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Insights on Energy Demand

Synthesis of Findings from the UKERC Phase 2 Demand Theme, 2009–2013

Working Paper

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1. Introduction

This report spans a critical period for energy policy. The International Energy Agency have argued that energy savings should be treated as a 'first fuel', and that demand reduction allows governments to buy time and ease the transition to low-carbon economies (IEA, 2013), but this has also been a period in which unconventional hydrocarbons have come to the fore in policy debate. In the UK context, the report covers outputs since the introduction of the UK Climate Change Act 2008, which set a target for cutting Greenhouse Gas emissions by 80% by 2050 from their 1990 levels, and established the Committee on Climate Change (CCC) to advise Government on progress to a low-carbon economy and set carbon budgets, with an interim target of 34% reduction by 2020.

At the outset of the period covered by the report, the technical feasibility of achieving substantial contributions to reducing energy demand had been established in some detail, but was tempered by recognition of diverse economic, institutional, social, and professional 'barriers'. UKERC researchers addressed this diversity by operating across several domains, addressing fundamental issues and principles, analysing different perspectives on demand reduction, developing research methods, contributing to policy development, and providing detailed critical appraisal of current policies while suggesting new or adapted policy instruments.

Work on the Demand Theme started from the premise that demand for energy services drives energy systems, influencing not only the amount of energy used, but also the choice of vectors (fuel, electricity), and the location and characteristics of end use technologies.

Studying energy demand is inherently inter-disciplinary, calling for an understanding of changing technologies, the institutional and policy frameworks within which technical and social decisions are made, and the interactions between these. The objectives of the Demand Theme were to research how socio-economic and technical change affects energy demand in the UK, and apply this research to address the need for more radical change to respond to climate and energy security challenges.

Between 2009 and 2013, the Demand Theme research team carried out the following projects, each listed along with one or more contacts:

- Energy Use in Industry (Geoff Hammond, University of Bath)
- Energy Use in Buildings (Bob Lowe, University College, London; Katy Janda, University of Oxford)
- Energy Use in Transport (Jillian Anable, University of Aberdeen)
- Energy Modelling (Christian Brand, University of Oxford)
- Cross-Cutting Research (Nick Eyre, University of Oxford)
- UNLOC - Understanding Local and Community Governance of Energy (Yacob Mulugetta, University of Surrey)
- EnGAGE Scotland (Elizabeth Bomberg, University of Edinburgh)
- Bottom-Up Industrial Energy Use (Geoff Hammond, University of Bath)
- Disaggregated scenarios for demand studies (Steven Firth, Loughborough University)
- Future role of thermal energy storage (Philip Eames, Loughborough University)
- Value propositions for energy-efficient renovation decisions (VERD) (George Chryssochoidis, University of East Anglia)

A full list of researchers is given at www.ukerc.ac.uk/support/tiki-index.php?page=ED+Team&structure=Energy+Demand

The research has been disseminated through academic publications, working papers, responses to Government consultations, and stakeholder events where academics, policymakers and practitioners learn from each other. The programme generated a total of 61 journal papers, 19 book chapters, a UKERC report and seven working papers, two policy briefings and seven contributions to government consultations and select committee inquiries.

There is not room here to cite more than a few of these outputs, but readers are referred to the listing of outputs at http://ukerc.rl.ac.uk/UCAT/cgi-bin/ucat_query.pl?URadio=R_1&GoButton=Find+Publications where they can find references to all the original papers, reports, books, book chapters, and presentations generated during UKERC Phase 2.

This brief synthesis report is based on a review of all outputs from the Demand Theme, in the following topic areas:

- Energy and climate change governance
- Transport
- Industry
- Buildings

The aim is to offer answers to the questions *‘What do we know now that we did not know before the programme began?’* and *‘What are the implications of this knowledge for policy and research?’* What we have learned, summarised below, comes from five years of work focussed on the implementation of energy policy aimed at a low-carbon transition. It relates to the governance of energy systems and the central importance (literally) of ‘middle actors’ in energy systems; the socio-technical nature of energy systems - the division between ‘technology’ and ‘behaviour’ is increasingly seen as a poor reflection of reality; and the growing significance of infrastructures of demand.

2. Energy and climate change governance

Since 2007, policy has been shaped by four aims: reducing climate impacts, energy security, affordable energy services, and liberalised markets (DTI 2007); the first three of these forming the 'energy trilemma'. UKERC research has been guided by these aims in evaluating policies that are already in place, responding to consultations as part of policy development[1], and contributing indirectly to policy through research.

There has been a fundamental reorganisation of energy policy in recent years, including a departure from free-market principles on the supply side (e.g. Electricity Market Reform) and an intensified reliance on the market to deliver outcomes on the demand side (e.g. Green Deal).

2.1 Efficiency

The range of energy efficiency technologies and measures with different operational characteristics, costs, benefits and market penetrations offers plenty of scope for confusion. In order not to add to this, it is vital that demand-side policies, programmes and projects are monitored using measured rather than estimated savings wherever possible, and accounting for effects such as additionality, rebound[2], prebound[3] and free riding[4] (Griffin *et al.* 2012, Rosenow and Galvin 2013).

Achieving efficiency goals will rely on individuals as well as organisations, behavioural as well as technological change (Eyre 2009, Parag and Strickland 2010, Schwanen *et al.* 2011). The Green Deal has been of particular interest as an innovative policy during the period of UKERC Phase 2, and illustrates

[1] The Demand theme of UKERC responded to DECC consultations on Electricity Demand Reduction (Eyre and Wilson, 2013), the Renewable Heat Initiative (Sansom and Eyre, 2010), the Green Deal (Eyre *et al.*, 2012, Electricity Market Reform (Skea *et al.*, 2011), consumption-based emission reporting (Barrett *et al.*, 2011, and proposals for RHI financial support (Eyre *et al.*, 2010).

[2] Where potential efficiency savings are taken instead as additional energy services, e.g. heating a building to a higher temperature.

[3] Where baseline consumption in low-efficiency buildings is lower than estimated, and predicted savings from efficiency improvements are therefore overestimated.

[4] Where people accept an incentives for doing something that they would have carried out without it.

the complexities of design and implementation. Predicated on overcoming financial barriers to investment in domestic efficiency via loans, early experience has confirmed that there remain plenty of other barriers to uptake of efficiency measures (Mallaburn and Eyre 2013). As an on-bill finance mechanism, the scheme was designed to leverage private investment without requiring large subsidies. However, this was not suited to low-income households and, while the Energy Company Obligation (ECO) scheme is directed at addressing this through subsidy, it is paid for by consumers and could exacerbate fuel poverty (Rosenow *et al.* 2013). By the Government's own assessment, ECO and the Green Deal as originally set up would not deliver enough insulation to meet energy demand reduction targets. The UKERC response to the GD consultation in 2012, while welcoming the underlying idea and the proposal to stimulate uptake of solid wall insulation, raised concerns that some key governance issues – such as how to prevent the "Big 6" energy companies from dominating the market, or overcome barriers preventing local authorities from engaging in local partnerships – had not been addressed.

Suggested approaches included complementing the Green Deal with a soft loan scheme like the 'CBRP' in Germany (Rosenow *et al.* 2013), and balancing supply side subsidies with energy saving feed-in tariffs (ESFiTs), based on the widespread success of feed-in tariffs in promoting the adoption of renewable energy technologies (Eyre 2013a). These offer a promising way of improving energy efficiency and reducing demand, and could avoid a bias towards investment in new supply. In that way, they offer a means of decarbonising the electricity supply with a lower impact on bills, while offering incentives for involving a wide range of actors, including householders, community groups, local authorities and businesses. Methods for ex-ante assessments, ex-post monitoring, grant calculations and payment processes have already been used in supplier obligation, white certificate, renewable FiT and household grant schemes. ESFiT carries the flexibility to create a level playing field with the Electricity Market Reform 'contract for difference' FiT, and to address further barriers to investment.

The concept of ESFiTs was developed in the context of concern that electricity market reform lacked substantial measures to promote energy efficiency.

While not yet adopted, it was discussed widely with policy makers in DECC, resulting in a government consultation on options to reduce electricity demand, and a cross-party amendment at the Report Stage of the 2012 Energy Bill to require 'demand reduction regulations' to allow ESFiTs. Further afield, the European Commission and Regulatory Assistance Project have published work that builds on the evidence presented in the UKERC policy briefing on the topic (UKERC, 2013).

2.2 Urban energy systems

Blackfriars Bridge, London. Source: Network Rail

Strands of research on global city governance for climate change have largely been pursued in isolation but are now beginning to be integrated. These strands include mitigation, adaptation, studies of 'front-runner' pioneer cities and (relatively few) analyses of more universal urban issues. Meeting the challenges of climate change and energy security requires massive investment in infrastructure, building and equipment, and also choices about appropriate scales for implementation and governance.

Four modes of action at city level were identified across built environment, transport and infrastructure provision, in a wide-ranging reflection on governance and planning for mitigation and adaptation:

- Self-governance – municipal authorities doing what they can to manage and reduce impacts from their own assets (buildings and vehicle fleets);
- Regulation – building codes and provisioning – creating infrastructures or services which (re-)shape behaviours and markets;
- Enabling action – providing information, reward and recognition to private sector partners and individuals;
- Partnership – working with private and voluntary sector partners to develop and deliver projects, from retrofits to carbon offsetting (Bulkeley *et al.*, 2011).

Understanding how spatial factors can enable or frustrate policy goals is of great practical value, given the space requirements for energy system components such as pipelines, power plants, heat networks and reservoirs. Implementing a low- carbon economy will be both creative and destructive, changing how places are related to each other economically, politically and even culturally, and at different scales (Bridge *et al.*, 2013).

In the UK, barriers to greater community engagement were found to include a lack of trust among citizens in their local government agents, plus a lack of resources enabling the local authorities to engage more meaningfully. The tier of local government in the UK is less well-resourced and lacks formal powers, compared with sub-national counterparts in the USA and in some European countries (Peters *et al.*, 2012).

2.3 Governance for Innovation: not just top-down or bottom-up, but 'middle out'

Government and institutional views of a low-carbon future have tended to be techno-centric and top-down, dominated by national actors. In contrast, much social research has been 'bottom up', focusing on individuals and households. Probably the most significant shift in UK academic research into energy and climate governance over the years 2009-2013 has been a move into the 'middle' territory of actors and decision-makers, along with a growing recognition of the need for social and process innovation (Janda and Killip, 2013).

This 'middle' territory includes communities, professionals and businesses, and has qualities and characteristics which make it unique and essential to societal transformation. 'Middle actors' such as Local Authorities and NGOs have roles in both energy demand and supply systems. The concept is mutable, however, so that energy suppliers may be seen as middle actors in relation to government and consumers, and also as 'top' actors in energy supply systems.

Bulkeley *et al.* (2011) argue that effective governance for integrated climate action (mitigation and adaptation) requires stronger development of local government leadership, knowledge and capacity. Deep emissions reductions cannot be achieved by local action alone, but either can they be achieved without translating policies into local action (Peters *et al.* 2012).

'Local' is a term used to cover activity carried out through the structures of local government and also through more informal initiatives, which were also explored and analysed. Arguably, two types of resources are needed to mobilise community energy projects: structural, such as money, policy support, and volunteer time; and symbolic, such as identity, authority, and autonomy (Bomberg *et al.*, 2012). Trust, familiarity and shared values are highly significant. Bergman *et al.* (2010) argue that social innovations inevitably engage values and ethics, so that that the purpose or value of an innovation (e.g. sustainability or justice) is at least as important as any technical outcomes or efficiency gains. In some cases, though not often, the ethical purpose and technical pursuit of low-carbon energy are aligned, as when a community-owned wind turbine generates renewable energy and income for local projects. Social innovation mechanisms typically include exchange of ideas and values, shifts in roles and relationships among actors, and the integration of private capital with public and philanthropic support. These cannot all be quantified but it is still possible to develop indicators, and to broaden out the focus from new technology to new socio-technical systems.

Middle actors have influence ‘upstream’ to policy, ‘downstream’ to energy users and micro-generators, and sideways to other middle actors. They can enable (or disable) technology adoption; mediate (or resist) change through interactions across the system; and aggregate and apply lessons from various sources to shape change. Networks of middle actors can help spread social or technological innovations, and social network analysis is emerging as a potentially powerful tool for promoting our understanding of interactions between groups (Parag *et al.* 2013).

These under-researched middle actors have provided a lens through which mainstream technology uptake and socio-technical system changes can be explored. ‘Energy’ or ‘low-carbon’ issues may present them with new opportunities, but may also perturb established practices, and the challenge for researchers is to understand better how systems can be reconfigured so that climate and energy become everyday concerns of middle actors (Janda and Parag, 2013). Oreszczyn and Lowe (2010) make the case for an ambitious programme of action research into building performance. They argue that the construction industry and academic researchers need to collaborate much more fully, with a likely need for new authoritative, independent institutions to coordinate new learning. Institutionalising a culture of monitoring, learning and improvement represents a huge shift in working practices. It also requires a body of inter-disciplinary researchers, combining technical and social science skills.

2.4 Social as well as technical innovation

As energy efficiency fits well within the dominant market economic paradigm, it has currency and legitimacy in debate, even if its potential remains elusive on the ground. Yet while there is still great scope for improved end-use efficiency, there is recognition that it does not go far enough on its own. Hence a growing interest in social innovation among groups who may have radical values and modes of governance. While the credibility of research may be called into question if the only sources of data are small numbers of people operating on the margins of normal practice, the study of mainstream practices offers less insight into potential innovation. Bergman *et al.* (2010) examined the potential of bottom-up social innovation for addressing climate change in some detail, noting how transition theory and strategic niche management offer a framework for experimentation and policy development, and commenting on the difficulties in scaling up when new practices come into close contact with mainstream values. For example, social innovations may lack the technical elements that are readily seen as economically desirable, and they are prone to being dismissed as impractical, in marked contrast to most technological innovations. This may have something to do with the common complaint in research and policy circles that sustainable social change is unattainable. However, Bergman *et al.* (2010) argue that overlapping 'circles' of innovation – social, bottom-up and technological – together produce viable lifestyle-related low-carbon change (Figure 1).

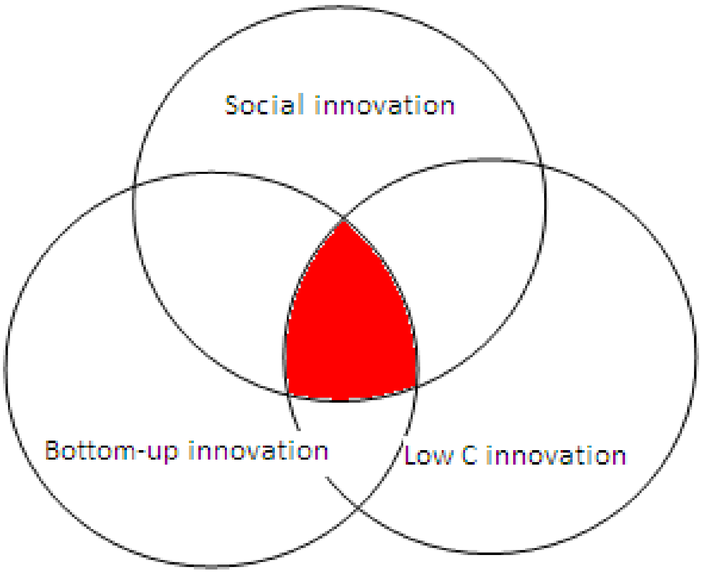

Figure 1. Low-carbon, bottom-up social innovation as the intersection of a Venn diagram (Bergman *et al.*, 2010).

2.5 Systemic governance issues

Systemic issues emerged from various strands of work on the Demand theme. Three closely related papers on principles to guide energy system transition (Cranston and Hammond 2010a; Cranston and Hammond 2010b; Cranston *et al.* 2010) evaluate national and regional responsibilities in addressing climate change. Using IPCC scenarios, the authors concluded that serious commitment to environmental protection is required in both the industrialised 'North' and the more populous 'South'; industrialised countries have been primarily responsible for emissions and should take the lead in reducing them, while promoting technology transfer to assist other nations. Consumption-based emissions accounting techniques, in conjunction with production- and territory-based inventories, give insights into carbon leakage between nations, (as with embodied carbon in imports), and encourage least-cost emissions reduction (Barrett *et al.* 2011).

Also addressing questions of research practice and logic, Hammond and Winnett (2009) presented a multidisciplinary critique of the use of thermodynamic concepts in ecological economics, and point out that these can only be shown to operate as a metaphor, rather than representing a basis for economics. They suggest the approach requires empirical validation rather than unquestioned adoption. Papers by Eyre (2012) and Janda (2011) pointed out how too tight a focus on economic rationality can screen out or sideline other approaches and policy tools which have been identified and evaluated over decades of research.

Policy analysis included a historical review of Supplier Obligations in the UK (Rosenow, 2012), recognising their gradual and growing scope and relative success. Rosenow and Eyre (2013) set disappointing results from the innovative Green Deal programme in context identifying the risk that commercial-rate loans might not attract householders, the implications for the supply chain of a shift towards more sophisticated efficiency measures, the need for GD providers to bear the risk of credit default, and the reduction in resources to address fuel poverty.

In an exploratory analysis of energy efficiency implementation actors in the UK, Parag and Darby (2009) identified a problematic three-way relationship between government, energy suppliers and household consumers. Their analysis suggests that the policy design itself creates conflicts and problems of trust and transparency, which serve to undermine the policy’s ultimate goal, , and comes up against severe principal-agent problems. Possible ways of improving the situation would include paying more attention to government-consumer relations (given that consumers are also citizens), while developing grounded, positive visions for a lower-carbon future.

Further system-level analyses included papers on policy characteristics, the nature of governance, and research practice. Some research developed themes from previous work, reframing the roles of energy system actors. For instance, Eyre (2013) extended an earlier analysis of the implications of a low-carbon economy to take into account the highly centralised nature of much energy governance, with utilities in a more dominant role than energy users. A low-carbon transition will inevitably involve diverse actors (including engaged citizens), with consequent decentralized governance, and proposes widening responsibility for policy formulation to include departments such as transport and built environment, as well as local government input. In an energy system constrained to 80% carbon emissions reduction, the effect of social and lifestyle change was modelled, indicating a reduction in the annual costs of delivering a low-carbon energy system by up to £70bn (Eyre 2009). The term 'social and lifestyle change' covers a vast range of possibilities, and raises questions as to how they might be realised. One of these 'how?' possibilities was addressed in particular detail during phase 2 of UKERC: the concept of personal, tradable carbon allowances, seen as a downstream measure that empowers individuals to reduce their environmental impact. Radical in nature, this was nonetheless explored by DEFRA as a policy option in the later 2000s.

UKERC research examined what individuals would need in order to implement PCT (Parag and Strickland 2009), and what might be learned from community projects (Howell 2009). It analysed implications of permit surrender and enforcement (Eyre 2010), investigated the barriers to PCT (Parag and Eyre 2010), and evaluated the case for further research and evidence gathering (Fawcett 2010, 2012). Parag *et al.* (2011) drew on surveys to propose that policies to make carbon emissions more visible (such as personal carbon allowances or carbon tax) encourage people to act to reduce them. The research demonstrated how PCT would require a paradigm shift in the policy arena, implying changes in the beliefs that dominate decision-making forums and a shift from technology- and business-oriented instruments towards citizens' responsibilities and personal engagement (Parag and Eyre 2010). There was considerable interest in this among policymakers during the late 2000s, with DEFRA producing a pre-feasibility study into tradable energy quotas in 2008. They concluded that the concept was essentially ahead of its time, but that the government would continue to monitor research in this area and would revisit personal carbon trading if the value of carbon savings and the implementation cost implications were to change.

Further outputs included papers on policy characteristics, the nature of governance, and research practice. There was some development of themes from previous work, reframing the roles of energy system actors. For instance, Eyre (2013) extended an earlier analysis of the implications of a low-carbon economy to take into account the highly centralised nature of much energy governance, with utilities in a more dominant role than energy users. He argued that a low-carbon transition will inevitably involve diverse actors (including engaged citizens), with consequent decentralized governance, and proposed widening responsibility for policy formulation to include departments responsible for transport and the built environment, as well as local government input.

3. Transport

Transport accounts for more final energy demand in the UK than any other sector, and almost all the demand is met by oil, raising concerns about future price, environmental impacts and availability. Since the 1950s, the UK has witnessed a six-fold increase in licensed road vehicles, and the challenge of containing emissions from transport has been seen as particularly intractable. However, while the 2006 Energy White Paper predicted an increase in transport-related emissions between 1990 and 2020, by 2010 the fourth Carbon Budget for the UK saw scope for 26% reductions on 2008 levels by 2020.

An early UKERC priority was a review of the literature on policy instruments designed to reduce demand for energy intensive transport modes (road and air), and integration of these into a series of detailed quantitative models which allow decision makers to understand how technical or policy changes may affect the sector. Researchers also explored what might motivate individuals to adopt more active forms of mobility, and examined the potential to shift cars from oil to electricity, by assessing consumer response to low-carbon vehicles.

3.1 Transport sector modelling

The UK transport sector is highly complex, with diverse modes, behaviours and trip patterns, making it challenging to model. The UK Transport Carbon Model (UKTCM) (Brand *et al.*, 2012) provides an effective tool for forecasting how the entire transport system – freight and passenger, by land, sea and air – could change in a range of different conditions. The model is broad in its appeal, and able to forecast changes in energy demand alongside estimated carbon emissions and other environmental impacts. The UKTCM has assisted researchers at UKERC to examine in detail the dynamics of the sector and has contributed to our understanding of the driving forces. These are highly varied, and sometimes surprising: although income, working status, age, and car ownership are significantly related to overall emissions, factors related to accessibility, household location, and gender are not (Brand, 2009).

Models are also useful at forecasting how the sector may change in the future in response to a range of policy options. Alterations to circulation taxes (vehicle exercise duty), and the introduction of scrappage schemes and feebate[5] policies are all levers available to government in order to influence the transport market. Assessing the possible impacts of these policies, Brand *et al.* (2013) modified the UKTCM to explore how alterations to the policy mix will affect what cars are bought, how they are used, and the impact this has on emissions. The findings suggest that introduction of a modest feebate policy would provide a balanced response, decreasing emissions from the sector whilst being fiscally neutral (Figure 2).

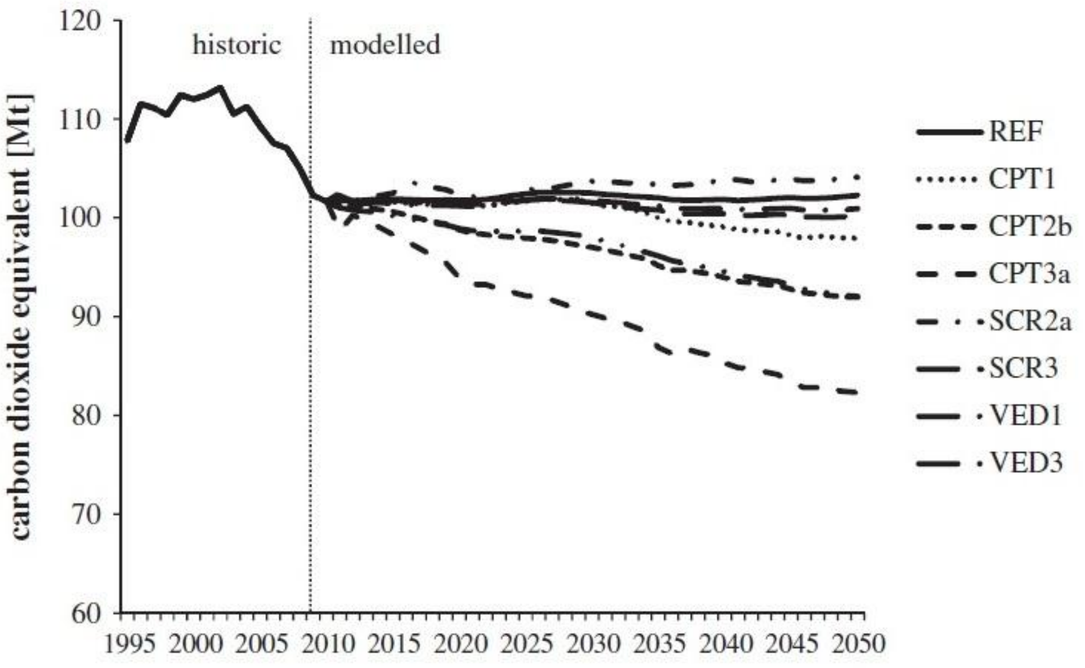

Figure 2. Estimated effects of different policy options and different levels of intensity over UK transport carbon dioxide emissions towards 2050 (CPT = feebates; SCR = scrappage; VED = circulation taxes) (Brand *et al.*, 2013).

Bridging the gap between technical modelling and social perspectives is a significant challenge facing researchers in this field. Anable *et al.* (2012) illustrate how transport systems modelling can be integrated with qualitative

[5] Self-financing system of charges and rebates to incentivise

storylines to examine the effects of behavioural change in transport forecasting. This is achieved through the application of lifestyle scenarios which demonstrate how concerns regarding energy use, environmental degradation and well-being can influence mobility practices. The results suggest that significant decreases in emissions can be achieved by fostering an environment supportive of lifestyle change (Figure 3). Even with relatively rapid uptake of electric vehicles, such a scenario involves less need for massive electrification to meet carbon targets, due to lower demand. The paper argues strongly for pursuing both demand- and supply-side options in order to reduce emissions and foster energy security.

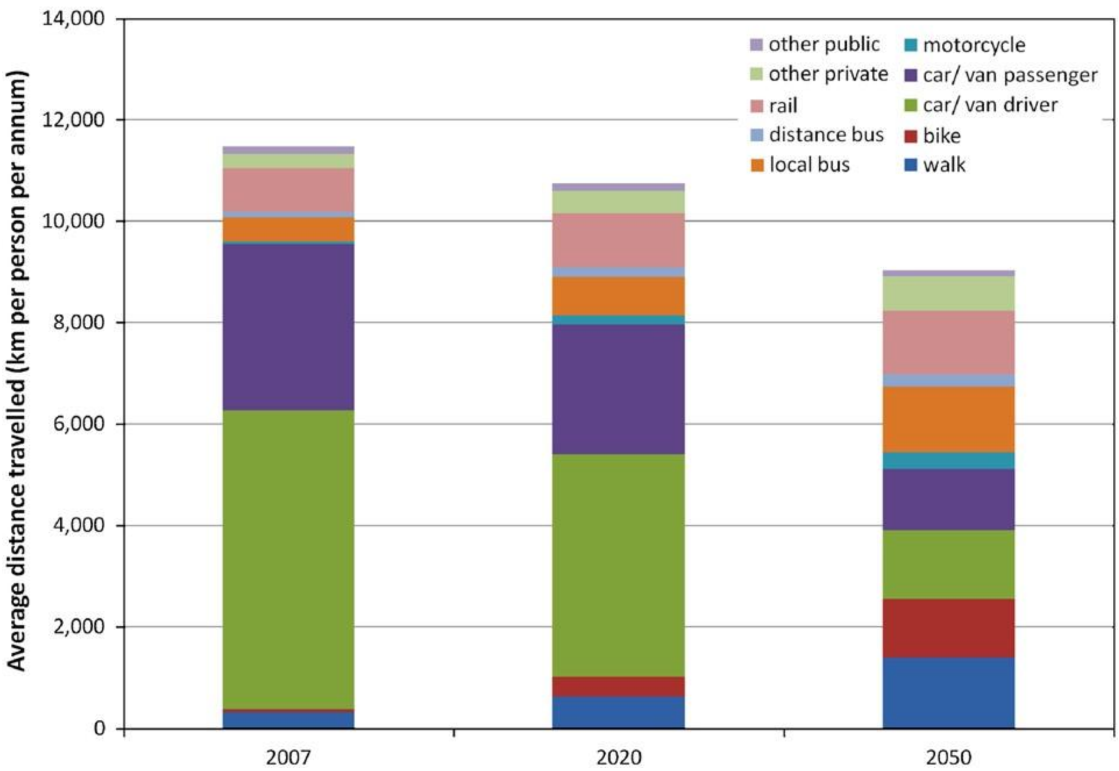

Figure 3. Surface passenger transport by distance and mode split in different years in the Lifestyle Reference and Lifestyle low-carbon variants (Anable *et al.*, 2012).

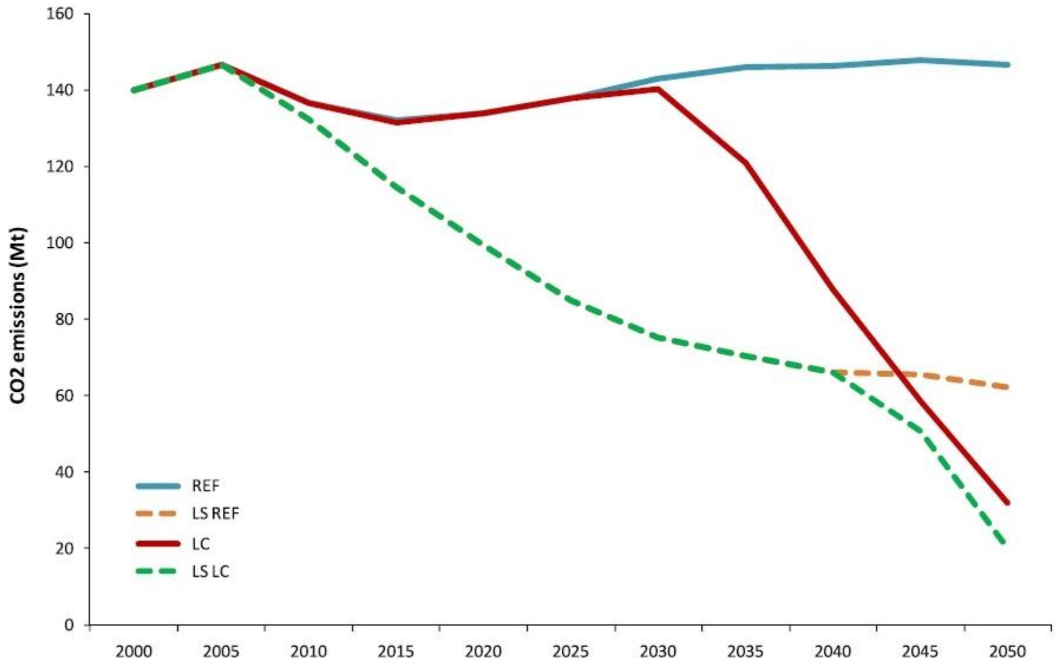

Figure 4. Forecasting the effect of 'Lifestyle reference' and 'Lifestyle low-carbon', compared with reference case and constrained reference case (LC – assumes widespread use of second-generation biofuels) over carbon dioxide emissions in the UK transport sector (Anable *et al.*, 2012).

3.2 Active travel choices

Car journeys account for an estimated 83% of distance travelled in the UK, and UKERC research has provided insights into alternative travel futures which tend to a rebalancing of the modal split away from this dominance (Pangbourne and Anable, 2011). In order to promote active travel, UKERC researchers explored the factors which appear to encourage people to adopt or reject walking and cycling. Their findings show that individual characteristics and aspects of the built environment have a significant effect on the proportion of trips made 'actively': bicycle and car ownership, body mass index and age of the individual, population density and access to workplaces and shops. The results highlight the influence of settlement patterns over active travel modes, and support the case for integrated urban design. They also point to the need to cut demand for long-distance journeys through use of ICT, and to explore the role of incentives or disincentives for purchasing certain vehicles, restricting car parking, lowering speed limits, and subsidising bike ownership. Encouraging more widespread adoption of active travel is potentially an exceptionally low-cost method of reducing transport-related emissions (Song *et al.*, 2013).

3.3 Low-carbon vehicles

Internal combustion engine (ICE) vehicles account for 99% of new car registrations in the UK, evenly split between petrol and diesel fuelled cars. ICE vehicles typically travel only 1 to 1.5 miles per kilowatt hour of electricity equivalent[6]. Electric Vehicles (EVs), powered by on-board battery packs, can achieve a threefold increase in energy efficiency and offer distinct advantages from their ability to be fuelled by low-carbon energy, while diversifying the sectoral supply mix. The UK Government has made £400m available between 2009-2014 to accelerate development of this technological pathway, with an additional £500m committed between 2015-2020[7]; while the European Commission has allocated over €5bn to the European Green Cars Initiative (EGCI).

In order to build understanding of the emerging market for these vehicles, UKERC researchers carried out a market structure analysis to determine whether new consumer segments are forming in reference to low-carbon vehicles (Morton, 2013). The results indicate that groups of consumers are indeed coalescing, with the most likely adopters tending to display concern for environmental issues, and the individuals who appear to place the most value on car ownership and technology tending to show only muted preferences, possibly due to the 'environmental' image currently associated with EVs. In an effort to attract conventional adopters of advanced technology to EVs, policy makers may want to consider toning down the environmental connotations, and place more stress on EVs as embodiments of innovative technology.

Despite substantial R&D efforts, sales of low-carbon vehicles have been low to date. In Great Britain, registrations of cars emitting less than 100g CO_2/km amounted to 8.6% of new car sales in 2012, while 1.3% of new car

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[6] Office for Low Emissions Vehicles, 2013
[7] DfT, 2009; OLEV, 2013

registrations were either hybrid or pure battery electric vehicles[8]. If the UK is to meet 2050 carbon targets, it is estimated that all new car sales after 2035 will need to be ultra-low emission vehicles[9], in which case there is a little over 20 years to transform low-carbon cars from niche to norm. UKERC studies which examine the emerging markets for low-carbon vehicles have concentrated on the less visible features. For example, Wang *et al.* (2013) analysed the spatial distribution of petrol and diesel consumption (Figure 3), to assist planning for new infrastructure such as EV charge points in areas where demand is likely to be high.

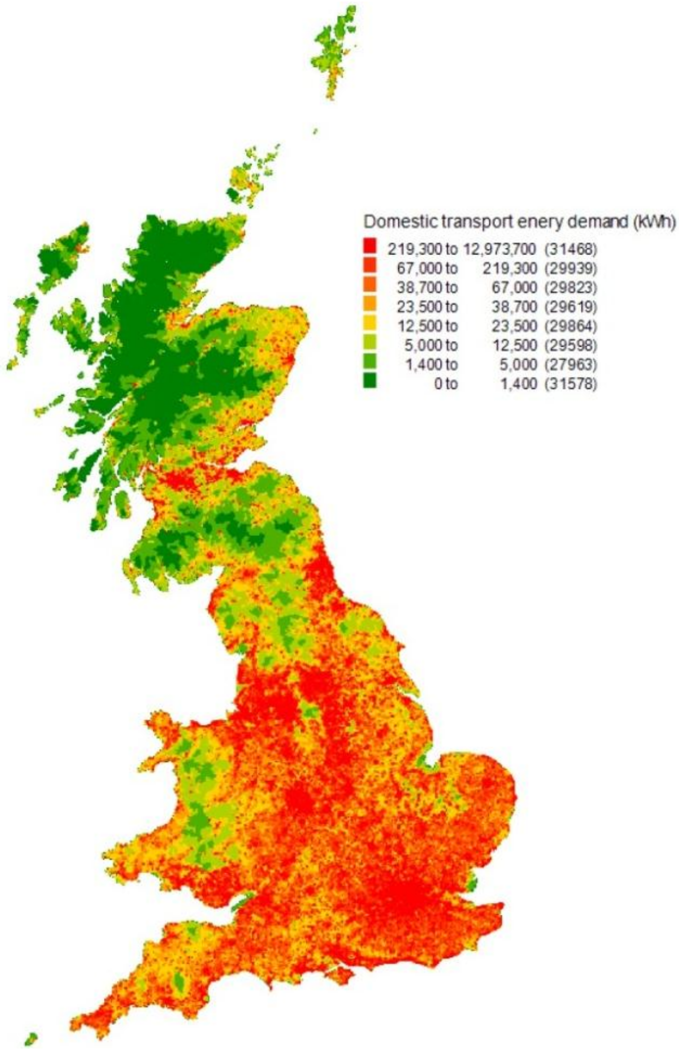

Figure 5. UK transport energy demand, 1km^2 resolution (Wang *et al.*, 2013).

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[8] Department for Transport, 2014. Vehicle Licensing Statistics, 2013.
[9] CCC, 2010. The Fourth Carbon Budget: Reducing emissions through the 2020s.

4. Industry

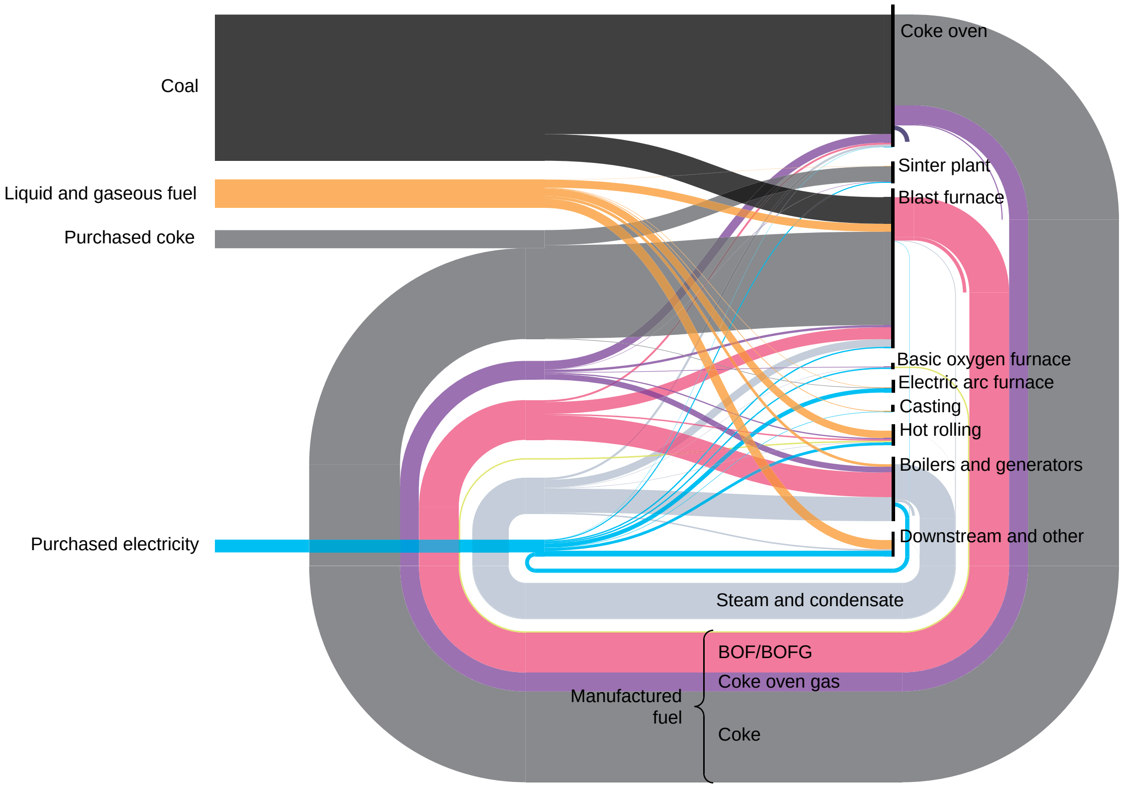

Figure 6. Sankey energy flow diagram of UK iron and steel sector in 2007.

4.1 Developing the evidence base on energy demand and opportunities for emissions reduction

The quality and coverage of data on UK industrial energy use is low, compared to that on household and transport demand. The research priority was to analyse the thermodynamics of energy-intensive industry sectors, and one of the main outputs has been a major assessment of industrial energy demand in the UK (Griffin *et al.* 2013), with a Usable Energy Database that details baseline energy use and emissions in 2010, along with improvement potentials. The bottom-up assessment is based on industry subsectors, supplemented with information on cross-cutting technologies that can be applied throughout industries. The work is in a Beta version at the time of writing, awaiting feedback from interested parties, and offers a novel framework for future inputs.

The iron and steel sector has several sub-processes, producing various intermediate products which are used as part of an integrated system. Figure 6 is a Sankey diagram illustrating the fuel, steam and electrical energy flows of the sector in 2007 at plant level. Most of the coal is converted into coke by coke ovens for use in blast furnaces and sinter plant. Other manufactured fuels include coke oven gas (COG), blast furnace gas (BFG) and basic oxygen furnace gas (BOFG) which are process by-products of the plant from which they are named. These gasses are combusted to supply process heat or to raise steam in boilers, which is used at the process plant or in turbine generators for electricity production. Natural gas is typically used to supplement these by-product gasses or as the chosen fuel input to processes, particularly those situated outside integrated steelworks sites. A small amount of fuel and gas oil is generally used for ancillary processes. In 2007 a significant amount of fuel oil was consumed as blast furnace injectant, but this has since been substituted by coal, further reducing the requirement for coke.

Promising technologies associated with carbon capture and storage (CCS) in steelworks include 'Top-gas recycling' and 'HISarna' which may be retrofitted or implanted into existing integrated steelworks. Without CCS, the sector would need to undergo structural change in order to achieve deep emissions cuts. This could entail reversing a historical trend away from recycling (electric arc furnace steelmaking) and deploying alternative ironmaking processes such as direct reduced ironmaking and, in the long-term, innovative electrolysis methods.

4.2 Drawing on UK experience: data availability

In the bottom-up modelling exercise, baseline energy use and emissions were identified as far as possible for each subsector, prior to assessing the improvement potential offered by the application of technologies in the short and longer term. However, in some cases, especially when examining longer-term improvement potential, information was not available at the required level to allow inclusion of technologies within the database.

The UK has a history of energy efficiency programmes that are rich in lessons for policymakers and that show how the success of industrial RD&D schemes has depended on objective information and management, close engagement with industry and the continuing presence of a single, trusted management organisation to provide cohesion to technology networks across the innovation chain (Griffin *et al.* 2012). However, removal of funding for Carbon Trust schemes has left policy information gaps in the industrial sector and, in returning to in-house policy delivery, the government has reversed the trend of the past 40 years of outsourcing policy delivery to independent agents (Mallaburn and Eyre 2013). There are signs that the legacy of information built up over the years is in danger of dissipating, and free access to unbiased information and support has been withdrawn.

5. Buildings

UKERC Demand Theme research was carried out in the context of policy development and implementation to deliver demand reductions evaluated against a trajectory prescribed by the Committee on Climate Change. Despite the downward trend in CO_2 emissions from buildings in the second half of the twentieth century, the prospects for continuation are bleak, given that the switch to natural gas from 'dirtier' fossil fuels accounted for most of the reduction (Oreszczyn and Lowe, 2010).

This section outlines the contribution to two research domains:

- Energy demand in buildings, for instance methodology related to field research, or best practice in retrofit;
- Policy instruments at sector, societal, and systems level, including building regulations, feed in tariffs, energy saving obligations, actor roles and relationships.

Research priorities in the residential sector were development and use of an open-access technical model of the housing stock; policy analysis of instruments such as carbon caps, designed to address energy service demands is summarised in section 2. In non-domestic buildings, the priority was to analyse technological options for constraining the fastest-growing areas of energy demand: lighting and ICT.

The need for change to happen at different scales and in different sectors at the same time has been a recurrent theme in research findings, as reflected in the Demand Theme contributions to the UKERC flagship projects 'UK Energy in a Global Context' and 'Energy Strategy under Uncertainty'. The first of these, in particular, stresses the centrality of energy efficiency in addressing all aspects of the Energy Trilemma: affordability, environmental impact and security; this centrality offers options for policy at all levels from individual appliances and actors to entire systems. The point is also made that efficiency strongly affects overall levels of demand and thus ability to reach renewable energy targets, and the report concludes that 'If renewables come down in cost relative to fossil fuels, energy efficiency programmes are effective and there is genuine public engagement about the direction of change, the additional costs [of low-carbon energy] … could come to be regarded as one of the best investments in both secure and affordable energy that this country could make' (Ekins and Watson, 2014).

5.1 Research background: knowledge base and methods

There is a generally low level of understanding of how buildings work, while the common experience of buildings reinforces a view that building location is unimportant and energy wastage is normal (Janda 2011). A weak research base was identified as one cause of this state of affairs, with an unflattering comparison drawn between the low quality and quantity of data available for research in building energy studies and the evidence base for health research. This situation has been exacerbated by the privatisation of public-sector knowledge since the 1990s. Current efforts to increase the funding for research in this field are needed, but will meet a chronic problem of under-capacity to do the necessary work (Oreszczyn and Lowe, 2010).

The dominant approach in building energy research is based on an experimental mode of investigation borrowed from the physical sciences, and it is proving wholly inappropriate to the task. The aim should not be to control for single variables, but to study the complex interaction (and resulting energy demand) of all factors – physical, technological and human/social. Action research is proposed as the most appropriate approach, in which research is co-created with industry partners, not derived from seeing those partners as research subjects. Without such a collaborative ethos, we see a failure to build on previous work. Instead, researchers often find themselves answering old questions from scratch, using incompatible tools and methods, muddying rather than clarifying the messages. The nature and structure of the construction industry is a further complicating factor, with fragmented roles undermining any concerted attempts at improving the sector's understanding of building energy performance. Institutionally and culturally, these are uncomfortable but necessary ideas to take on board (ibid.).

Summerfield and Lowe (2012) have argued that the energy and buildings research community is not immune from a much needed overhaul of culture and practice, through different modes of research (such as action research) and more effective translation of research outcomes for a wider range of actors. The days of focussing on reductions in annual energy demand based on normative models, without reference to measured savings and wider sociotechnical context, are coming to an end. As an example of UKERC systems-focussed research, Axon *et al.* (2012) explore the complex social, economic, organisational, and legal relationships in tenanted commercial properties and set out the urgent case for a multidisciplinary research agenda that brings together law, property, social science, and engineering to examine the nature of landlord-tenant relationships.

The need for holistic design and integrated team management is the opposite of current industry practice, and should not be underestimated. The challenge is to link national policies and targets to a devolved system for developing delivery mechanisms. A new support structure of regional innovation networks is proposed to take this development work forward (Janda and Killip, 2013).

5.2 Energy demand in buildings

Buildings, and the activities within them, are responsible for around a third of global final energy demand and energy-related CO_2 emissions, about half of which relates to heating and cooling (IEA, 2011). A policy focus on buildings appears justified, given the technical feasibility of substantial reductions in demand. For instance, a 2050 scenario reduces by almost half (46%) the global heating and cooling energy use in 2005, after allowing for increases in floor area, in the comprehensive overview by Urge-Vorsatz *et al.* (2012). This work demonstrated that substantial energy demand reductions from buildings are already technically feasible, even more so with expected innovations in technology and materials, yet more reductions may become feasible. The review showed the necessity of integrated design process, up to and including urban planning; the significance of retrofits, especially given the need to enable substantial renewable supply; and a range of socioeconomic and health benefits from strong, enforced codes for both new and existing buildings.

Urge-Vorsatz *et al.* (2012), Summerfield and Lowe (2012) and Lowe (2009) have also discussed economic, institutional, social, and professional issues exposed by the scale, scope and urgency of policy requirements, and the need for:

- Basic empirical evidence, from indoor temperatures to variations in energy use according to occupants, building types, technologies, and other variables;
- Research protocols and analytical tools to identify appropriate initiatives for different situations;
- A systems or sectoral level of analysis that recognises changing roles and inter-relationships of actors such as householders, employees, installers, utilities, and educators;
- Identification of policy instruments to encompass the breadth of stakeholder activity, including property law, supply chains, economic incentives, innovation, and building practices;
- Assessment of research practice, in light of typical project and policy cycles, in evaluating and responding to unintended consequences such as health hazards arising from changes in air-tightness, or perverse economic incentives.

A report on renovation decisions, based on surveys and interviews among over 300 homeowners, offered insights into how and why homeowners go about deciding to make changes to their homes, and the time (often over a year) between first thought and completion. The findings, from over 300 households, challenge the view that homeowners renovate primarily to save money, improve comfort and help the environment. The project showed that they are much more likely to decide to install efficiency measures as part of 'amenity' renovations, and that renovation decisions are rarely made overnight but through a lengthy process that is influenced by social norms, attitudes, and a disposition towards seeing the home as a 'project'.

From a policy standpoint, then, factors relevant to amenity renovation become highly significant. The main consideration, from the homeowner's standpoint, is not so much the payback time as an attractive value proposition with low upfront cost, reliable contractors, minimal disruption and good face-to-face customer support.

'Choice experiments' indicated that a Green Deal-type offer was more than twice as attractive as conventional financing arrangements for energy efficiency, and the authors note the potential for the Green Deal to 'piggyback' efficiency measures on to amenity renovations, given that amenity renovation is the most common type and is seen in a positive light, requiring no external incentives (Wilson *et al.*, 2013).

5.3 Policy considerations

While detailed quantitative and technical analysis can provide specific recommendations for empirical research practice, it also has implications for the policy and research environment. For example, Layberry (2009) underscored the importance of collecting high quality data and making it readily available. He identified potential errors in degree-day calculations, using standard weather datasets, and highlighted the need to use weather stations close to the buildings in question.

The fieldwork of Summerfield *et al.* (2010a) demonstrated the need for policymakers to look beyond annual average residential energy consumption figures and focus on subsectors of the building stock, such as those with the highest demand and where the trend of increasing demand is strongest. Further empirical methods to strengthen the evidence base include tools at sector and system levels, with Urge-Vorsatz *et al.* (2012) applying life-cycle emissions analysis to develop low-carbon pathways, widening policy choices from those based solely on operational savings.

Summerfield *et al.* (2010b) demonstrated the use of simple stochastic models using publicly available national data for residential demand, to identify trends after allowing for fluctuating external temperatures and energy prices. These can act as a transparent first test to show whether changes in demand can be attributed to policy initiatives. Wilson *et al.* (2013) examined gas and electricity flow through transmission grids to show the implications of a shift towards electrical heating, and the fundamental role of demand reduction in enabling this to take place.

Several UKERC researchers analysed relationships between actors involved in or affected by policy implementation at the sectoral level, stressing the need for policymakers to adopt a broader outlook. Bergman and Eyre (2011) provided a constructive appraisal of microgeneration in the UK, beginning with evidence on the relatively low levels of uptake and poor performance. They diagnosed implementation weaknesses, and pointed to the radical shift in perceptions that is required when 'consumers' are re-recognised as 'energy citizens' who act as producers, consumers and investors. In the longer term, this implies realignment of the supply industry and infrastructure, and a need to develop energy literacy with the aid of skilled, communicative installers. Along similar lines, Bergman (2013) evaluated renewable heat underperformance in the UK, identifying a mix of technical problems and poor installations, institutional issues, poor information for users, and improper use of the technology. This appraisal highlighted the need to develop policy using measured rather than deemed energy savings, and a systemic socio-technical approach that recognised the significance of knowledge transfer through the supply chain.

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Link to online list of all references, taken from our spreadsheet, in normal alphabetical author.