desire only clear, high-level results.
- Policy makers, by contrast, are generally more in sync with academics and so can be involved more deeply not just in these types of discussions, but to some extent, even in the modelling process itself.
- It is important to engage policymakers as much as possible, and not simply to wait until a given model or study is perceived as being "ready".

Final Comments

The UK research community has been discussed widely but this workshop has not really addressed the European perspective. A lot of Europe's funding is moving in the direction of collaborative projects that sit between different sectors, users and producers. These types of projects often pose problems for project coordinators, but this is the way the European research community is heading. Is complexity an adequate response in this context? Whole systems energy research is where this agenda fits and a great deal of funding is expected to go that way in the future. There are therefore opportunities in that direction. If coherent ideas for project could be developed from this workshop then undoubtedly funders would listen.

APPENDIX A List of data sources

Participants were asked to place on a post it note what data sources they used, they are listed below in no particular order:

- National Travel Survey
- Census
- ITN network (GB Scale)
- Neighbourhood stats
- ONS
- Openly available data: emissions, expenditure, national accounts, etc..
- DECC stats (e.g. FIT monitoring)
- AEA Microgeneration Index
- EHCS > EHS
- HCA – performance indicator annual returns of registered providers
- Labour Force Survey
- Construction Statistics
- Essex Park Archive
- National Housing Survey
- Construction cost Survey
- WIOD
- PLATTS
- NEED
- HEED
- Elexon
- National Grid
- DCLG Housing Reports
- Consumer Focus
- BADC (weather)
- Weather Channel
- DUKES
- Energy Demand Research Project
- British Transport Survey
- Time Use Surveys (Centre for Time Use Research)

APPENDIX B Programme

Energy & Complexity: the Way Forward

05 July 2012; Exam Schools, Oxford

Aim: A one day workshop presenting state-of-the-art complexity science approaches to address energy challenges and developing insights and lessons from four major EPSRC projects to inform future energy research and decision making.

09:00 Registration and arrival refreshments

09:30 **Introduction to Complexity Science**
Speaker: *Liz Varga (Cranfield University)*

09:50 **Scene Setting Presentations: Sharing learned experiences**
Chair: *Stephen Peake (Open University)*

1. **Project title**: Energy decision-making for cities
   Presenters: *Nick McCullen (University of Leeds) and Tao Zhang (University of Nottingham)*
2. **Project title**: Preventing wide-area blackouts through adaptive islanding of transmission networks
   Presenter: *Janusz Bialek (Durham University)*
3. **Project title**: SCALE (Small Changes Lead to Large Effects)
   Presenters: *Minette D'Lima (UCL) and Joan Serras (UCL)*
4. **Project title**: Complex Adaptive Systems, Cognitive Agents and Distributed Energy (CASCADE)
   Presenters: Liz *Varga (Cranfield University) and Rupert Gammon (De Montfort University)*

11:20 Refreshment break

11:40 Knowledge Café 1: **Research, gaps and overlapping issues between complexity science techniques and their application**
Chair: *Catherine Bale (University of Leeds)*

12:40 **Report back from Knowledge Café 1**
Chair: *Catherine Bale (University of Leeds)*

13:00 Lunch

13:50 **Panel Discussion: Energy Challenges in Complex Systems**
Chair: Tim Foxon (University of Leeds)

Panellists: Andrew Richards (National Grid); Stephen Peake (Open University); Joe Ravetz (University of Manchester); Jim Skea *(RCUK Energy Programme Strategy Fellow)*

- *What key insights or lessons do these 4 projects offer us – and for whom?*
- *What are the main challenges in understanding energy systems that we could tackle with the tools of complexity science?*
- *What areas are priorities for research?*

14:30 Knowledge Café 2: **Mobilising Collaboration: Research, Policy and Engagement**
Chair: *Peer-Olaf Siebers (Nottingham University)*

15:30 Refreshments

15:40 **Report back from Knowledge Café 2**
Chair: *Francesca Medda (UCL)*

16:00 **Way Forward**
Chair: *William Gale (University of Leeds)*

Speaker: Jim Skea (RCUK Energy Programme Strategy Fellow)

16:30 Close and Drinks Reception

Appendix C Attendee list

First Name	Surname	Organisation
Ahmed	Abuhussein	University of Leeds
Uwe	Aickelin	University of Nottingham
David	Arrowsmith	Queen Mary, University of London
Oleg	Bagleybter	Alstom Grid UK
Catherine	Bale	University of Leeds
Andrei	Bejan	University of Cambridge
Janusz	Bialek	Durham University
Peter	Boait	De Montfort University
John	Brenner	Independent Researcher
Jacek	Brodzki	University of Southampton
Waqquas	Bukhsh	University of Edinburgh
Rui	Carvalho	Queen Mary, University of London
Ruchi	Choudhary	University of Cambridge
David	Coley	University of Bath
James	Cruise	Heriot Watt University
Craig	Dennett	Combined Heat & Power Association
Chris	Dent	Durham University
Dhriti	Dhaundiyal	King's College
Tim	Dixon	University of Reading
Minette	D'Lima	University College London (QASER)
Angela	Druckman	University of Surrey
Denis	Fan	De Montfort University
Max	Fennelly	University of Southampton
Graham	Fletcher	Cranfield University
Tim	Foxon	University of Leeds
William	Gale	University of Leeds
Rupert	Gammon	De Montfort University
Nigel	Gilbert	University of Surrey
Phil	Grunewald	Imperial College London
Cian	Harrington	Cranfield University
Nick	Hughes	Imperial College
Nick	Jagger	University of Leeds
Tooraj	Jamasb	Heriot-Watt University
Hannah	James	University of Leeds
Ying	Jin	Cambridge University
Scott	Kelly	University of Cambridge
Rehan	Khodabuccus	University of Surrey
Enrique	Kremers	EIFER
Wuxing	Liang	Alstom Grid UK

First Name	Surname	Organisation
Xuezhi	Liu	Cardiff University
Babak	Mahdavi Ardestani	De Montfort University
Chris	Martin	University of Leeds
Nick	McCullen	University of Leeds
Robert	McKay	University of Warwick
Ken	McKinnon	Edinburgh University
Francesca	Medda	University College London
Ron	Millen	Independent Researcher
Liz	Morgan	University of Leeds
Sukumar	Natarajan	University of Bath
Vijay	Pakka	De Montfort University
Sarah	Parker	Equinoxe Services Limited
Stephen	Peake	Open University
Alexandra	Penn	University of Surrey
Rahmatallah	Poudineh	Heriot-Watt University
Jonathan	Radcliffe	Energy Research Partnership
Gopal	Ramchurn	University of Southampton
Joe	Ravetz	University of Manchester
Andrew	Richards	National Grid
Darren	Robinson	University of Nottingham
Katy	Roelich	University of Leeds
Alastair	Rucklidge	University of Leeds
Ruben	Sanchez-Garcia	University of Southampton
Joan	Serras	University College London
Peer-Olaf	Siebers	Nottingham University
Jim	Skea	Imperial College London
Stefan	Smith	De Montfort University
J Richard	Snape	De Montfort University
Iain	Soutar	University of Exeter
Neil	Strachan	University College London
Peter	Taylor	University of Leeds
Vladimir	Terzija	University of Manchester
Briony	Turner	King's College London
Liz	Varga	Cranfield University
Huifu	Xu	University of Southampton
Stan	Zachary	Heriot-Watt University
Tao	Zhang	University of Nottingham

Appendix D Steering Committee

Dr Catherine Bale	University of Leeds
Dr Tao Zhang	University of Nottingham
Dr Ruben Sanchez-Garcia	University of Southampton
Prof Mark Rylatt	De Montfort University
Dr Francesca Medda	University College London
Dr Mark Winskel	University of Edinburgh
Karyn McBride	UKERC Meeting Place