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UK innovation support for energy demand reduction

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While significant reductions in energy demand can be achieved by deploying existing technologies and management approaches, innovation can unlock further opportunities in the longer term. Research, development and demonstration plays a key role in enabling the development of innovative products and services. Energy efficiency has traditionally accounted for a low proportion of UK public sector energy research and development spend, although funders are now placing an increasing emphasis on the demand side. This paper addresses two questions – what are the priority themes for demand-side research and how should research be conducted and supported in order to maximise the quality of its outputs? It draws on a series of expert workshops organised by the Research Councils UK Energy Strategy Fellowship during the development of its UK energy research and training needs prospectus. The following priority themes for UK energy demand research are identified: system-level and socio-technical perspectives on energy demand; energy use in non-domestic buildings; examination of how large-scale and incremental technological innovations could reduce energy demand. To develop these themes there is a need for interdisciplinary research, field trials, arrangements for data collection and sharing, and raising funding support to levels comparable to those for energy supply technologies.

1. Introduction

Energy policy in the UK, as elsewhere, has three main drivers – energy security, affordability and environmental concerns, notably those associated with climate change. At the same time, governments are concerned with the contribution that energy can make to recovery following the economic crisis. Energy efficiency and demand reduction are recognised as having the potential to help address each of these policy drivers (DECC, 2012; Ryan and Campbell, 2012; US EPA, 2006). A variety of policy instruments has been adopted to promote the reduction of energy demand. At the highest level, the 2012 EU energy efficiency directive (EC, 2012) requires member states to set non-binding national energy efficiency targets to achieve a reduction of 20% by 2020 compared with ‘business as usual’ levels. To implement this directive and respond to wider energy policy challenges, the UK’s energy efficiency strategy (DECC, 2013a) sets out the UK’s energy efficiency targets and how it intends to meet them. The strategy specifically identifies the need to support innovation with the potential to ‘improve energy services, reduce energy bills, strengthen energy security and drive economic growth’ (DECC, 2013a: 4).

The rationale is that while the deployment of existing technologies and management approaches can deliver significant energy demand reductions, support for energy demand reduction research, development and demonstration (RD&D) can in fact further expand the potential for energy demand reduction. Although UK government support for energy efficiency RD&D has significantly increased in recent years (IEA, 2013a), it has been argued that

- developed countries such as the UK have often marginalised support for energy demand research in favour of supply-side research; and
- a significant number of energy demand innovation opportunities still exist (Gallagher *et al.*, 2011, 2012; Wilson *et al.*, 2012).

This paper addresses the following questions

- What are the priority themes and topics for energy demand research in the household, commercial, industrial and transport sectors?
- How should research be conducted and supported in order to maximise the quality of the outputs?

The main source of evidence is a series of expert and stakeholder workshops organised by the Research Councils UK (RCUK) Energy Strategy Fellowship (ESF) as part of a process leading to a prospectus for UK energy research and training needs (Skea *et al.*, 2013).

The paper is structured as follows. Section 2 sets the context by describing patterns of energy demand in the UK. Section 3 outlines current and historic levels RD&D support for energy demand reduction. Section 4 sets out the way the evidence was collected, and priority themes and topics are discussed in Section 5. Section 6 presents recommendations as to how research might be conducted and supported in order to enhance quality and impact. Finally, conclusions are presented in Section 7.

2. The UK's energy demand profile

Final energy demand in the UK rose gradually between the early 1980s until the mid-2000s (Figure 1), before falling in more recent years. In 2012, final energy demand was 148 million tonnes of oil equivalent (mtoe), nearly 6% lower than in 1970 (DECC, 2013b). Table 1 shows the sectoral breakdown of final energy demand in 1970 and 2012. Industrial energy demand has decreased significantly since 1970, with its share of total demand falling by 23%. The shares of the transport and domestic sectors in final energy demand rose by approximately 18% and 6%, respectively, while demand from agriculture, public administration and commerce (collectively referred to as 'other energy use') rose by only 1%.

UK final energy demand has remained fairly constant as a result of falls in energy intensity offsetting growing demand for energy services (DECC, 2013c). Energy intensity levels depend on a range of factors, including the mix of economic activities, energy prices and income levels. However, one particularly influential factor is energy technology innovation, which can play a key role in reducing the amount of energy required to satisfy a given level of functionality (Bernstein *et al.*, 2003).

3. Energy demand RD&D in the UK

Data published by the International Energy Agency (IEA) are used in this section to examine historical levels of support for energy demand RD&D in the UK relative to support for other types of energy RD&D. The IEA data covers demonstration activities as well as research and development (R&D) activity, but do have three major limitations. First, the data cover only public sector RD&D. Second, IEA's energy RD&D data collection is primarily focused on technological innovation and thus ignores non-technological innovations that can have an impact on energy-demand levels such as business model innovation or novel industrial processes. Third, the data supplied

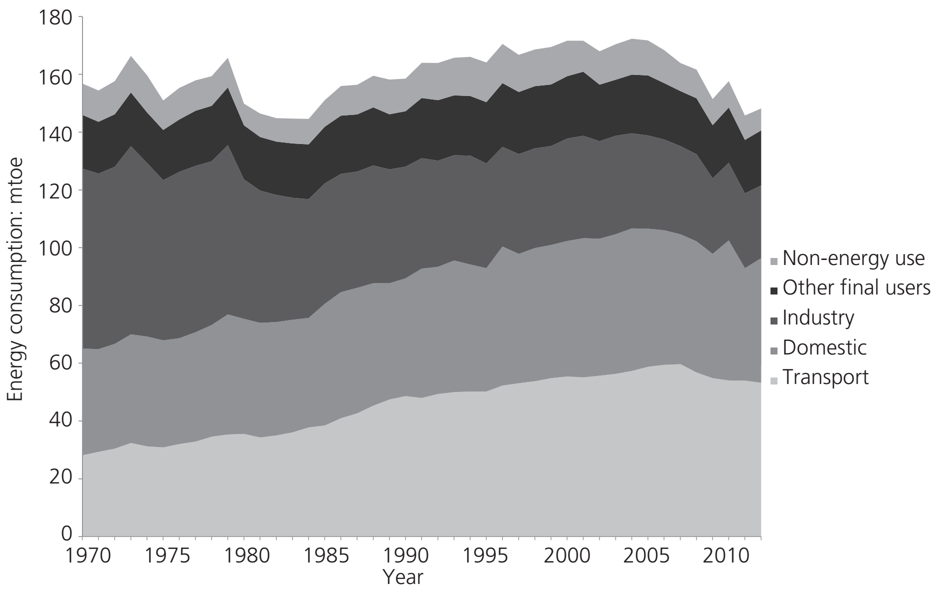

Figure 1. Final UK energy consumption by sector 1970–2012 (DECC, 2013c)

	Final energy consumption 1970		Final energy consumption 2012		Change between 1970 and 2012: %	
	Total: mtoe	Share: %	Total: mtoe	Share: %	Total final energy consumption	Share of final energy consumption
Industry	62	40	25	17	−60	−23
Domestic	37	24	43	29	+17	+5
Transport	28	18	53	36	+89	+18
Other energy use[a]	19	12	19	13	+2	+1
Non-energy use[b]	11	7	8	5	−30	−2
Total	157	100	148	100	−6	

Note: Sums of columns may not add precisely to the total due to rounding errors
[a]Covers agriculture, public administration and commerce; prior to 1990, also includes electricity used at transport premises
[b]Includes the consumption of energy products that have not been used to directly provide energy (e.g. chemical feedstock, solvents, lubricants and road-making materials)

Table 1. Total UK final energy consumption for 1970 and 2012 (DECC, 2013c)

to the IEA by the UK do not provide a detailed breakdown of the energy efficiency RD&D budget beyond the sectoral level, which covers: industry; residential and commercial buildings, appliances and equipment; transport; and 'other'.

3.1 Historic RD&D support

Between the mid-1970s and the early 1990s, public support for energy demand RD&D was broadly comparable to that for fossil fuels and renewables (Figure 2). However, following the 1970s oil crises and price spikes, energy efficiency became a matter of national importance and additional support was provided. Support fell dramatically during the early 1990s following privatisation and the introduction of competition into the gas and electricity sectors. This triggered the shutdown of national energy laboratories such as those operated by the Central Electricity Generation Board (CEGB). These developments also took place against a background of falling oil prices. Prices fell during the mid-1980s and remained low until

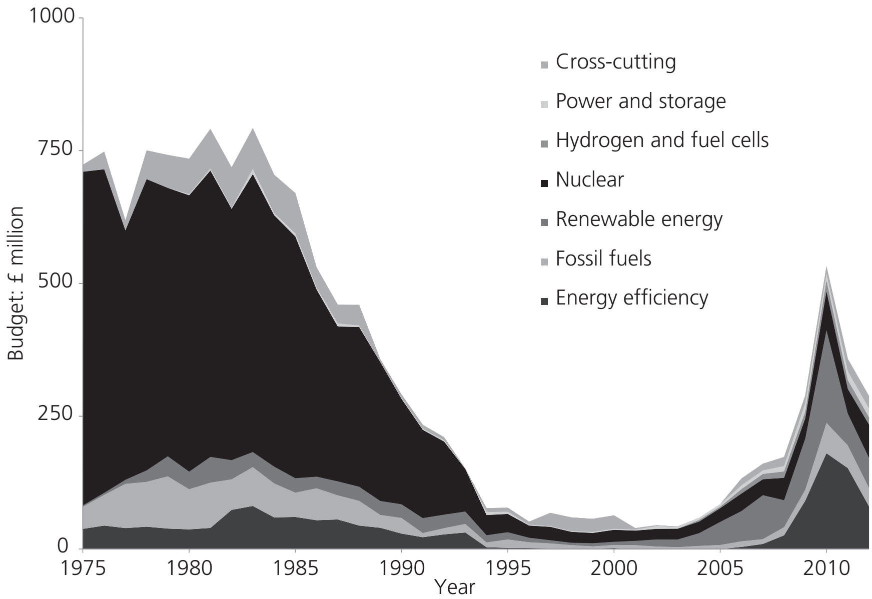

Figure 2. UK annual energy public RD&D budgets 1975–2012 (2012 prices) (IEA, 2013a)

2008–2009, thus reducing the incentive to improve energy efficiency. The tide turned in the mid-2000s, prior to the rise in oil prices, as concerns about climate change and energy security climbed the political agenda. Support for energy efficiency RD&D, along with wider energy RD&D, spiked in 2010 as funding bodies committed budgets prior to the general election and because a new spending review period started. However, absolute levels of support have fallen since then. Even so, energy efficiency still accounted for approximately 28% of the UK's £288 million public energy RD&D budget in 2012, with a budget of £80·2 million (IEA, 2013a). (Statistics for public RD&D data generally refer to budgets rather than expenditure. Capital budgets are accounted for entirely in the year that funds are appropriated.)

3.2 Current RD&D support

3.2.1 Public sector

The majority of the £80·2 million budget for energy efficiency RD&D in 2012 focused on transport (£50·7 million); £16·3 million was committed to buildings, appliances and equipment energy efficiency, £2·8 million to industrial energy efficiency and the remainder (£10·4 million) committed to 'other energy efficiency' projects (Figure 3). However, data on public energy RD&D spend should be treated with great caution because

- the UK data comprise data from a number of different bodies
- some bodies may report spend on demonstration, which is more costly than pure research
- the data include capital as well as operating spend, the former being made concentrated in nature and can therefore cause large swings from one year to another.

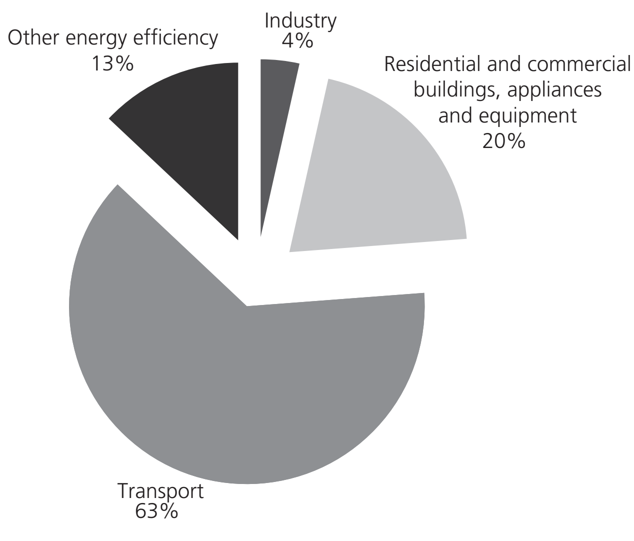

Figure 3. Breakdown of UK annual energy efficiency public RD&D budget for 2012 (IEA, 2013a)

Significant levels of funding were also committed to electricity transmission and distribution RD&D (£12·4 million), including smart grid development. This area of innovation entails greater interaction between energy demand and energy supply. £4·4 million was also committed to energy systems analysis, which includes research into energy policy and regulation, consumer behaviour and energy modelling – all of which are relevant to energy demand. Consequently, the IEA data suggest that, in 2012, approximately a third of UK public sector RD&D contributed either directly or indirectly to reducing energy demand.

In terms of how this funding is managed, the UK research councils have primary responsibility for funding basic energy research in universities. The majority of their support for energy demand research is committed by way of the cross-council RCUK energy research programme. Funding in this area has expanded recently, with over £30 million committed in 2013 to six new end use energy demand (EUED) centres (http://www.eued.ac.uk/home), each of which will operate for 5 years. Industrial partners have committed a further £14 million in support. The centres cover

- energy epidemiology (the centres will provide an evidence base for government and industry to support end use energy reduction across buildings and transport)
- sustainable energy use in food chains
- industrial energy and materials use
- the emergence, diffusion and impact of low-energy innovations
- the dynamics of energy, mobility and demand
- the storage, transformation and upgrading of thermal energy.

While none of the EUED centres focus exclusively on transport, other similar centres have been established, including the Centre for Sustainable Road Freight Transport. A number of other research centres that cover energy demand as part of a broader remit have been established under the RCUK energy programme. These include the UK Energy Research Centre (UKERC), which includes an interdisciplinary energy demand research theme covering the residential, commercial, industrial and transport sectors. The RCUK energy programme also supports a number of energy demand oriented centres for doctoral training such as the Centre for Doctoral Research in Energy Demand and the Industrial Doctorate Centre: Transport and the Environment.

Other UK public sector organisations that fund energy-demand RD&D operate further along the innovation chain towards the applied R&D and demonstration stages. The two most active bodies in this regard are the Technology Strategy Board (TSB) and the Energy Technologies Institute (ETI).

TSB, the UK's innovation agency, provides funds for businesses to help them develop new products and services and bring them closer to market. Its energy programme commits up to £35 million annually to support innovation capable of addressing the 'trilemma' of energy security, affordability and sustainability. However, this programme is focused predominantly on energy supply, supporting innovation in areas such as offshore wind, marine energy and fuel cells. However, other programmes, such as the 'built environment' and 'transport' themes, do have an explicit focus on energy demand reduction. TSB has recently established a series of 'Catapult' centres. This flagship initiative will enable leading businesses, scientists and engineers to work side-by-side on late-stage R&D to transform 'high potential' ideas into new products and services to generate economic growth. The activities of the energy systems catapult, announced in 2014, will be relevant to energy demand.

ETI is a public–private partnership between industry and government aimed at accelerating the development of low-carbon technologies. It runs a number of energy demand oriented projects such as the 5-year £100 million 'Smart Systems and Heat' initiative, the aim of which is to create and demonstrate the tools and capability to provide practical, cost-effective local solutions for the provision of energy-efficient heat (ETI, 2014). ETI also runs the £3 million project 'Building Supply Chain for Mass Refurbishment of Houses', as well as various transport projects focusing on, for example, improving the efficiency of heavy duty vehicles and the challenges facing the development of an intelligent, plug-in electric vehicle infrastructure.

The UK energy regulator Ofgem (Office of Gas and Electricity Markets) has also helped to enable energy RD&D through the low-carbon networks fund (LCNF). It is expected to allocate up to £500 million in funding between 1 April 2010 and 31 March 2015, making a significant additional contribution to support for energy RD&D. Through the LCNF, a small proportion of revenue received from electricity distribution network operators (DNOs) from consumers' energy bills is directed towards innovative projects to help the DNOs provide a secure, cost-effective and low-carbon energy supply in the future. (Ofgem is currently implementing its new price control framework called RIIO (revenue=incentives + innovation + outputs), which will include the network innovation competition (NIC) to replace the LCNF.) While the focus of the many projects funded through this initiative is on energy demand shifting rather than reduction, projects such as the £5·5 million vulnerable customers and energy efficiency scheme (UKPN, 2014a) have an explicit focus on achieving demand reduction in ways that defer or avoid network reinforcement.

3.2.2 Private sector

The private sector makes significant investments in R&D relevant to energy demand reduction. Vehicle manufacturers, diversified engineering companies with interests in transport equipment, appliance manufacturers and manufacturers of electronic equipment all conduct R&D associated with enhanced energy efficiency. However, published data on private R&D expenditure (e.g. the EU industrial R&D scoreboard (EC, 2013)) relevant to energy demand are difficult to interpret because the definition of industrial sectors is broad, individual companies have a wide range of commercial interests and individual strands of R&D may have multiple purposes; for example, they may be designed to enhance a range of features attractive to consumers other than energy efficiency. Private sector R&D that enhances energy efficiency may be stimulated, at least in part, by performance standards set through public policy expressed in terms of energy efficiency or carbon emissions. For instance, buildings, motor vehicles and electrical appliances are all subject to such standards. Given these data limitations, the remainder of this paper focuses exclusively on public sector RD&D.

4. Evidence for research needs in the energy demand area

The results presented here are based on a series of expert and stakeholder workshops that supported the production of an energy research training and prospectus (Skea *et al.*, 2013) aimed at extending the evidence base on which RCUK could plan activities under its energy programme. The prospectus report spans the energy research landscape and is supported by a series of subject-specific reports (RCUK ESF, 2014a).

The most important input into these reports was a series of 12 workshops held between October 2012 and September 2013 engaging nearly 250 participants from academia, industry and government (RCUK ESF, 2014b). Four workshops – Energy in the Home and Workplace, Transport Energy, Industrial Energy and Energy Infrastructure – focused specifically on energy demand. These workshops identified priority research topics and addressed ways in which research might be conducted and supported in order to maximise the quality and impact of outputs. These covered, for example, training, data collection and curation (i.e. the long-term management of data for future analysis), research infrastructure, links between different stages of the innovation chain and international working.

5. Priority innovation themes

5.1 Adopting a system-level perspective of energy demand

A common theme running across the energy demand oriented workshops was the need to examine the drivers of energy demand from a system-level perspective. This flows from the observation that energy demand is the product of a range of factors operating at multiple spatial scales and stemming from a variety of system dimensions (institutional, technological, environmental, etc.). For instance, an individual's level and pattern of energy demand depends on the wider context such as their social network (e.g. family, work), built environment (e.g. home, office) and institutional setting (including formal and informal rules). Addressing just one of these categories or scales will result in an incomplete picture of the factors shaping energy demand.

Importantly, a system-level perspective could also help promote an understanding of how the different factors that shape energy demand may co-evolve. Positive feedbacks between factors can, for example, lock society into 'high-demand' energy practices. The system-level approach provides insights into whether rebound effects associated with changes in energy use practices, at a variety of scales from the micro to the macro, might offset energy demand reductions achieved through energy efficiency. A system approach can also provide valuable insights into the design of demand reduction strategies at different levels (e.g. individual, household, city and sector).

5.2 Integrating technological and non-technological perspectives

It is widely acknowledged that technological innovation will play a key role in delivering significant reductions in energy demand. However, both the workshop findings and previous research (Bergman *et al.*, 2010; Edquist, 2005; Hannon, 2012; Steward, 2012; Witkamp *et al.*, 2011) indicate that in order for demand-side technologies to achieve wide-scale uptake, complementary non-technological innovations such as innovative business models, government policies and financing mechanisms are also needed. This approach embodies a socio-technical perspective on energy system change that emphasises the inter-connectedness and mutual dependence of social and technical elements (Geels, 2002, 2005).

In this vein, the joint development of technological and non-technological innovations, rather than developing them independently, could offer advantages in terms of better integrated and more efficient energy systems. One example highlighted at the transport workshop was the co-development of electric vehicles and car club schemes, with vehicles specifically designed to cater for car club members rather than the use of vehicles designed with private ownership in mind. Relevant performance factors include passenger capacity, range and speed. Another example identified at the workshops was the development of low-energy industrial processes relying on, for instance, novel manufacturing technologies, industrial catalysts and materials. However, for these to be effective consideration should be given to how these novel technologies are configured and managed as part of an integrated, energy-efficient production chain.

5.3 Energy demand reduction research in non-domestic buildings

There was a widespread view at the workshops that there is currently a better understanding of energy demand reduction opportunities in domestic buildings as opposed to non-domestic buildings such as public buildings, offices, retail outlets and restaurants – a view echoed by the UK Department of Energy & Climate Change (DECC, 2014a). The focus on reducing energy demand in the 'home' rather than the 'workplace' is partly due to the fact that the non-domestic sector is much more heterogeneous than the domestic sector. Non-domestic buildings (including agriculture, public administration and commerce) accounted for 13% of energy consumption in 2012 (DECC, 2013c). Additional support for research on energy demand in non-domestic settings could help the UK take advantage of the considerable demand reduction opportunities that exist in this sector (CSE and ECI, 2012).

The way that innovation in energy demand in domestic buildings could impact the service sector, and vice versa, should also be explored, particularly with respect to behavioural 'spill-over' effects. For example, energy-consuming practices in domestic settings may influence consumption behaviour in the workplace. These could involve relatively simple changes in behaviour such as turning off lights and appliances after use. Wider reaching impacts may take the form of changes to organisations' business strategies triggered by senior employees' positive experiences of the financial, social and environmental benefits of reducing energy demand at home. These may include prioritising the leasing of more energy-efficient offices with extensive efficiency controls in place or supporting low-energy travel to work schemes (e.g. cycling, public transport).

5.4 Radical and incremental technological innovation

Radical technological innovations represent a step-change from the prevailing technological paradigm. In the energy demand area, these include smart meters, voltage optimisation and micro-CHP (combined heat and power) technology. Incremental innovations involve performance improvements in existing energy technologies such as boilers, internal combustion engines and industrial motors. While research into radical energy demand technological innovations should continue given the demand reductions novel technologies could provide, significant efficiency gains could still be achieved through incremental performance improvements in existing technologies. For example, steady efficiency improvements of 1% per annum were achieved by car manufacturers between 2000 and 2010 (Bosseboeuf, 2012), largely in response to rising fuel prices and more stringent environmental regulations. However, there are concerns that accelerating should be performance gains in incumbent, fossil fuel aligned energy technologies such as internal combustion engines could further entrench a high-carbon energy regime and undermine the long-term move towards a low-carbon energy system.

5.5 Large-scale innovations for energy demand reduction

Energy demand-side management has typically been associated with small-scale innovations, typically at the scale of the appliance, vehicle or building. However, larger-scale developments such as a nationwide information and communications technology (ICT) network and transport planning also have the potential to deliver significant reductions in energy demand.

Focusing on the former first, the development of smart grids and the deployment of smart meters are dependent on a nationwide ICT network. They will enable network operators to better balance electricity demand with supply through demand-side management. Operators can reduce energy demand during peak periods when generation capacity is stretched, for instance through time-of-use electricity tariffs and automated demand-response controls (Davito *et al.*, 2010). Flattening the demand profile has the benefit of not only avoiding the construction of additional generation capacity but also increasing the flexibility of generation sources used to meet demand (Davito *et al.*, 2010). Demand can also be reduced in absolute terms by providing customers with better information on how they are using energy and the associated costs. A recent Ofgem study indicates that consumption can be reduced by approximately 3% on average (Ofgem, 2011). Fast broadband enables remote working and home shopping, thus reducing energy needs associated with travel. Home shopping is highly dependent on freight and logistics, which can be optimised through ICT. Ensuring that someone is home to take receipt of a delivery can avoid repeat journeys and enable two-way freight flows (i.e. drop off and pick-up).

Strategic spatial planning at the regional and national level could help to reduce energy demand by facilitating the use of public transport and alternative modes of transport (walking, cycling, etc.). It could also help to optimise the efficiency of all forms of transport by reducing congestion and moderating traffic speeds. Finally, careful town planning can obviate the need to travel by locating new homes close to workplaces and essential services.

6. Conduct and support of research

6.1 Interdisciplinary research

Interdisciplinary research was mentioned at every workshop and can add value across the energy domain. In the UK, the research councils have made considerable efforts to advance interdisciplinary research in the energy demand area, most notably through support of the EUED centres and the UKERC. While the RCUK energy programme should continue to support these interdisciplinary research initiatives, further opportunities exist.

Disciplines, especially from the social sciences (e.g. management science, political science), that have played comparatively little role in the energy domain at present, could become more involved. Another example is law, which could provide valuable insight into the formation and subsequent influence of energy demand regulation. However, law falls within the remit of the Arts and Humanities Research Council (AHRC), which at present isn't engaged in the cross-council RCUK energy programme. Broadening the scope of such energy programmes to incorporate the inputs from other disciplines could provide valuable insights into delivering large-scale energy-demand reduction.

As noted earlier, energy demand is shaped by both technological and social factors. However, the RCUK energy programme is currently framed by engineering and physical science perspectives. This can largely be attributed to the Engineering and Physical Sciences Research Council's leadership of the programme and the relatively low visibility of energy in the strategies of other councils. The workshop findings emphasise that energy research programmes should be receptive to ways of framing energy demand research challenges derived from a wider range of disciplinary perspectives, such as economics, sociology and psychology.

Finally, many academic incentives undermine interdisciplinary university research. These include promotion criteria in universities and the perceived value attached under the Research Excellence Framework to publication in single-discipline journals. Redesigning incentives under such systems should help promote interdisciplinary energy research.

6.2 Field trials

Conducting and evaluating energy demand management interventions is essential. For example, in the context of minimising domestic fossil fuel consumption, the UK's Energy Saving Trust (EST) undertook field trials for heat pumps, LED lighting and solar thermal technology (EST, 2014). The EST is also managing field trials for solid wall insulation and energy controls for optimising household energy consumption. At a larger scale, the Low Carbon London consortium is leading a field trial of smart meters in conjunction with 5800 EDF Energy customers, of which 1100 are taking part in a dynamic time-of-use tariff trial in which are offered 'day-ahead' electricity prices by way of their smart meters (UKPN, 2014b). These types of studies provide valuable insights into how effective these technologies might be in reducing energy demand and the types of interventions that can maximise their effectiveness. The outputs of such trials should be made available to researchers for secondary analysis, while taking into account the commercial sensitivity of the intellectual property of such data.

6.3 Data collection, curation and sharing

High-quality energy demand research needs to build on previous research insights. This can be underpinned by effective data collection, curation and sharing. Two themes emerged from the workshops – first, the need to address perceived gaps in data collection, and second, the need to establish and maintain appropriate systems for data curation and sharing.

Significant progress has been made in the UK in relation to household energy data collection through, for example, the English House Condition Survey and the emerging National Energy Efficiency Data framework (DECC, 2014b). However, echoing generic conclusions reached by the IEA (2013b), significant data gaps relating to energy consumption have been identified. For instance, the lack of data on industrial/business energy consumption below the basic sectoral level, in terms of the use of energy in specific applications (high-temperature heat, motors, etc.), represents an important data gap. The flow of data from the private sector to academia could be increased by explicitly managing confidentiality and non-disclosure issues, for example by way of trusted intermediaries.

In terms of data curation and sharing, RCUK operates under general OECD guidance, which stipulates that the results of publicly funded research should be open access while taking account of confidentiality and intellectual property issues (OECD, 2007). All research councils require those that they fund to have data management policies in place. The Economic and Social Research Council (ESRC), one of the main funders of energy demand research, imposes 'strong' data collection sharing requirements and supports a data repository into which researchers must deposit the data they collect. The EPSRC devolves this responsibility to the researchers it funds. However, much of the energy demand data generated through EPSRC-supported research in the transport, buildings and industry areas has 'common good' characteristics. There is therefore a case for EPSRC to put in place stronger data sharing policies and establish a suitable data repository. Some of these concerns are addressed by the establishment of the Energy Epidemiology Research Centre (http://www.energy-epidemiology.info/), which is designed to provide an evidence base for government and industry to support end use energy demand reduction.

6.4 Levels of research funding support

While financial support for energy demand reduction research has grown in recent years, there is a case to be made that support for demand-side research should be on a level comparable to that on the supply side. Additional funding would best be directed towards the middle stages of the energy innovation chain, where innovative energy products and services typically fail to progress beyond the development and demonstration stages to commercialisation, a phenomenon commonly referred to as the 'valley of death' (Partha and David, 1994). This funding could usefully be used to encourage private sector organisations to take forward promising demand reduction innovations through demonstration and pre-commercialisation initiatives.

7. Conclusion

The UK has made important progress in recent years towards rescuing its energy demand, illustrated by a small but significant reduction in absolute consumption since 1970, driven in part by reductions in energy intensity across many sectors. However, opportunities to further reduce energy demand still exist and could be unlocked through additional support for energy-demand reduction innovation. This paper has therefore highlighted a number of priority research themes, as well as a number of recommendations as to how such research might best be conducted and supported.

The paper identifies the need to support RD&D that is sensitive to the systemic nature of energy demand, as well as the importance of technological and non-technological innovations. It also emphasises the importance of broadening the past focus on energy demand in domestic settings to include non-domestic, which constitutes a more heterogenous sector and thus presents a more challenging arena for energy-demand reduction. The paper also underlines the importance of incremental *and* radical technological innovation. Finally, there is a need to conduct research into opportunities for demand reductions achieved through large-scale energy initiatives (e.g. infrastructure change and spatial planning) to complement research into applications at smaller scales (e.g. appliance or building design).

The paper also identifies a number of ways in which the quality and impact of this research agenda could be improved. First, an interdisciplinary research approach should be adopted considering that energy demand is shaped by a myriad of factors stemming from different system dimensions (e.g. technologies, institutions and user practices). Extensive field trials are also needed to assess how demand-side interventions perform in 'real-world' settings. Data from field trials and other energy-demand research should be made available to researchers for secondary analysis. This could be facilitated by the establishment of more stringent data sharing policies and supporting infrastructure for data collection and curation. Finally, financial support for energy demand research should be brought in line with support for research on the energy supply side considering that both approaches will play a key role in helping the UK meet its climate change, energy security and economic goals.

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