Research Councils UK Energy Programme Strategy Fellowship

ENERGY RESEARCH AND TRAININGPROSPECTUS: REPORT NO 3

Energy in the Home and Workplace

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Research Councils Energy Programme

The Research Councils UK (RCUK) Energy Programme aims to position the UK to meet its energy and environmental targets and policy goals through world-class research and training. The Energy Programme is investing more than £625 million in research and skills to pioneer a low carbon future. This builds on an investment of £839 million over the period 2004-11.

Led by the Engineering and Physical Sciences Research Council (EPSRC), the Energy Programme brings together the work of EPSRC and that of the Biotechnology and Biological Sciences Research Council (BBSRC), the Economic and Social Research Council (ESRC), the Natural Environment Research Council (NERC), and the Science and Technology Facilities Council (STFC).

In 2010, the EPSRC organised a Review of Energy on behalf of RCUK in conjunction with the learned societies. The aim of the review, which was carried out by a panel of international experts, was to provide an independent assessment of the quality and impact of the UK programme. The Review Panel concluded that interesting, leading edge and world class research was being conducted in almost all areas while suggesting mechanisms for strengthening impact in terms of economic benefit, industry development and quality of life.

Energy Strategy Fellowship

The RCUK Energy Strategy Fellowship was established by EPSRC on behalf of RCUK in April 2012 in response to the international Review Panel's recommendation that a fully integrated 'roadmap' for UK research targets should be completed and maintained. The position is held by Jim Skea, Professor of Sustainable Energy in the Centre for Environmental Policy at Imperial College London. The main initial task was to synthesise an Energy Research and Training Prospectus to explore research, skills and training needs across the energy landscape. Professor Skea leads a small team at Imperial College London tasked with developing the Prospectus.

The Prospectus contributes to the evidence base upon which the RCUK Energy Programme can plan activities alongside Government, RD&D funding bodies, the private sector and other stakeholders. The Prospectus highlights links along the innovation chain from basic science through to commercialisation. It is intended to be a flexible and adaptable tool that takes explicit account of uncertainties so that it can remain robust against emerging evidence about research achievements and policy priorities.

One of the main inputs to the Prospectus has been a series of four high-level strategic workshops and six in-depth expert workshops which took place between October 2012 and July 2013. The main report, *Investing in a brighter energy future: energy research and training prospectus*, was published in November 2013. This is one of nine topic-specific documents supporting the main report. All reports can be downloaded from: www3.imperial.ac.uk/rcukenergystrategy/prospectus/documents/reports. This first version of the Prospectus will be reviewed and updated on an annual cycle during the lifetime of the Fellowship, which ends in 2017.

This report is the product of work conducted independently under EPSRC Grant EP/K00154X/1, Research Councils UK Energy Programme: Energy Strategy Fellowship. The draft report was reviewed by Nick Eyre of the Environmental Change Institute, University of Oxford, Chuck Lawrence of Lawrence Berkley National Laboratory and Sam Thomas of DECC. While the report draws on extensive consultations, the views expressed are those of the Fellowship team alone.

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Executive Summary

This report examines research and training needs in relation to **energy in the home and workplace**. The most important input to this report has been a two-day facilitated expert workshop attended by academics along with representatives from the private sector and public sector organisations. The report sets out its conclusions in the context of the UK's scientific and industrial capabilities, policy ambitions, global and UK developments, and outputs from existing roadmaps and needs assessments. The main findings are:

- University research is expected to play a critical role in underpinning UK policy on energy in the home and workplace. A range of priority research areas is identified in this report, spanning from technology focused, engineering based research, to behaviour focused, social science based research. In practice, these different research challenges overlap given the socio-technical nature of the home and workplace. In many cases, there is a need to adopt a more systems-level and inter-disciplinary approach. The priority research challenges include: **building energy technologies; energy consumption behaviour; energy governance and business arrangements;** and **socio-economic systems analysis.**
- The majority of research funding in this area has focused on the home rather than the workplace and there remains a poor understanding of how energy is consumed in commercial settings. There is a pressing need for research into the factors that shape commercial energy consumption behaviour and the role of policy interventions.
- The Fellowship expert workshop identified few basic technological research challenges associated with decentralised energy technologies (e.g. heat pumps), even though many UK energy scenarios foresee their having a key role. The basic research challenges identified were more socio-economic in nature, typically concerned with the conditions for technology uptake. However, previous roadmaps and needs assessments have identified a range of decentralised energy technology research and development (R&D) challenges.
- Interdisciplinary research is required given the many interconnected social and technical components of energy consumption in the home and workplace. This type of research could be supported by: issuing specific interdisciplinary funding calls; improving the peer review process for interdisciplinary proposals by establishing cross-disciplinary panels; sharing interdisciplinary best practice; and incorporating 'getting to know you' phases within research grants to allow interdisciplinary teams to build a working relationship. Longer term research perspectives are needed for longitudinal studies of energy consumption changes.
- There is a need to collect and curate energy consumption data, particularly for the non-residential sector. This would open up valuable research opportunities. Special attention should be paid to confidentiality and intellectual property. In terms of infrastructure, there is a need for 'whole-house' testing facilities that would allow the impacts of household energy interventions to be assessed.
- There is a need for interdisciplinary training at postgraduate level to foster interdisciplinary research. PhD studentships funded partly by industry could help bring academia and industry closer together and provide PhD students with valuable industrial experience. Centres for Doctoral Training (CDTs) and project studentship funding can be seen as complementary PhD funding models.
- There is a need for better coordination and collaboration between the research councils and R&D funding bodies such as the Technology Strategy Board (TSB) and the Energy Technologies Institute (ETI). A number of solutions were identified including jointly-funded research projects, multi-directional secondment schemes and centres of excellence and best .
- The research community believes that public engagement has an important role to play.

Acronyms

2DS	Two degree scenario
AC	Alternating current
BBSRC	Biotechnology and Biological Sciences Research Council
CASE	Collaboration Awards in Science and Engineering
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CDT	Centre for Doctoral Training
CERT	Carbon Emissions Reduction Target
CHP	Combined Heat and Power
DC	Direct current
DCLG	Department for Communities and Local Government
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment, Food and Rural Affairs
EC	European Commission
ECO	Energy Company Obligation
ECBCS	Energy Conservation in Buildings and Community Systems
EERA	European Energy Research Alliance
EPSRC	Engineering and Physical Sciences Research Council
ESCos	Energy Service Companies
ESRC	Economic and Social Research Council
ETI	Energy Technologies Institute
FiT	Feed-in tariff
FP7	Seventh Framework Programme
GHG	Greenhouse gas
HiDEF	Highly Distributed Energy Future
IA	Implementing Agreement (IEA)
ICT	Information and Communication Technology
IEA	International Energy Agency
JP E3s	Joint Programme on Economic, Environmental and Social Impacts
LCA	Life cycle assessment
LCICG	Low Carbon Innovation Coordination Group
MARKAL	Market Allocation (Model)
Mtoe	Million tonnes of oil equivalent
NCIL	No clear international lead
NERC	Natural Environment Research Council
NGL	Natural Gas Liquids
NGO	Non-governmental organisation
NHS	National Health Service

OECD	Organisation for Economic Co-operation and Development
PPP	Public-private partnership
PSS	Product Service System
PV	Photovoltaic
R&D	Research and development
RCEP	Research Councils UK Energy Programme
RCUK	Research Councils UK
RD&D	Research, development and demonstration
REViSITE	Roadmap Enabling Vision and Strategy in ICT-Enabled Energy Efficiency
RHC	Renewable Heating and Cooling
RHI	Renewable Heat Incentive
STFC	Science and Technology Facilities Council
TINA	Technology Innovation and Needs Assessment
TRL	Technology Readiness Level
TSB	Technology Strategy Board
UKERC	UK Energy Research Centre
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

This document is one of a series of reports that sets out conclusions about UK research and training needs in the energy area. The focus of this report is **energy in the home and workplace**. The primary audience is Research Councils UK (RCUK) which supports energy research in UK higher education institutions through the RCUK Energy Programme (RCEP).[1] However, other bodies involved in funding energy research and innovation, notably those involved in the UK's Low Carbon Innovation Carbon Group (LCICG),[2] may also find the content useful. The report is being disseminated widely throughout the UK energy research and innovation community to encourage debate and raise awareness of the work conducted under the Fellowship.

The most important input to this report has been a two-day, facilitated expert workshop held at Scarman House, University of Warwick on 5-6 February 2013. Excluding the Fellowship and facilitation team, 31 attendees attended the workshop most of whom were academics and researchers falling within the communities supported by the Engineering and Physical Sciences Research Council (EPSRC) and Economic and Social Research Council (ESRC). In addition, a number of attendees were from private sector and government organisations.

A full report of the workshop has previously been published as a working paper.[3] The working paper constitutes a document of record of the workshop outputs and represents an intermediate step in the production of this report which focuses on key messages and recommendations. The workshop also drew upon the outcomes of a series of 'strategy' workshops which addressed: **energy strategies and energy research needs; the role of the environmental and social sciences**; and **the research councils and the energy innovation landscape**. Reports of these workshops are also available on the Fellowship's website.[4]

The conclusions respond to a recommendation of the 2010 International Panel for the RCUK Review of Energy[5] that the research supported by the research councils should be more aligned with the UK's long-term energy policy goals. The key criteria used in developing this report have been the three pillars of energy policy – environment, affordability and security – coupled with potential contributions to UK growth and competitiveness.

The Fellowship team is using the EU/International Energy Agency (IEA) energy Research and Development (R&D) nomenclature[6] to map out the energy research landscape. This report primarily covers **Area I, Sector 2 Energy Efficiency – Residential and Commercial.** However, other aspects of the energy system are also incorporated, including decentralised energy generation; energy governance; energy business; and socio-economic energy system analysis. The report also covers generic technologies used in light industry (lighting, motors etc.) and industrial decision-making, but excludes energy-intensive industry. This is the subject of Prospectus Report No 2, **Industrial Energy.**

The research challenges and needs identified in Section 5 of the report fall into four broad areas: **building energy technologies; energy consumption behaviour; energy governance and business**

1 http://www.rcuk.ac.uk/research/xrcprogrammes/energy/Pages/home.aspx
2 http://www.lowcarboninnovation.co.uk/
3 https://workspace.imperial.ac.uk/rcukenergystrategy/Public/reports/Expert%20Workshop%20Reports/Energy%20in%20the%20Home%20and%20Workplace%20Working%20Document%20Final.pdf
4 http://www3.imperial.ac.uk/rcukenergystrategy/prospectus/documents/reports
5 http://www.epsrc.ac.uk/SiteCollectionDocuments/Publications/reports/ReviewOfEnergy2010PanelReportFinal.pdf
6 http://ec.europa.eu/research/energy/pdf/statistics_en.pdf

arrangements; and **socio-economic systems analysis.** Table 1 maps these on to the IEA nomenclature.

Table 1: Mapping of this report's coverage against the IEA R&D Nomenclature

IEA Nomenclature	Building Energy Technologies	Energy Consumption Behaviour	Energy Governance and Business Arrangements	Socio-Economic Systems Analysis
I. 2. Energy Efficiency - Residential and Commercial	• Space heating and cooling, ventilation and lighting control systems other than solar technologies • Low energy housing design and performance other than solar technologies • New insulation and building materials • Thermal performance of buildings • Domestic appliances • Other			
I. 4. Energy Efficiency - Other	• Waste heat utilisation • District heating • Heat pump development			
VII. 1 Other Cross-Cutting Technologies and Research - Energy System Analysis		• Sociological, economic and environmental impact of energy which are not specifically related to one technology area ○ Consumer attitudes and behaviour ○ Technology acceptance ○ Other	• Sociological, economic and environmental impact of energy which are not specifically related to one technology area ○ Policy and regulation	• Systems analysis related to energy R&D not covered elsewhere ○ Energy modelling ○ Other

This report is structured as follows. **Sections 2-4** provide the wider context within which research and training challenges are identified. Section 2 focuses on the possible role of residential and commercial energy consumption in future energy systems both globally and in the UK. Section 3 describes the current UK research landscape and capability levels. Section 4 reviews existing roadmaps and assessments of research and innovation needs. **Sections 5-8** draw heavily on the Warwick workshop. Section 5 sets out high-level research challenges across four different categories. Section 6 focuses on the ways in which the research councils operate, how the research they support is conducted and underlying needs for research infrastructure and data collection/curation. Many of the conclusions are generic in the sense that they may be applicable beyond the area of energy in the home and workplace, across the energy domain or even more widely. Section 7 addresses training provision. Section 8 addresses generic issues about the role of the research councils within the wider UK energy innovation system and EU/international engagement. **Section 9** outlines the key conclusions and recommendations from the report.

2. Current and future role of energy in the home and workplace

This section addresses the future role of energy consumption in the home and workplace. The section first covers the global context before focusing on the UK. Following this, the section presents the views of experts attending the Fellowship's strategic workshops regarding how energy consumption in the home and workplace might change in the future.

2.1 Global perspectives on residential and commercial energy consumption

The residential and commercial sectors account for 24% and 8% respectively of global energy consumption. Globally, the amount of energy consumed by the residential and commercial sectors has grown by over 80% in the last 35 years (Figure 1). The increase has been similar in the two sectors but has been much more pronounced in non-OECD countries (112%) than in OECD countries (51%). The increase in demand can be explained largely by economic growth and developments in energy technology that have given a larger number of people easy and affordable access to energy. This, coupled with broader economic and social developments that have involved people consuming more energy to satisfy their needs and aspirations (e.g. for hygiene, comfort, nutrition, leisure), has caused the rise in energy demand.

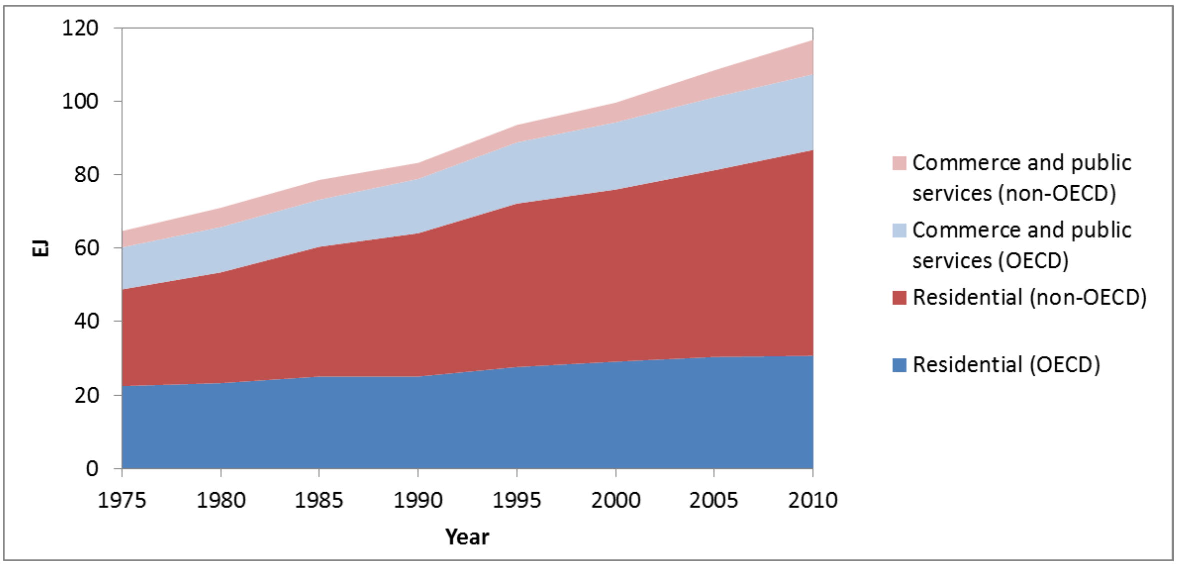

Figure 1: OECD and Non-OECD Residential and Commercial Energy Consumption 1975 - 2010
Source: IEA

As Figure 2 shows, fossil fuels such as oil, coal and gas have traditionally satisfied the majority of demand. Electricity consumption has increased significantly, with its share of total residential and commercial energy consumption growing from 13% in 1975 to 28% in 2010. The market share of gas grew by around 5% during 1975-2010, whilst the shares of oil and coal have each fallen by around 10%.

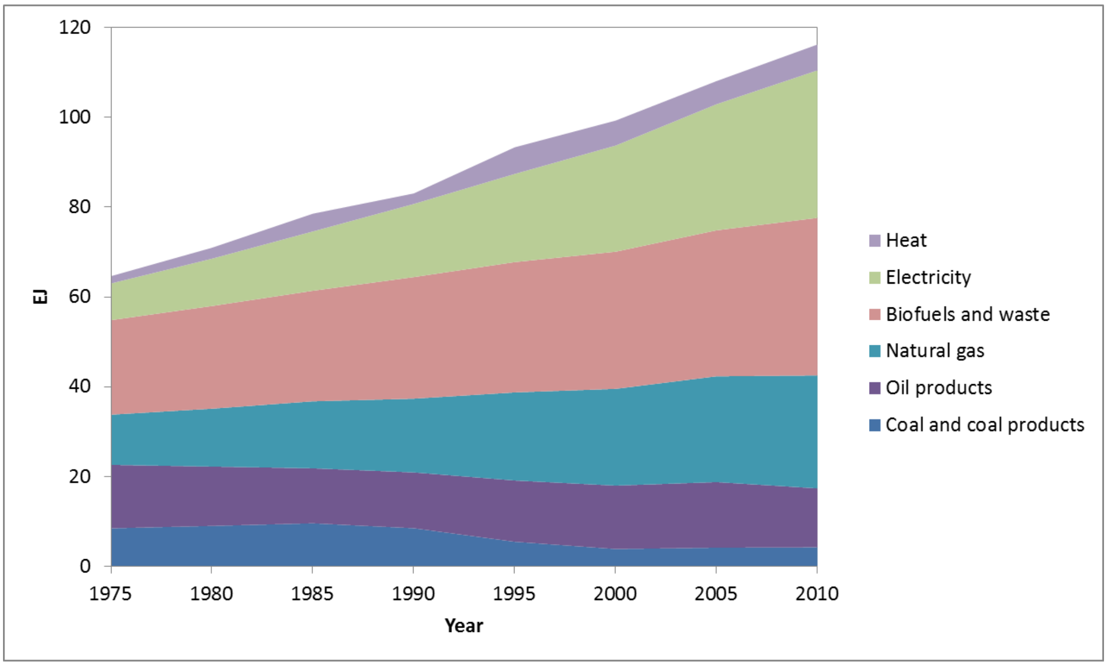

Figure 2: Residential and Commercial Energy Consumption by Fuel Source[7]
Source: IEA

There are mounting concerns about the security, affordability and environmental sustainability of fossil fuels. Consequently, a number of countries have begun to move away from fossil fuels. Biomass and waste have accounted for a significant proportion, currently about 30%, of residential and commercial energy needs (Figure 2). Other non-fossil fuel energy sources have experienced rapid market growth in recent years. For instance, wind and photovoltaic (PV) energy accounted for only 0.14PJ of residential and commercial energy supply in 1975. However, by 2010, this had grown to 221PJ. The market share for heat has increased by a factor of 3.5 during this same period. Technologies such as combined heat and power (CHP) represent an efficient means of sourcing heat. These developments highlight the transition away from fossil fuels towards alternative, more sustainable energy sources.

This change in the energy supply mix has been coupled with a drive towards improving energy efficiency levels, particularly in OECD countries. This has been achieved primarily via technologies such as insulation and energy efficiency lighting. Non-technological interventions, such as education schemes, have also played a key role in reducing energy demand.

In order to get a picture of how global residential and commercial energy demand may change in the future we examine IEA's **Two Degree Scenario (2DS)** and Shell's **Mountains** scenarios (Figure 3). The former is a **normative** scenario. These tend to be climate-driven and identify combinations of technologies capable of meeting the United Nations Framework Convention on Climate Change (UNFCCC) goal of keeping global temperature increases 2°C below pre-industrial levels by 2050. The latter is an **exploratory** scenario. Extrapolative scenarios and projections typically assume lower levels of deployment of 'new' energy technologies and extend current trends in the use of fossil fuels into the future.

The scenarios suggest that, in the absence of efforts to reduce greenhouse gas (GHG) emissions, residential and commercial energy demand will rise by approximately 50% by 2050. Even if global temperature increases are restricted to 2°C, energy demand is still projected to increase by more than

[7] This diagram omits: solar/wind/other; geothermal; crude, NGL and feedstocks; and peat because they represent a negligible proportion of the overall energy mix and therefore would not be visible on the diagram

10%. Energy demand is likely to increase over the coming years, regardless of whether action is taken on climate change.

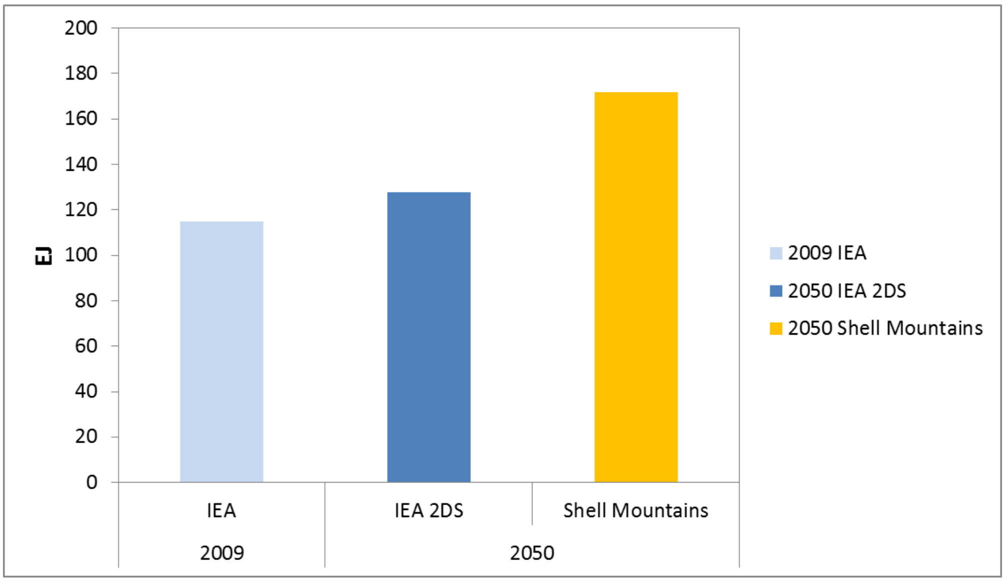

Figure 3: Projected residential and service sector energy demand in 2050[8]
Source: IEA and Shell

2.2 UK Perspective on Residential and Commercial Energy Consumption

In 2012 the UK's residential and commercial sectors were responsible for almost half of the UK's final energy consumption, with the residential sector accounting for approximately 31% and the services sector 13%.[9]

Residential energy demand increased by 17% between 1970 and 2012 (Figure 4). However, since the early to mid-2000s, there has been a downward trend punctuated by spikes associated with harsh winters. This decline may be attributable to improvements in the energy efficiency of new buildings and domestic appliances and more active energy efficiency policies.

The energy mix has changed too, with a shift from solid fuels to natural gas. Electricity consumption has remained relatively constant despite the increasing numbers of home electrical and electronic devices. Figure 4 also shows that alternative forms of energy such as biomass, waste and renewable heat technologies (e.g. heat pumps, district heating etc.) continue to account for a tiny fraction of domestic energy supply.

[8] IEA makes reference to energy consumption from 'buildings', whilst Shell combines 'Services'; 'Residential Heating & Cooking'; & 'Residential Lighting & Appliances'. These are taken as comparable.

[9] See Table 1.10 in DECC (2012) Energy Consumption in the UK - Chapter 1: Overall data tables

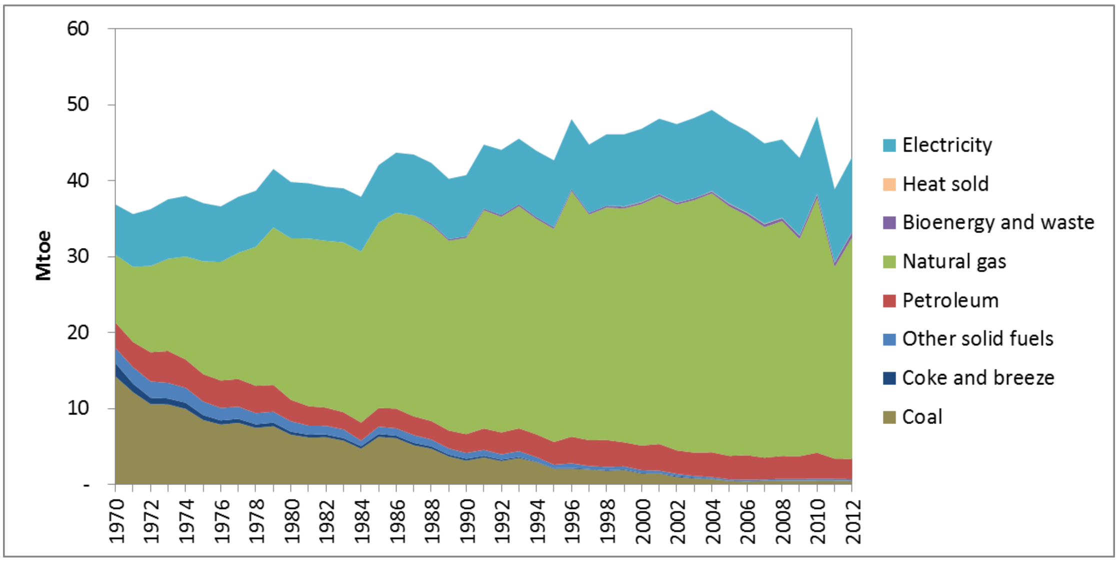

Figure 4: Profile of UK Residential Energy Consumption 1970 – 2012[10]
Source: DECC[11]

Commercial sector energy demand has followed a similar pattern, with demand peaking during the 1990s and a noticeable decline in recent years (Figure 5). There has been a similar steady decline in coal consumption and an increase in gas consumption. However, historically there has been a much greater proportion of oil and electricity consumption compared to the domestic sector. Direct heat consumption, provided via systems such as CHP, has also been more widespread in the commercial sector. Heat supply grew rapidly in the late 1990s but has since fallen.

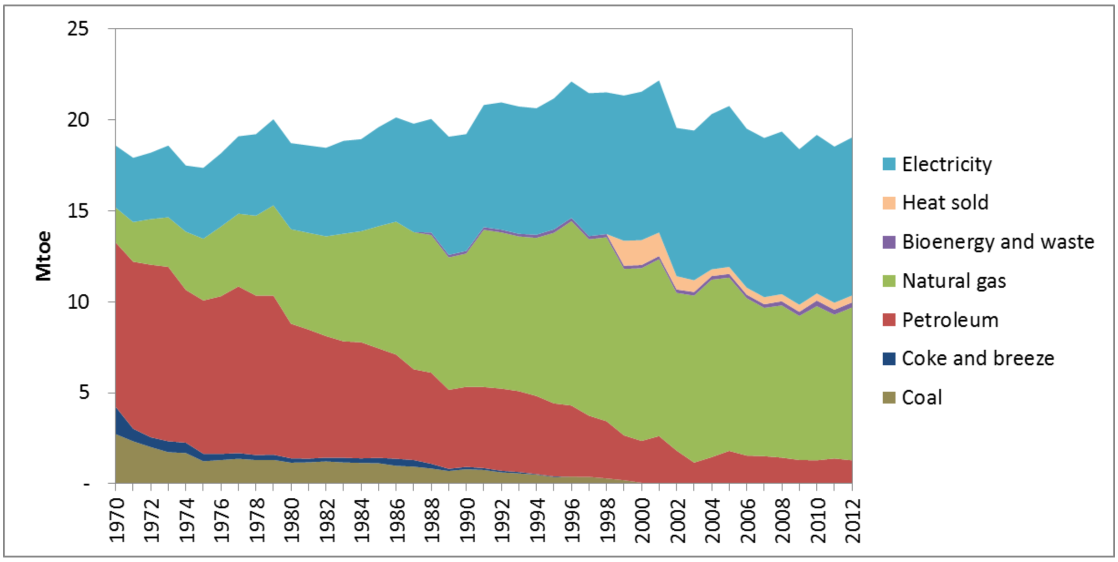

Figure 5: Profile of UK Service Sector Energy Consumption 1970 – 2012[12]
Source: DECC

UK residential and commercial consumers are very dependent on gas and centrally supplied electricity to satisfy their energy needs. However, the government has been encouraging consumers to adopt

10 'Heat sold', i.e. as a service, isn't incorporated in the figure as it constitutes a negligible amount of domestic consumption.
11 https://www.gov.uk/government/publications/energy-consumption-in-the-uk
12 Refers to DECC's 'services' sector, which can be split into can be split down into public administration, commercial, agriculture and miscellaneous.

micro-generation in recent years via feed-in-tariffs (FiTs) for electricity and the Renewable Heat Incentive (RHI). So far, these schemes have had little impact on the UK's residential and commercial consumption. Policies have also been directed towards improving the energy efficiency of the UK's building stock via schemes such as the Energy Company Obligation (ECO), the former Carbon Emission Reduction Target (CERT) and, more recently, the Green Deal. Whilst some of these schemes, such as CERT, have had a noticeable impact, the UK faces a challenge in improving the efficiency of its building stock given that much of it is old and does not lend itself to easy and affordable energy efficiency measures such as loft and cavity wall insulation.

To understand how UK residential and commercial energy consumption might change in the future, two sets of scenario were assessed. The first was the revised UK Energy Research Centre (UKERC) **Energy 2050** scenario set,[13] which used the UK MARKAL model,[14] a bottom-up, technology-rich cost optimisation model. The two scenarios reviewed from this set were the **reference scenario** (REF), which assumes that current policies extend into the future and a **low-carbon scenario** (LC), which is compatible with the 2050 GHG target. Current policies in **REF** include the assumption that the carbon price floor will rise to £30/tonne of CO_2 by 2020 and £70/tonne by 2030 in line with current government intentions. This provides a significant incentive for low carbon technologies even in the absence of other measures.

The second scenario set was derived using the DECC **2050 Pathways Calculator**[15], which integrates user-specified assumptions about the level of effort expended on different energy technologies. Two pathways, the **reference case pathway** (REF) and **pathway alpha** (ALPHA), were selected from a set published by DECC.[16] The former assumes minimal efforts to decarbonise or diversify energy supply, whilst the latter assumes a balanced effort to decarbonise across all sectors resulting in compliance with the 80% GHG reduction target.

Figure 6 shows both the DECC and UKERC scenarios, illustrating the high degree of uncertainty concerning the future level of UK residential and commercial energy demand. The DECC and UKERC 'business as usual' reference scenarios project have very different energy demand profiles. The UKERC **reference** scenario projects a demand increase of only 4% by 2050, whereas the DECC **reference** scenario envisages an increase of 27%. There is similar divergence between the 'low-carbon future' projections. For example, DECC's **Alpha** scenario projects a 2% increase in commercial and residential energy demand out to 2050, whilst UKERC's **Low Carbon** scenario projects a 33% reduction in demand.

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[13] UKERC, 'Energy 2050 Scenarios: Update 2013', http://www.ukerc.ac.uk/support/ES_RP_UpdateUKEnergy2050Scenarios

[14] UCL Energy Institute, 'UK MARKAL model', http://www.ucl.ac.uk/silva/energy-models/models/uk-markal

[15] DECC, '2050 Pathways Calculator,' https://www.gov.uk/2050-pathways-analysis

[16] DECC, '2050 Pathways Analysis Report', 2010, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/68816/216-2050-pathways-analysis-report.pdf

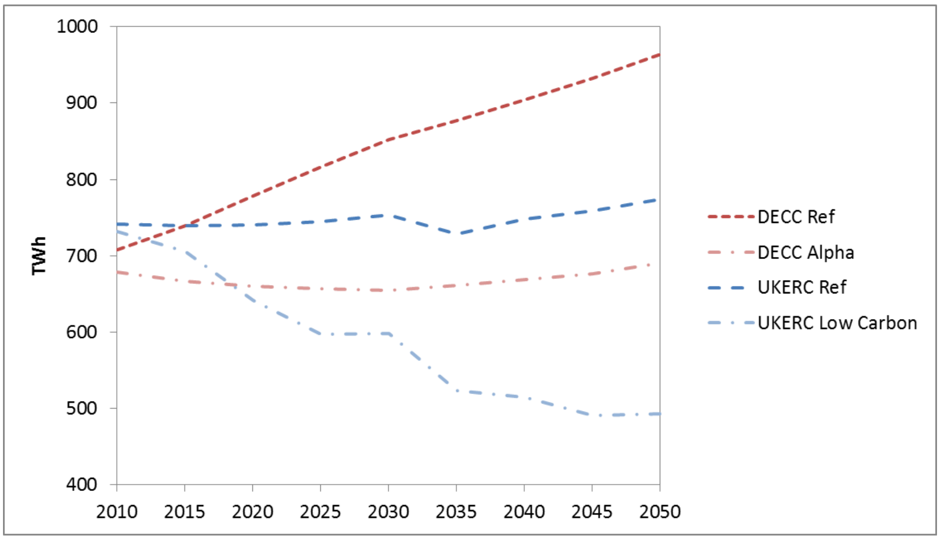

Figure 6: UK domestic and service sector projected energy demand between 2010 and 2050
Source: DECC and UKERC

Heat supply in the residential and commercial sectors is projected to undergo significant change (Figure 7). All scenarios suggest that, by 2050, electricity will account for a greater proportion of heat supply than at present, accounting for between around 15% (UKERC) and 30% (DECC),[17] compared to approximately 11% at present.[18] Both sets of scenarios envisage heat pumps supplying around 40-50% of heat in 2050, even though they have yet to reach commercial deployment. Both district and solar thermal heating are projected to become much more common than at present, but less so than heat pumps. Together, these technologies could reach the market share currently held by gas, oil and coal.

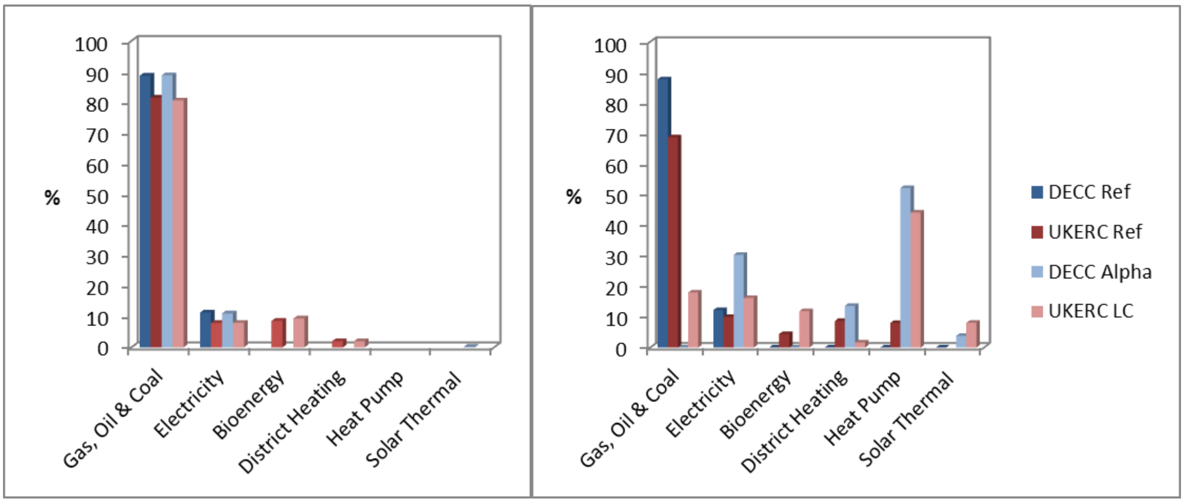

Figure 7: UK residential and commercial heat supply mix in 2010 and projected for 2050
Sources: UKERC and DECC

2.3 Energy aspirations and expectations

The Fellowship strategy workshop **Energy strategies and energy research needs** explored the role that different technologies and approaches (e.g. behaviour change) might play across a range of

[17] The figures account for electricity used in heat pumps.
[18] Average between UKERC and DECC reference scenarios.

different energy futures. Participants were invited to consider what technology mix for heat supply they **wanted** to see in 2050 (aspiration) and what they '**expected'** to happen, given their knowledge of barriers, policy directions, technology limitations and other factors (Figure 8).

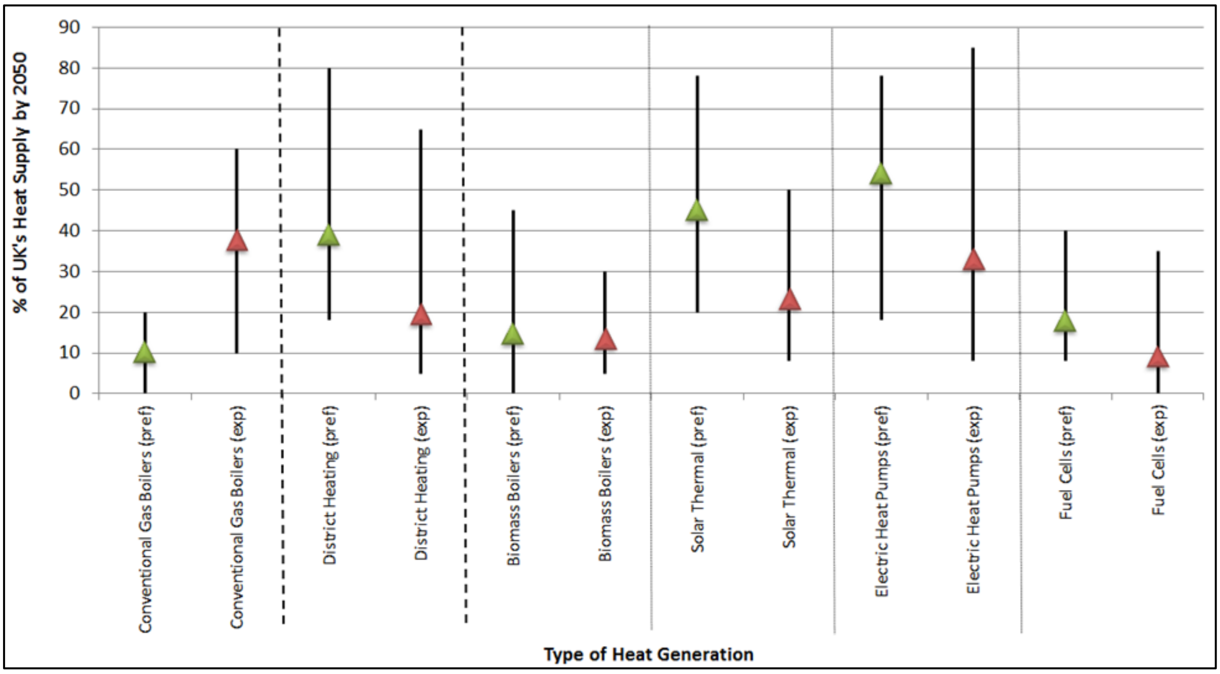

Figure 8: Preferred (green) and expected (red) ranges and mean average values for heat supply technologies by 2050

In general, people's aspirations were aligned with a world with ambitious climate policies, but they expected much slower progress to be made in reality. Participants had divergent expectations and aspirations about the heating mix in 2050. However, in general, participants hoped that conventional gas boilers would play a much smaller role in the UK's heat supply, with a much greater role for district heating, solar thermal technologies and electric heat pumps. Participants expected conventional gas boilers to continue to dominate the market in 2050, with heat pumps and to a lesser degree solar thermal and district heating taking a smaller but still significant market share. They expected a low level of uptake for fuel cells and biomass boilers.

3. Current UK research capabilities

3.1 Overview

This section begins with some general observations about the overall shape of the research community that focuses on residential and commercial energy. The section is based on three sources of evidence:

a) subjective judgements made at the first strategic workshop on **Energy Strategies and Energy Research Needs** and the second strategic workshop on **The Role of Environmental Science, Social Science and Economics;**
b) subjective judgments of UK research capability levels made at the expert workshop on **Energy in the Home and Workplace**; and

c) peer-reviewed assessments of UK R&D capabilities documented in the UKERC Energy Research Atlas 'landscape' documents.[19]

3.2 Strategic level workshops

3.2.1 Energy Strategies and Energy Research Needs

Figure 9 is one of the key outputs of the Fellowship's strategic workshop on **energy strategies and energy research needs**. The diagram plots subjective judgments concerning the 'relevance' of various research areas to UK energy futures (e.g. in terms environment, affordability, security, economic opportunity etc.) and the UK's current level of industrial capability relative to competitors. The size of the circles represents a subjective judgment about the UK's scientific capabilities. The research areas relevant to this report - residential and commercial, district heating and heat pumps - are mapped in yellow and light brown (energy system analysis). Research areas to the left of the vertical axis represent areas where there is thought to be no clear international lead in terms of industrial capability or a clear lead has yet to be established.

The figure shows that the UK is believed to possess very strong scientific and industrial capabilities in **energy system analysis**, which is considered important to the UK's energy future. Participants believed the UK to possess slightly weaker scientific and industrial capabilities in relation to **residential and commercial** buildings efficiency. This was considered to be of great importance to the UK's energy future. Finally, participants believed that the UK scientific and industrial capabilities in the areas of **district heating** and **heat pumps** were much weaker and that these research fields were of less importance to the UK's energy future.

[19] The UKERC Energy Research Atlas has two landscape documents falling within the scope of this report: **socio-economic research**; and **residential and commercial energy efficiency.**

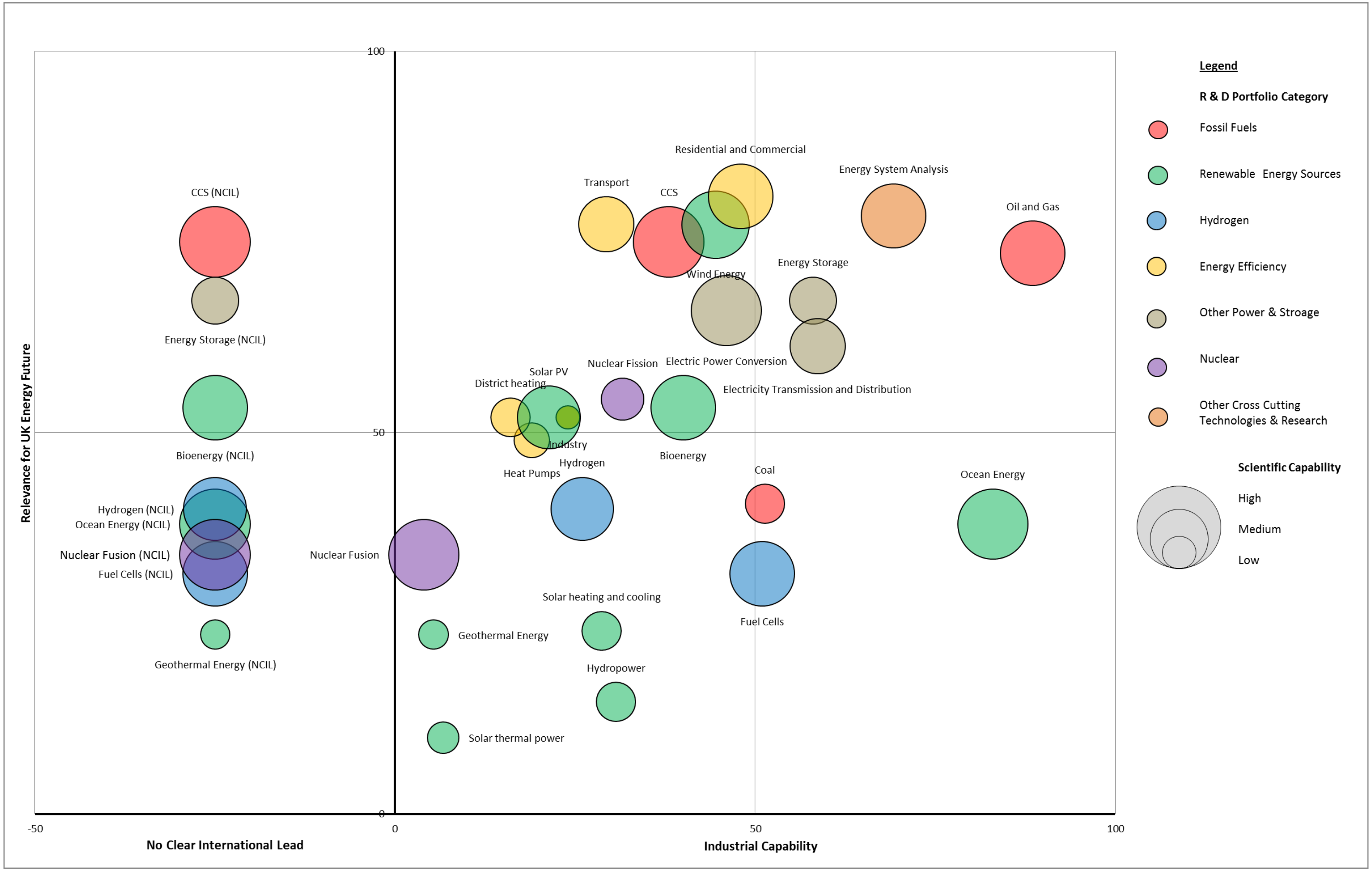

Figure 9: The UK's current and future energy R&D portfolio

3.2.2 The Role of Environmental Science, Social Science and Economics

A multitude of social and technical factors influence energy consumption in the home and workplace. The strategic workshop **The Role of Environmental Science, Social Science and Economics** focused on the way in which different disciplinary approaches could be integrated to contribute to meeting energy research and policy goals.

Participants believed that the UK was an international leader in interdisciplinary energy research. They acknowledged that significant efforts were already being made, particularly by RCUK, to reinforce the UK's interdisciplinary research capabilities. Participants were able to identify a number of success stories in relation to research on energy practices in the home and workplace at various centres and universities throughout the UK. Despite these successes, the UK's ability to undertake interdisciplinary energy research was constrained by a number of factors including:

- **Resource intensity.** There is a high cost incurred with interdisciplinary research, in terms of time, funding and effort. Unfortunately, these costs are not generally balanced by associated benefits for researchers in career terms.
- **RCUK and funding landscape.** Participants generally felt that the disciplinary nature of the research councils and the way the research funding landscape is structured (e.g. funding calls) have constrained interdisciplinary energy research.
- **UK education system.** There are concerns that both schools and universities have been structured according to discipline, thus encouraging mono-disciplinary thinking from an early age.
- **International academic journals.** These are typically disciplinary in nature and encourage reviewers to tackle only sections of the papers they are reviewing.
- **UK government and policy making.** There are concerns that policy is often techno-centric and not very interdisciplinary in nature.
- **Mismatch between disciplinary approaches**. There is little common language, terminology and methodology across disciplines, nor are there conceptual frameworks that researchers from different disciplines can use to communicate and collaborate with one another.

3.3.3 Expert workshop

Participants at the expert workshop were asked were asked to consider how well placed they considered the UK to be at present in terms of energy research capabilities relevant to energy in the home and workplace. They were invited to score these on a scale of 0-10 (0 = no chance, 10 = well set up). The average score was 4.9 +/- 2.1. However, there was a sharp divide between the UK's capacity to address 'home' and 'workplace' energy research challenges, with the former scoring 5.7 +/- 1.2 and the latter 2.6 +/- 2.6. This emphasises the UK's perceived strengths in residential energy research and weaknesses in energy research focusing on commercial contexts. Another striking outcome is the polarisation of views about the UK's interdisciplinary research capabilities, with scores ranging from 3 to 7.

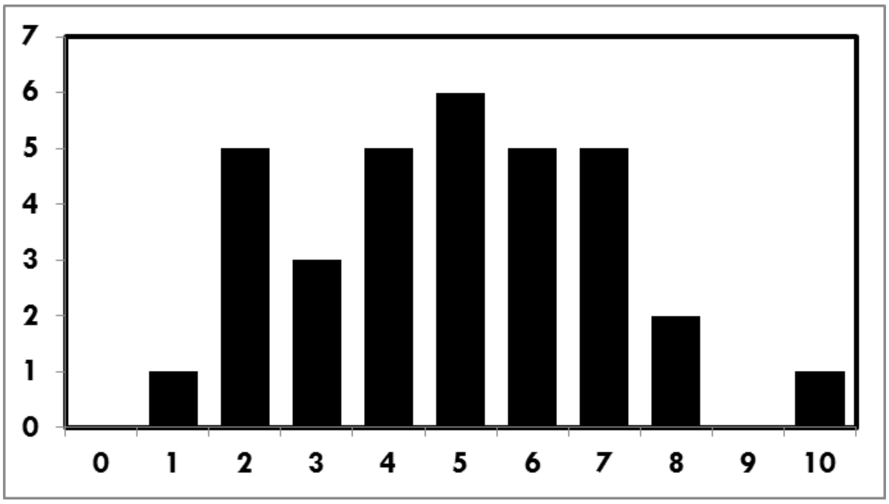

Figure 1: Distribution of perceived UK capability levels to address existing energy research challenges

3.4 UKERC Research Landscapes

UKERC's **Socio-Economic Research** landscape report[20] notes that a significant proportion of the research concerned with the consumption end of the energy supply chain (i.e. energy in the home and workplace) draws heavily upon economics and the social sciences including sociology, psychology and human geography. Researchers in this area typically view energy systems as complex socio-technical systems, which are comprised of a multitude of inter-connected, and constantly interacting 'technical' (e.g. technology, infrastructure etc.) and 'social' (e.g. institutions, user practices, regulation, business models etc.) elements.

The UK socio-economic energy research community has grown significantly in recent years both in terms of size and prominence. This can be attributed largely to a substantial increase in funding support from both the ESRC and EPSRC, mainly via the RCUK Energy Programme. This financial and institutional support has reinforced the community and led to the emergence of a healthy number of research groups, many of whom are considered to be international leaders in their field. However, although socio-economic energy research is prospering, the volume of funding continues to be lower than that allocated for technology-based energy research undertaken by the engineering community.

Table 2 highlights where the UK's relative strengths and weaknesses lie in terms of residential and commercial socio-economic energy research.

[20] A UKERC landscape document on **Residential and Commercial Energy Efficiency Research**, which focuses on the more technical aspects of energy in the home and workplace is currently being commissioned and is not available for public dissemination at present

Table 2: Socio-Economic Research Capability Assessment

UK Capability	Area
High	• Energy economics • Energy scenario building and modelling • Design and impacts of energy policy and regulation • Energy system governance • Dynamics and drivers of energy system change and innovation • Domestic energy use behaviours and decision-making
Medium	• Energy business model innovation • Politics and acceptability of energy • Energy investment decision making
Low	• Low carbon skills and training • Commercial energy use behaviours and decision-making • International comparisons of energy systems

Source: UKERC Research Landscapes

3.5 Specific research areas

Drawing on the strategic workshops, the expert workshop and the UKERC research landscape, this section explore the UK's research capabilities in relation to four specific research areas.

3.5.1 Energy efficiency technologies

Whilst there is no UKERC landscape available for building energy efficiency technologies, the strategic level workshop on **Energy Strategies and Energy Research Needs** reached the conclusion that the UK possessed high scientific capabilities in this field but medium industrial capabilities. This observation is supported by the large number of high-profile UK research projects and funding programmes relating to building energy efficiency. These are both engineering-focused and more interdisciplinary in character. The UK also engages in projects at the European level, including the **Energy-efficient Interactive Buildings** sub-programme of European Energy Research Alliance's (EERA) **Joint Programme on Smart Cities**[21] and various EU Framework Programme (FP7) projects. The UK engages at the wider international level through a number of IEA Implementing Agreements that focus on residential and commercial building energy efficiency, such as the **Energy Conservation in Buildings and Community Systems (ECBCS)**.[22]

3.5.2 Decentralised energy generation

Although there is no UKERC landscape document covering decentralised energy generation, this is an important part of the UK's energy research landscape. The strategic workshop on **Energy Strategies and Energy Research Needs** reached the conclusion that the UK possesses poor scientific capabilities across the key decentralised energy research areas (i.e. district heating, heat pumps, solar heating and cooling and solar thermal power) but relatively strong capabilities in PV. However, these scores reflect weaknesses in relation to technical capabilities. UKERC's **Socio-Economic Research** landscape notes that the UK possesses strengths relating to the governance and business aspects of decentralised energy generation. However, the UK engages with a number of international energy research projects that are more technologically than socio-economically focused. For example, the UK is engaged in FP7

21 http://www.eera-set.eu/index.php?index=30
22 http://www.ecbcs.org/index.htm

funded programmes such as **Ecoheat4Cities**[23] and IEA Implementing Agreements, such as **District Heating and Cooling**[24] and **Heat Pumping Technologies.**[25]

3.5.3 Energy consumption behaviour

A significant amount of research has been undertaken in the UK into the factors shaping people's energy consumption behaviours and the analysis of socio-economic phenomena 'beyond the meter'. This has drawn on a combination of psychological, sociological and economic theory to improve our understanding of consumers' energy decision making processes and the characterisation of energy demand. The strategic workshop on **The Role of Environmental Science, Social Science and Economics** recognised the UK's world-leading capabilities in interdisciplinary energy research, much of which has so far focused on consumers' energy behaviour. In addition, the UKERC **Socio-Economic Research** landscape report highlights the UK's very strong capabilities with respect to **domestic energy use behaviours and decision-making research**. It did however highlight weaknesses in terms of **commercial energy use behaviours and decision-making**, as well as the **politics and acceptability of energy**.

The UK's strengths in this field are exemplified by five **End Use Energy Demand** research centres[26] that have been recently established. These will run from 2013 – 2018. These centres will strengthen the research base relating to energy consumption behaviour and measures to promote levels of energy efficiency. The centres are funded by the RCUK Energy Programme, as well as a number of industrial partners, with a total investment of £39 million. The UK has engaged in energy consumption behaviour research at the international level. These include: the European Energy Research Alliance's (EERA) **Economic, Environmental and Social Impacts of Energy Policies and Technologies Programme;**[27] a number of relevant EU FP7 funded projects; and some IEA Implementing Agreements such as the **Demand-Side Management Programme.**[28]

3.5.4 Energy governance and business arrangements

According to UKERC's **Socio-Economic Research** landscape, the UK possesses strong research capabilities in relation to energy system governance and the design and impacts of energy policy and regulation. A number of large research consortia are focusing on energy supply and the role of regulation. While the UK may possess broad strengths in this area, work on energy demand policy analysis could be strengthened.

There is an underdeveloped but fast growing capability in relation to alternative paradigms for supplying energy to consumers. This work covers alternative energy business models (e.g. Energy Service Companies) and energy governance arrangements (e.g. community or city-owned energy companies) which not only generate income but may also help to achieve normative goals, such as the sustainable, affordable and secure supply of energy. Much of this work has focused on decentralised energy generation, such as micro-generation (e.g. PV, micro-wind, heat pumps etc.) and district heating (e.g. CHP) technologies, thus having some relevance to the work described in Section 3.5.1.The majority of research in the UK has been funded via the **Energy and Communities Collaborative Venture**[29] and

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23 http://www.ecoheat4cities.eu/en/
24 http://www.iea-dhc.org/home.html
25 http://www.heatpumpcentre.org/en/Sidor/default.aspx
26 http://www.epsrc.ac.uk/newsevents/news/2012/Pages/energyefficiencycutcarbonuse.aspx
27 http://www.eera-set.eu/index.php?index=127
28 http://www.iea.org/techno/iaresults.asp?id_ia=8
29 http://www.esrc.ac.uk/news-and-events/press-releases/3400/using-communities-to-find-the-answers-to-energy-demand-problems.aspx

the **SUPERGEN Highly Distributed Energy Future (HiDEF)** research programme,[30] with relatively little work being undertaken at the international level.

3.5.5 Socio-Economic Systems Analysis

The UK is internationally leading on research adopting a 'systems thinking' perspective connecting technical and non-technical aspects. This field of research, by its very nature, transcends energy in the home and workplace but locates residential and commercial energy consumption in the broader context.

Participants at the workshop on **Energy Strategies and Energy Research Needs** indicated that the UK had very strong scientific capabilities in **Energy System Analysis**. This view is echoed in UKERC's **Socio-Economic Research** landscape, which rated the UK strongly in the fields of **dynamics and drivers of energy system change and innovation**, as well as **energy scenario building and modelling**. The landscape report notes that research capabilities in this area have developed rapidly in recent years due to an increase in funding. However, there is still room for further development given its nascent status.

A number of high profile projects are currently underway at the UK level including the **Realising Transition Pathways - Whole Systems Analysis for a UK More Electric Low Carbon Energy Future** consortium[31]. The UK is also engaged in various projects at the European level including two relevant sub-programmes within EERA's **Joint Programme on Economic, Environmental and Social Impacts**[32] that incorporate some degree of systems thinking, as well as a number of FP7 European funded 'systems focused', commercial and residential consumer facing energy research projects.

4. Existing training and research roadmaps and needs assessments

This section reviews existing energy research and training roadmaps needs assessments relevant to energy in the home and workplace at the UK, EU and international levels. It highlights priority research challenges and the types of resources or arrangements required to facilitate the research. The reports, generally from government or non-departmental public bodies, are analysed according to the five categories set out in section 3. We begin with a summary of the key findings.

4.1 Summary

This section highlights the diversity of the research agenda in this area. Whilst there are some technology specific research challenges, particularly in relation to energy efficiency and decentralised energy generation technologies many of the priority research challenges are 'socio-technical' in nature. Whilst some of the challenges are at the level of buildings or individual technologies, many at a higher level, relating for instance to energy governance and market arrangements, or even energy system-wide issues.

There is less analysis available regarding the resources and arrangements needed to support research in this area. However, the review has identified some recommendations regarding research conduct. The first is the need for an interdisciplinary research approach. The second is the importance of collaborative relationships between academia and other stakeholders across government, industry and the third sector. This can be facilitated by knowledge exchange networks or other fora (e.g. Zero

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30 http://www.supergen-hidef.org/Pages/Home.aspx

31 http://ukerc.rl.ac.uk/cgi-bin/ercri5.pl?GChoose=gecatcat&GRN=EP/K005316/1&GCatSum=07-02&GSumCat=72

32 http://www.eera-set.eu/lw_resource/datapool/_items/item_779/draft_eera_folder_jpe3s_revised.pdf

Carbon Hub). The third is for researchers to undertake more public engagement activities. The fourth is for a more 'joined up' UK research community facilitated through high-level networking between theme leaders, funders and users to disseminate best practice and identify potential synergies. The fifth recommendation is for a balance between individual and project-based PhD studentships and Centres for Doctoral Training (CDTs), with the latter playing an important role for addressing priority research challenges.

4.2 Energy efficiency technologies

UK

LCICG has undertaken a series of Technology Innovation and Needs Assessments (TINAs) which identify and value the innovation benefits associated with specific low carbon technology families to inform the prioritisation of public sector investment in low carbon innovation. The **domestic buildings**[33] and **non-domestic buildings**[34] reports highlight the following priority research areas:

- **Pre-construction and design innovations:**
  - Modelling and software tools to improve passive house design strategies;
  - Tools to identify and implement retrofit opportunities quickly, cheaply and accurately; and
  - Design tools and services to better integrate micro-generation and district heating.
- **Management and Operation:**
  - Smart controls and systems diagnostics that optimise performance of building services;
  - Assisting behavioural change by encouraging users to interact with buildings; and
  - Overcoming 'split responsibility' between landlord and tenant.
- **Build process:**
  - Smart manufacturing processes, e.g. off-site construction;
  - Methods to reduce the cost of refurbishing existing buildings and improving their performance; and
  - Commissioning energy efficiency building services as part of the build process.
- **Materials and components:**
  - Fenestration to improve levels of comfort, lighting, warmth etc.;
  - Lighter-weight, thinner, cheaper advanced insulation products; and
  - Innovation low carbon cooling and ventilation methods, e.g. facades, HVAC.

The TINA reports argue that a sophisticated national energy performance database should be established covering both domestic and non-domestic energy efficiency. They underline the importance of knowledge exchange networks to disseminate key research findings to building designers and developers. The commercial buildings report highlights the need for an organisation analogous to the domestic focused **Zero-Carbon Hub** to help identify best practice, develop standards, undertake innovation road-mapping and encourage cross-sectoral collaboration.

DECC's report **What are the factors influencing energy behaviours and decision-making in the non-domestic sector?**[35] highlights the need to examine energy consumption behaviours and investment decision-making across organisations of different sizes and from different sectors. It calls for research to examine the energy saving potential for different types of energy efficiency measures interventions across the commercial sector. Finally, it recommends research into the design of individual policies to ensure this potential is realised.

[33] http://www.lowcarboninnovation.co.uk/working_together/technology_focus_areas/domestic_buildings/
[34] http://www.lowcarboninnovation.co.uk/working_together/technology_focus_areas/nondomestic_buildings/
[35] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65601/6925-what-are-the-factors-influencing-energy-behaviours.pdf

EU

The European Commission **Energy-Efficient Buildings PPP Multi-Annual Roadmap and Longer Term Strategy**[36] presents a list of research priorities as part of the Multi Annual Roadmap to develop sustainable energy generation and energy efficient buildings. The priorities included the following topics:

- integrated, energy efficient, retrofit solutions that account for constraints of existing buildings;
- understanding energy efficiency solutions drivers and barriers to support their uptake, such as via innovative financing mechanisms and business models; and
- reducing the cost and improve the performance of energy efficiency technologies.

Focusing specifically on ICT-related energy efficiency improvements, the **Roadmap Enabling Vision and Strategy in ICT-Enabled Energy Efficiency (REViSITE)** project team identify a number of research priorities and analyse recent and current research initiatives in the area.[37] These include research into the technical interoperability and standardisation of energy efficiency ICT solutions, as well as the developments of metrics and methods for quantitative assessment of ICT impacts.

4.3 Decentralised energy generation

UK

LCICG has recently published a **Heat** TINA[38] which focuses on the role heating technologies, particularly heat pumps and heat networks, could play in the UK. The report calls for demonstration schemes relating to these technologies that test not only methods for their design and installation, but also how they might be integrated with other technologies, particularly energy storage and generation technologies.

EU

At the European level the European Technology Platform on **Renewable Heating and Cooling** produced a **Strategic Research and Innovation Agenda for Renewable Heating and Cooling**[39] in 2013. The report highlights the following three renewable heating and cooling (RHC) priority research areas:

- enhancing RHC system performance and reliability;
- significantly reducing the cost of RHC technologies for different applications and capacities; and
- reducing RHC system payback time.

International

The IEA **Technology Roadmap Energy-efficient Buildings: Heating and Cooling Equipment**[40] identifies a number of decentralised energy technology specific research areas:

- **Active solar thermal:**
    - integration of solar collectors in building components;
    - alternative materials;
    - solar cooling systems;

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36 http://www.ectp.org/cws/params/ectp/download_files/36D1191v1_EeB_Roadmap.pdf
37 http://www.revisite.eu/
38 http://www.lowcarboninnovation.co.uk/working_together/technology_focus_areas/heat/
39 ftp://ftp.cordis.europa.eu/pub/etp/docs/rhc-sra_en.pdf
40 http://www.iea.org/publications/freepublications/publication/buildings_roadmap.pdf

- low-cost compact thermal storage;
  - intelligent control systems; and
  - improving automation of manufacturing.
- **Combined Heat and Power (CHP):**
  - reciprocating engines;
  - microturbines and gas turbines;
  - Stirling engines; and
  - fuel cells.
- **Heat pumps:**
  - decreasing costs;
  - improving reliability and performance through more efficient components, as well as optimising integration, design and installation of technology; and
  - systems that combine multiple functions and are paired with other energy technologies.

Energy storage was also highlighted as a priority research area. This is addressed in **Prospectus Report No 10, Energy Infrastructure**.

4.4 Energy consumption behaviour

We have identified relevant documents only at the UK level in this area. EPSRC convened a workshop to map out an **Agenda for Social Science Research in Energy** in 2006.[41] The subsequent report identifies the following priority research areas:

- **Engagement and Communication:**
  - 'mapping' people's current energy perceptions;
  - developing and testing innovative methods of public engagement; and
  - the role of the media and mass communications in influencing energy consumption.
- **Lifestyle Change:**
  - exploring the key social, psychological and institutional obstacles to lifestyle change;
  - identifying the social-psychological drivers of energy efficient behaviours; and
  - identifying lessons from previous or existing behaviour change initiatives.
- **Equity Implications of Energy Policies:**
  - developing measures of energy inequality for 'direct' and 'indirect' energy consumption;
  - understanding equity impacts of policy interventions, institutions and regulatory structures;
  - considering equity in issues of planning and siting, climate change mitigation etc; and
  - identifying the local priorities of disadvantaged communities and how to integrate these into energy policy initiatives.

The 2011 **Research Councils UK Energy Programme: End-use Energy Demand Workshop**[42] echoed the importance of social science energy research aimed at understanding how social behaviour at the individual, group and macro (economic) levels impacts energy use. The report recommends a genuinely interdisciplinary research approach underpinned by strong single discipline research. It emphasises the need to support radical and speculative research and to embed public engagement within research projects. The report calls for greater collaboration between academia and other key stakeholders, such as policy makers, industry and charities. It also recommends high-level networking between theme leaders, funders and users to disseminate best practice and identify potential synergies. Finally, the

[41] http://www.epsrc.ac.uk/SiteCollectionDocuments/Publications/reports/SocialScienceEnergyResearch2006.pdf

[42] http://www.rcuk.ac.uk/documents/energy/EUEDWorkshopReportFinal.pdf

report calls for individual PhD studentships to foster innovative thinking, with CDTs addressing specific research needs.

4.5 Energy governance and business arrangements

We have identified relevant documents only at the UK level in this area. EPSRC's 2006 **Agenda for Social Science Research in Energy** emphasises the need to explore the 'product-service shift', i.e. how to move from selling units of energy towards selling energy services, in order to improve levels of energy efficiency. The report highlights the following research questions:

- What does an energy service infrastructure look like?
- What is the energy utility business model for demand reduction?
- What are the implications of the product-service shift for incentives structures in the supply/distribution industries?
- How do households (companies) respond to an 'energy services' environment?
- What characteristics of energy/fuel do people value and how do they express this value?

The report also identifies a number of governance specific research challenges:

- What are the appropriate role, feasibility and implications of carbon trading in delivering energy policy goals?
- Whether, how, and under what conditions community-based initiatives can be 'scaled up'?
- Whether 'incentive' or 'dictat' is a more appropriate policy response, given the broad ranging nature and high social importance of long-term energy policy goals?
- Whether the institutions which characterise the existing energy system adequately reflect the need to address energy security issues (including demand reduction)?

4.6 Socio-economic systems analysis

We have identified relevant documents only at the UK level in this area. EPSRC's **Agenda for Social Science Research in Energy** underlines the importance of understanding the relationship between technological change, institutional change and social change. The report argues that a key role for the social sciences is to improve our ability to understand and manage energy system change.

The need for a 'whole systems' approach is echoed in the **Research Councils UK Energy Programme: End-use Energy Demand Workshop** report. This notes the complex interaction between sectors, as well as the need to define the role of research at each phase of transition to a low carbon economy via transitional pathway analysis.

5. High-level research challenges

This section outlines the priority research challenges as identified by participants at the expert workshop. These fell into the following four categories:

- building energy technologies;
- energy consumption behaviour;
- energy governance and business arrangements; and
- socio-economic systems analysis.

The scope of the four broad research challenges are outlined in the Tables 3-6, with detailed research questions set out in Annex B.

Table 3: Research challenges in the area of building energy technologies

Sub-Topic	Challenge	Notes
Building and energy technology design and development	Cost-effectiveness and trade-offs of different technologies	
	Understanding technological under-performance	
	'Whole-system', integrated building design	
	Generation, supply and demand management interface	
	Designing buildings to be flexible for the future	e.g. hotter summers; increased appliance use
	Construction industry decision making	e.g. building design; manufacturing methods; materials selection
	Life Cycle Assessment (LCA) analysis of whole building systems	
	Building and technology end-of-life issues	e.g. decommissioning and recycling
	Building design to promote energy equity and comfort	
	Development of building energy technologies and materials	e.g. cheap, thin insulants such as 'aero-gel'
Building retrofitting	Making retrofitting easy-to-do and appealing	e.g. replacing a gas boiler with a heat pump
	Heritage building retrofitting	
	Energy efficiency improvements with architectural merit	
	Decommissioning old technologies and/or repurposing them to provide new value	
	Diagnostic tools to optimise selection of retrofit technologies	
Smart technology and user interface	Compatibility of smart technologies with entrenched behaviours	
	Acceptability of smart energy technologies	e.g. issues around privacy
	Different consumer groups engagement with smart technology	
	New innovation opportunities presented by smart technologies	
	Impact of smart technologies on user behaviour and consumption	e.g. will smart technology actually reduce energy consumption?

Table 4: Research challenges in the area of energy consumption behaviour

Sub-Topic	Challenge	Notes
Energy decision making and behaviour	What is energy for?	
	Stages and influencing factors of the energy decision making process	
	Preconceptions/assumptions influencing behaviour	
	Mapping the network of energy decision makers	
	Understanding factors responsible for both triggering and sustaining changes in energy consumption behaviour	e.g. uptake of low-carbon energy technologies
	Investment decision making, especially for commercial users	
	Leveraging residential and commercial energy efficiency investment	
	Household and workplace rebound effects and ways of managing these	
	Causes and solutions for mismatch between reported and actual behaviour	
Demographics and energy behaviour	Impacts of past, present and future socio-economic trends on energy consumption	
	Consumption profiles of different demographic groups	

Table 5: Research challenges in the area of energy governance and business arrangements

Sub-Topic	Challenge	Notes
Innovative forms of energy governance	Local and community energy governance	
	Governance arrangements for large-scale, area-based energy initiatives	e.g. district heat; CHP; loft insulation; smart meters
	Impacts of 'higher-level' developments on local energy governance	e.g. policy, technology etc.
	Case and opportunities for multi-level energy governance	
	Lock-in effects of current/emerging governance arrangements	
	Governance lesson sharing with other sectors and countries	
Energy policy analysis	Metrics and methods currently used to evaluate energy policy	
	Policy evaluation's impact on policy design	
	Actors' influence on energy policy-making process	
	'Trading-off' of policy objectives against one another	
	Positive and negative impacts of energy policy	particularly energy demand policy
	Informing design of innovative energy policies	e.g. energy allowances; carbon budgets; 'time of use' tariffs
Energy equity: fair access to comfort and well-being	Equity analysis of current energy system	e.g. technology; policy; market etc.
	Ways of promoting equity in the energy system	e.g. policy
	Ways of empowering energy consumers	
Consumer engagement	New, untried methods of consumer engagement and education	
	Tailoring engagement approaches to different groups	
	Building energy consumers' faith in government's energy policy	
	Making consumer engagement fun and not boring	
	Building sustainability into consumers' value base	
	Role of high-profile, well-connected organisations in influencing energy consumers' behaviour	
Energy business models	Innovative energy business models and their impact on consumer behaviour	
	Drivers and barriers to energy business model innovation	
Energy skills	Influence of energy skills on energy system change	
	Skills required for transition and how to deploy these at scale	e.g. low-carbon retrofitting

Table 6: Research challenges in the area of socio-economic system analysis

Sub-Topic	Challenge	Notes
Energy scenario building and modelling	Developing scenarios that are robust against uncertainties	
	Socio-technical, not just technological oriented scenarios	
	Causes and solutions for discrepancies between projected and actual outcomes	e.g. modelling
	Modelling building performance and occupant behaviour	
	Modelling unintended consequences and rebound effects	
Energy system change and transitions	Opportunities to deliver swift and radical system change	
	Horizon scanning for disruptive developments and exploring how these will interact with one another	
	Resilience of future energy systems	e.g. climate change
	Nexuses of energy system with other sectors	e.g. water, waste, food
	Understanding system inertia and opportunities to negate it	e.g. lock-in; path dependencies etc.
	Roles of government/non-government actors in energy transitions	

6. Research conduct

6.1 Ways of working

Interdisciplinarity. Interdisciplinary energy research is essential in this field given the combination of social and technical factors that shape energy consumption in the home and workplace. Whilst interdisciplinary research is gaining momentum, there are opportunities for the energy research community to engage with other communities which have not traditionally engaged with energy (e.g. management; political science etc.). The following actions could help to facilitate interdisciplinary energy research: 1) promote a culture within academia of working together rather than in isolation or in disciplinary silos; 2) cultivate a common language or suite of concepts that enable researchers from different disciplines to share their ideas; 3) produce of a 'map' of the various institutes engaged in relevant disciplines (e.g. psychology; mathematics; architecture; economics; sociology; engineering etc.); and 4) support research 'roadshows' that showcase best-practice approaches.

Funding processes. There is a need to improve the quality and fairness of the peer review process for cross-council, interdisciplinary funding calls to ensure they are fairly and rigorously assessed using a balanced set of criteria. There is a need for a more homogenous approach to research funding across the research councils that would enable greater cross-council collaboration. Such collaboration is critical in this area of research. Both responsive and targeted mode research funding, as well as public/private funding models, could be valuable. Private sector participation could help raise additional funds for academic research. Finally, RCUK should avoid funding research further down the innovation chain that is within the remit of bodies such as the Technology Strategy Board (TSB), the Energy Technologies Institute (ETI) and private sector R&D companies.

6.2 Long-term perspectives

Longer-term funding is important in this area of research for two reasons. It could support interdisciplinary energy research by providing researchers from different disciplines with the necessary time to develop a mutual understanding and working relationships. It could also allow longitudinal studies of energy interventions at the home, workplace, community or city level.

6.3 Data

The curation and accessibility of data underpins effective research in this area. Whilst a large body of data on household energy consumption (e.g. English House Condition Survey) already exists, there is a lack of data on energy consumption in the workplace. This data would provide the research community with valuable insights into the consumption profiles of different sectors and provide baselines against which energy interventions could be measured. A large body of non-residential energy data already exists but is not freely available due to commercial sensitivities. The institutional framework in place for residential data does not exist for commercial energy consumption data. RCUK could help in this respect by pooling workplace energy data sets generated by past research and making these available to researchers using an approach similar to that adopted by UKERC's Energy Data Centre. Any data that is deemed commercially sensitive would need to be managed carefully. For both commercial and residential data, the community would like such a database to incorporate data from less common sources as a means of improving its richness.

6.4 Infrastructure and facilities

Whilst this research field does not normally demand large energy infrastructure there is a need for 'whole-house' testing facilities capable of assessing the impacts of household energy interventions. Software facilities, such as multi-scale computational models that synthesis a combination of qualitative and quantitative data to enable energy system analysis (at the building or city level), could also prove helpful for testing the potential implications of energy interventions. A register of exemplary case studies covering both the residential and commercial sectors could help inform the design of future empirical research.

7. Training

Postgraduate training. Masters and PhD level training could help nurture interdisciplinary researchers. This could be accomplished by ensuring that training focuses students' attentions on the 'bigger picture' to improve their understanding of the content and value of other relevant disciplines. For example, building control engineers could be taught about the various socio-economic factors that shape energy consumption behaviours. There is also a need for training in energy system modelling.

PhD funding models. Part industry-funded PhD studentships, e.g. Collaborative Awards in Science and Engineering (CASE) studentships, represent a potentially important way of bringing academia and industry closer together and providing PhD students with industrial experience. A balance should be struck between CDT and project studentship funding models given that these have complementary characteristics.

Vocational training programmes. Whilst the value of interdisciplinary PhD and MSc training is acknowledged, vocational training programmes still have an important role to play to ensure a steady supply of personnel capable of delivering energy interventions (e.g. technology installers, facilities managers; building service engineers). The development of formal training and accreditation frameworks could help support this training.

School-level education. Whilst outside the remit of RCUK, energy should be incorporated into the school syllabus in order to promote energy literacy. This would support consumer engagement but also 'plant the seeds' for the next generation of energy researchers.

8. Making connections

8.1 Connections across research areas

This area has connections with:

- **Transport Energy** (Prospectus Report No 4) in respect of the focus on demand-side consumption behaviour.
- **Electrochemical energy technologies** (Prospectus Report No 6) in relation to stationary fuel cell devices and energy storage.
- **Energy Infrastructure** (Prospectus Report No 10) in respect of demand side participation, smart grid and distributed generation.
- **With IEA Area I.4** (Energy Efficiency – Other) in respect of heat pumps and district heating.

8.2 Linkages outside RCUK

There is need for a more joined-up approach and greater coherence across the energy innovation landscape. In particular, the research councils should look to build stronger relationships with TSB, ETI, DECC, the Department for Communities and Local Government (DCLG), the Department for Environment, Food and Rural Affairs (Defra) and industry. Collaboration could be achieved via: 1) jointly-funded research projects; 2) multi-directional secondment schemes for early, mid and advanced career experts; 3) joint-evidence centres for policy making (e.g. What Works Centres); 4) centres of excellence and best practice (e.g. Zero Carbon Hub); 5) professional associations; 6) multi-sectoral energy conferences; and 7) knowledge exchange programmes. Such collaboration should be sensitive to the shared and contrasting strengths and objectives of these different parties.

8.3 International working

A coherent research agenda could play an important role in helping to coordinate research in this area at an international level.

8.4 Public engagement

Both researchers and research councils should make efforts to engage with the public. This could play an important role in managing the public's expectations and ensuring that they are kept abreast of what research is being supported through public resources and what it will achieve. Doing so could help to ensure the public remains supportive of publicly funded energy research.

8.5 The bigger picture

Neglect of workplace. Research into residential energy behaviour has typically taken precedent over non-residential. A balance should be struck given that both residential and non- residential energy consumption and generation will play an important role in the UK's energy future.

Usefulness of Technology Readiness Level (TRL) framework. Innovation takes many different forms and can emerge in many different ways, particularly in this area where innovations can often be smaller scale and non-technical in nature. Consequently, the TRL framework may be too narrow for this research area. Richer, more flexible frameworks may be more suitable.

Research topics boundaries. Specific research questions in this field should not be replaced with larger, more philosophical questions around energy consumption, such as 'what is energy for? Both types of question are valuable.

Research field interfaces. Care should be taken to identify interfaces between this research area and others in order to identify potentially fruitful research projects. For example, research into energy in the home and workplace shares a number of potential synergies with transport energy and energy infrastructure research (see Section 8.1).

9. Conclusions

The residential and commercial sectors account for almost half of UK energy demand. Demand is likely to fall, but the extent to which it does so depends on the extent of efforts to reduce GHG emissions. The key research questions in this area relate to how the energy service needs of consumers in the home and workplace can be satisfied in a secure, affordable and environmentally sustainable manner.

University research is expected to play a critical role in underpinning UK policy on energy in the home and workplace. A range of priority research areas is identified in this report, spanning from technology focused, engineering based research, to behaviour focused, social science based research. In practice, these different research challenges overlap given the socio-technical nature of the home and workplace. In many cases, there is a need to adopt a more systems-level and interdisciplinary approach. The priority research challenges include: **building energy technologies; energy consumption behaviour; energy governance and business arrangements**; and **socio-economic systems analysis.**

The majority of research funding in this area has focused on the home rather than the workplace and there remains a poor understanding of how energy is consumed in commercial settings. There is a pressing need for research into the factors that shape commercial energy consumption behaviour and the role of policy interventions.

The Fellowship expert workshop identified few basic technological research challenges associated with decentralised energy technologies (e.g. heat pumps), even though many UK energy scenarios foresee their having a key role. The basic research challenges identified were more socio-economic in nature, typically concerned with the conditions for technology uptake. However, previous roadmaps and needs assessments have identified a range of decentralised energy technology R&D challenges.

Interdisciplinary research is required given the many interconnected social and technical components of energy consumption in the home and workplace. This type of research could be supported by: issuing specific interdisciplinary funding calls; improving the peer review process for interdisciplinary proposals by establishing cross-disciplinary panels; sharing interdisciplinary best practice; and incorporating 'getting to know you' phases within research grants to allow interdisciplinary teams to build a working relationship. Longer term research perspectives are needed for longitudinal studies of energy consumption changes.

There is a need to collect and curate energy consumption data, particularly for the non-residential sector. This would open up valuable research opportunities. Special attention should be paid to confidentiality and intellectual property. In terms of infrastructure, there is a need for 'whole-house' testing facilities that would allow the impacts of household energy interventions to be assessed.

There is a need for interdisciplinary training at postgraduate level to foster interdisciplinary research. PhD studentships funded partly by industry could help bring academia and industry closer together and provide PhD students with valuable industrial experience. CDTs and project studentship funding can be complementary PhD funding models.

There is a need for better coordination and collaboration between the research councils and R&D funding bodies such as TSB and ETI. A number of solutions were identified including jointly-funded research projects, multi-directional secondment schemes and centres of excellence and best practice (e.g. Zero Carbon Hub).

The research community believes that public engagement has an important role.

Annex A: Research needs

The following section expands upon the priority research challenges identified in Section 5, as identified from the outputs of the expert workshop. These have been grouped in the same categories and where possible have been framed as specific research questions.

A.1 Building energy technologies

A.1.1 Building energy technology design and development

Building design and construction

- Designing energy technologies and buildings for an uncertain future.
- Designing building to be comfortable throughout all seasons.
- Manufacturing techniques to facilitate energy efficiency improvements, such as offsite manufacturing of building components.
- What are the boundaries to building energy efficiency?
- Avoiding negative impacts of energy efficiency improvements (e.g. reduced natural ventilation).
- Improving the aesthetic quality of energy efficiency solutions.

Technologies

- What is the cost-effectiveness and trade-offs of different technologies.
- Which energy technologies could reduce energy consumption the most (e.g. super thin insulation materials)?
- LCA of energy and buildings technologies.
- Understanding and remedying discrepancies between projected and actual energy performance.
- Examining the interaction between different energy technologies.
- Opportunities for community level electricity storage (e.g. vehicle to grid)?
- Exploring the slow, prolonged and less instantaneous release of energy from advanced heat storage building materials.
- Assessing the benefits of shifting from alternating current (AC) to direct current (DC) electricity supply?

A.1.2 Building retrofitting

- Identifying high-priority energy retrofit cases across the UK's building stock.
- Develop and refine diagnostic tools capable of optimising energy retrofit system performance (e.g. the Standard Assessment Procedure).
- Understanding the conditions required to support wide-scale, whole-building building retrofits, for instance skills, regulation, financial instruments, business models etc.
- What are the most appropriate retro-fit solutions for heritage/listed buildings?
- Can old technologies be used in the new ways to provide new forms of value?
- Decommissioning of antiquated infrastructure (e.g. gas networks) and buildings.

A.1.3 Smart technology and user interface[43]

- How can smart technologies be effectively 'rolled out' for different consumer groups?
- Who are the winners and losers of smart technology? How can negative impacts be resolved?

[43] Smart technology here refers to a group of ICT based energy technologies that also includes 'demand response' technology

- LCA of smart technologies.
- Should smart technology engage or bypass the consumer?
- Design of intuitive technology-user control interfaces that are sensitive to occupant behaviour.
- How might smart technology lead to other energy innovations, such as business models or building management methods?
- Pervasive sensing systems to assess and improve comfort of home/workplace environment.

A.2 Energy consumption behaviour

A.2.1 Energy decision making and behaviour

General

- What do people need energy for and how do they value it? How have these values changed?
- What are the different stages of the energy decision making process?
- Who is responsible for energy related decisions and how are these people connected?
- Does energy decision making differ between commercial and residential contexts?
- What assumptions shape people's energy decision making?
- How can we enable wider uptake of new and existing energy technologies?
- What are the causes for discrepancies between reported and actual energy consumption?
- What is the demand elasticity of different energy services?
- What are the rebound effects in commercial and residential contexts? What are their impacts?
- How do energy management systems change consumers' understanding of energy use?
- What opportunities exist to tie energy behaviour into natural cycles (e.g. seasonal; diurnal)?

Commercial decision making

- Is energy efficiency investment a separate/different decision compared to other organisational decisions? Who is responsible for these decisions?
- Do organisations in different sectors make different energy investment decisions and if so why?
- How do companies reinvest energy savings? How do this impact on levels of energy consumption?
- Macroeconomic analysis of how energy efficiency gains impact upon economic growth/productivity?

Energy efficiency investment

- What is required to deliver large scale energy efficiency investment?
- How can we mitigate against the real or perceived risk of energy efficiency investment. For example, skills certification, accreditation schemes, technology warranties etc.)?
- How has the economic crisis impacted upon levels of energy efficiency investment?
- What are consumers' varying levels of preparedness to pay for energy efficiency measures?

A.2.2 Demographics and energy behaviour

- How do demographics influence energy consumption behaviour (e.g. age; culture; wealth location)?
- How might energy solutions be tailored to the needs of different demographic groups?
- How might wider, international demographic developments influence the UK energy system?

A.3 Energy Governance and Business Arrangements

A.3.1 Innovative forms of energy governance

General

- Governance arrangements for the wide scale implementation of energy solution, such as loft insulation or smart meters.
- What are the strengths and weaknesses of multi-level energy governance?
- What are the potential lock-in effects of current and emerging governance arrangements?
- What can the UK learn from energy governance arrangements in other sectors (e.g. automobile; aerospace; and pharmaceuticals industries) and countries?
- How do intermediary organisations influence energy system change?

Local-level energy governance

- Why do locally-led energy projects emerge? What are their strengths and weaknesses?
- What are the drivers and barriers to local/community energy projects (e.g. regulation; skills)?
- What lessons might be learn from other countries about how to implement local energy projects?
- How might 'grass-roots' community action be harnessed beyond the local scale? To what extent are neo-liberalism and localism agendas compatible?
- Do local energy systems positively or negatively impact upon consumers' level of freedom and choice? For example, district energy schemes.
- What is the role of 'energy champions' in delivering local/community led energy projects.
- Opportunities for community projects to deliver energy along other types of services?

A.3.2 Energy policy analysis

Factors and methods shaping energy policy

- What metrics, methods and models are used to evaluate policy effectiveness? How effective are these?
- To what extent does evidence based policy appraisal currently shape energy policy making?
- How valid are entrenched, commonly used assumptions that inform policy-making?
- Which actors shape energy policy and how?
- What lessons can be learnt international about energy policy making, such as its impact on equity? How are different priorities traded off against one another, such as affordability, security and climate change mitigation?
- What have been positive and negative impacts of energy policy, both expected and unexpected? Especially for energy demand policies, which have been somewhat overlooked (e.g. the Green Deal, ECO, building standards etc.).

Energy budgets and allowances

- What are the expected costs and benefits? How do these compare to other policies?
- How technically feasible are energy budgets and allowances to implement (e.g. what ICT based monitoring is required)?
- At what spatial and temporal should they be deployed?
- How should these be structured? For example, should they be tradable?
- How socially acceptable are these policies?

A.3.3 Energy equity: fair access to comfort and well-being

- What are the equity implications of energy policies (e.g. Feed-in-Tariffs), technologies (e.g. smart meters); and market mechanisms (e.g. time-of-use tariffs)?
- What is the most effective way of promoting equity and autonomy in the energy system?
- What is the fairest way to reduce energy demand?
- What are the social implications of treating energy as a unit of exchange or currency?

A.3.4 Consumer engagement

Approaches to engagement

- What new, untried approaches are there to promote consumer engagement? For example, in conjunction with ICT and smart technologies?
- Developing consumer engagement as a two-way process, i.e. 'coproduction of knowledge'.
- What are the best channels to engage with different energy consumer groupings?
- What is the best time stage in a consumer's life to engage them (e.g. school; retirement etc.)?
- How can consumer engagement be made fun, not boring (e.g. via 'gamification')?
- Which organisations should be responsible for engaging consumers? Do they possess the necessary capacity to do so and levels of consumer trust?
- How can we build consumers trust in key energy stakeholders (e.g. Energy Utilities)?
- How can we build sustainability into consumers' value base?
- How can organisations best act as 'energy role models' (e.g. universities; National Health Service (NHS))?
- How can we get access to people's homes to trial new technologies?

Impact of information

- What impact does energy information have on consumers' energy behaviour and for how long?
- What proportion of energy information is understood by consumers? How do different consumers interpret energy information differently?

A.3.5 Energy business models

- Which energy business models will be required to deliver normative energy system changes?
- What conditions will be required to scale up/down different energy business models?
- How do different business models impact upon consumers' energy behaviour?
- What advantages can be gained through the joint provision of multiple services, such as energy; communications; water etc.)?
- How might the 'costs' of energy (e.g. carbon emissions; peak demand) be better internalised by energy businesses and market?

A.3.6 Energy skills

- How does the availability of energy skills influence future energy system change?
- Which portfolio of skills do we need to improve the energy efficiency of the UK's building stock?

A.4 Socio-economic systems analysis

A.4.1 Energy scenario building and modelling

- Developing scenarios that are robust against unforeseen events and unconventional wisdoms.
- Develop pessimistic energy scenarios to help us develop a 'back up plan'.
- Develop models and scenarios that are sensitive to multiple factors, i.e. social (e.g. policy; culture; demographics etc.), technical (e.g. technological maturity etc.) and economic (e.g. cost-effectiveness).
- Integrating of quantitative and qualitative energy scenarios.
- What are the causes and solutions for discrepancies between projected and actual system developments?
- Can whole building models be developed that incorporate agent based, physical and behavioural modelling?
- Modelling unintended consequences and rebound effects.
- Developing place specific futures/scenarios in the context of national futures (e.g. city, region etc.).

A.4.2 Energy system change and transitions

- What are the drivers and barriers to delivering swift and radical energy system change? How might barriers be addressed?
- Which transition pathways does our current governance paradigm allow for?
- How do the different dimensions of the energy system co-evolve with one another, such as energy technologies, practices, regulation, markets etc.?
- Horizon scanning for potentially disruptive energy system developments and innovations. How might these 'play-out' alongside one another?
- How resilient are current/future energy system to expected/unexpected system change?
- What are the roles of different actors in different transition pathways?
- How will present energy system developments impact upon the future energy system via phenomena such as path dependency, lock-in etc.?
- What are the key nexuses between the energy system and other sector (e.g. water, waste, food)? Are their benefits to aligning these systems more closely?

Annex B: Process for developing the prospectus

This Energy Research and Training Prospectus Report has been developed under the auspices of the RCUK Energy Strategy Fellowship which was established in April 2013. Fellowship activities leading the production of the Prospectus have gone through three phases.

Phase I (Spring – Summer 2012), **the scoping phase,** involved a comprehensive review of relevant energy roadmaps, pathways and scenario exercises in order to provide a framework for possible UK energy futures. Extensive consultation with stakeholders across the energy landscape was carried out in order to encourage buy-in and establish clearly the boundaries and links between the RCUK Prospectus and other products related more to deployment. One conclusion arising from the consultations was that linkage should be sought across the energy research domain and that consequently related topics linked by underlying research skills should be covered in single workshops during Phase II.

Phase II (Autumn 2012 – Summer 2013)**, the evidence-gathering phase,** relied heavily on workshops bringing the research community and stakeholders together round specific topics. Three 'strategic' workshops on **Energy Strategies and Energy Research Needs, The Role of Social Science, Environmental Science and Economics,** and **The Research Councils and the Energy Innovation Landscape** were held October 2012-February 2013. Six expert residential workshops on **Fossil Fuels and CCS, Energy in the Home and Workplace, Energy Infrastructure, Bioenergy, Transport Energy** and **Electrochemical Energy Technologies** were held January- June 2013. In addition, 'light-touch' activities were conducted in respect of: **Industrial Energy; Wind, Wave and Tide**; and **Nuclear Fission.** A final strategic level 'synthesis' workshop was held in July 2013. During Phase II, reports on each of these workshops were prepared and web-published following comments from participants.

During Phase III (Summer- Autumn 2013), **the synthesis stage,** the workshops reports were 'mined' and combined with contextual information to produce the Prospects Reports which were put out for peer review. The Prospectus, including a hard-copy Synthesis Report, was launched in November 2013.

Annex C: List of prospectus reports

No 1	Investing in a brighter energy future: energy research and training prospectus
No 2	Industrial energy demand
No 3	Energy in the home and workplace
No 4	Transport energy
No 5	Fossil fuels and carbon capture and storage
No 6	Electrochemical energy technologies
No 7	Wind, wave and tidal energy
No 8	Bioenergy
No 9	Nuclear fission
No 10	Energy infrastructure