

1 Introduction

New directions in energy demand research

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Introduction

Meeting the goal enshrined in the Paris Agreement of limiting global temperature increases to less than 2°C above pre-industrial levels demands rapid reductions in global carbon dioxide (CO₂) emissions. For example, the International Energy Agency (IEA) estimates that to provide a high likelihood (66 per cent probability) of meeting that target, cumulative global CO₂ emissions between 2015 and 2100 must be less than 880 Giga-tonnes (Gt) (IEA, 2017). For the energy sector alone, the IEA estimate a smaller ‘carbon budget’ of 790Gt. To put this in perspective, global energy sector emissions stood at 32.5Gt in 2017 – an increase of 1.4 per cent on the previous year and equivalent to ~4 per cent of the remaining budget (IEA, 2018). If emissions continue at this level, the budget will be exhausted in less than 25 years. Hence, to achieve the 2°C target, energy-related carbon emissions must fall very rapidly. The IEA estimate that emissions must fall by ~70 per cent by 2050¹ – implying a near complete decarbonisation of the electricity sector, retrofitting of the entire existing building stock, a major shift towards low-emission vehicles and an 80 per cent reduction in the carbon intensity of industrial sectors (IEA, 2017). By the end of the century, any residual anthropogenic CO₂ emissions would need to be balanced by CO₂ removals from the atmosphere.

There is no historical precedent for transforming energy systems at this scale and at this speed. Achieving this goal will require the rapid and extensive deployment of low-carbon technologies throughout all sectors of the global economy, with far-reaching implications for markets, infrastructures, institutions, social practices and cultural norms. What is more, emission reduction efforts will simultaneously have to address other concerns, including questions of social justice, energy access and energy security.

There is certainly some degree of political ambition to revolutionise the energy landscape. The 2016 Paris Agreement provides a strong basis for global mitigation efforts and these in turn have encouraged (and have been facilitated by) major improvements and cost reductions in renewable energy, electric vehicles, energy storage and other low-carbon technologies (UNFCCC, 2015). Electricity from wind and solar is projected to be cheaper than fossil fuels by the

mid-2020s, and global trends show a rapid uptake of these and other low-carbon technologies (Bloomberg New Energy Finance, 2018; IEA, 2017). Modern renewables now provide 10 per cent of global final energy demand and more than a quarter of global electricity generation, with a record 157 gigawatts (GW) being commissioned in 2017 (Frankfurt School–UNEP Centre/BNEF, 2018).

Yet despite these encouraging trends the rate of progress remains too slow, particularly in relation to improving energy efficiency and reducing energy demand. Global primary energy intensity (the ratio of primary energy consumption to GDP) fell by 1.2 per cent in 2017, but this is less than half the rate required to meet the 2°C target (IEA, 2017). While a business as usual scenario suggests a ~40 per cent increase in global primary energy demand by 2050, a 2°C scenario suggests practically no increase – unless negative emission technologies are deployed (IEA, 2017). There are a growing number of policy initiatives targeting energy demand, but many of these focus upon incremental technological improvements (e.g. insulation) and necessitate only modest changes in energy-related behaviour. But to meet the emission reduction targets, we must achieve *radical* changes in energy demand throughout all sectors of the global economy. Since only limited increases in global energy demand appear compatible with ambitious climate targets (Loftus *et al.*, 2015), developing countries must follow very different development paths than have been observed historically – leapfrogging to highly energy-efficient technologies and providing high levels of human welfare with much lower energy consumption that has been required in the past (Steckel *et al.*, 2013). And to allow space for increased energy demand in the developing world, there will need to be absolute reductions in energy demand in the developed world. Few countries have achieved this in the past, and it is likely to prove very challenging.

Reducing energy demand

The IEA estimates that improved energy efficiency and reduced energy demand could contribute up to half of the reductions in global carbon emissions over the next few decades (IEA, 2012a; IEA, 2015). In other words, changes in energy demand could contribute as much carbon abatement as all the low-carbon energy supply options combined. Similarly, the United Kingdom (UK) government has recognised that reducing energy demand can be a highly cost-effective approach to reaching climate targets, and positions both energy demand reduction and increased energy efficiency as core policy goals (DTI, 2003, 2007; DECC, 2011). But questions remain on how best to achieve these goals.

The demand for energy is driven by the demand for energy services, such as thermal comfort, illumination and mobility. Energy services form the last stage of an energy chain that begins with primary energy sources such as crude oil and nuclear power, continues through secondary energy carriers such as gasoline and electricity and then through end-use conversion devices such as boilers, furnaces, motors and lightbulbs. These conversion devices provide ‘useful energy’

such as low- and high-temperature heat, mechanical power and electromagnetic radiation, which in turn is preserved or trapped within ‘passive systems’ for a period of time to produce final energy services (Cullen and Allwood, 2010). So, for example, the heat delivered from a boiler (conversion device) is held within a building (passive system) for a period of time to provide thermal comfort (energy service).

It follows that there are three ways to reduce energy demand:

- 1 Improve conversion efficiencies and reduce transmission losses at all stages of the energy chain, including from primary to final energy (e.g. more efficient power stations) and from final to useful energy (e.g. more efficient boilers, engines and refrigerators).
- 2 Improve the ability of passive systems to trap energy for periods of time (e.g. more aerodynamic vehicles, better insulated buildings).
- 3 Reduce demand for energy services, such as heating, lighting and cooling, (e.g. lower internal temperatures, fewer overseas flights).

These changes can be achieved through a combination of retrofitting existing technologies (e.g. insulating a house), investing in new technologies (e.g. installing a condensing boiler) and changing energy-related behaviour (e.g. turning off lights when not in use). The latter in turn may involve either restraint (e.g. turning the thermostat down, giving up flying) or substitution by less energy-intensive services (e.g. shifting from cars to buses). Large improvements in energy efficiency are often associated with simultaneous shifts towards different energy carriers – such as replacing gas boilers with (more efficient) electric heat pumps or replacing gasoline cars with (more efficient) battery-electric vehicles. But much of the potential for reducing energy demand requires inter-linked changes in *all* of these areas. More fundamentally, radical reductions in energy demand are likely to require transitions to entirely *new systems* for providing energy services – such as intermodal transport, compact cities, and smart homes.

None of these options are straightforward and the complexity of the processes involved can easily be underestimated. Sorrell (2015) notes, for instance, that previous attempts to reduce energy demand have often proved unsuccessful; the assumptions on which policy interventions are based do not always reflect either the challenge involved or the factors shaping individual and organisational decision-making; and the complexity of economic systems can undermine the success of even well-designed interventions. There are numerous stumbling blocks on the road to energy demand reductions:

- **Reducing energy demand is complex:** Historically, economic growth has been closely linked to increased energy consumption, and few countries have achieved ‘absolute decoupling’ of primary energy consumption from gross domestic product (GDP) (see Chapter 8). The expectation that improved energy efficiency will lead to proportional reductions in energy

demand can be misleading (Sorrell, 2009). The links between efficiency and demand are complex and rebound effects – in which consumers increase their consumption of energy services to take advantage of the fact that these services are now cheaper – can partly offset and sometimes completely eliminate the associated energy savings. In this regard, projections of the impact of policy instruments on energy demand often rely upon oversimplified assumptions (Wilhite *et al.*, 2000; Sorrell, 2015).

- **Large-scale, rapid change is required:** Previous energy transitions (e.g. from localised wood use to centralised fossil fuels) have generally been long and arduous affairs (Smil, 2010). There may be some hope here, as past transitions have generally not been the result of deliberate government intervention (Geels *et al.*, 2017). Yet the urgency of the climate change agenda means that we require larger, faster and more pervasive changes than have been achieved before, supported by policy efforts that have not existed in previous energy transitions (Sovacool, 2016). Such efforts will require substantial and sustained political commitment, combined with global cooperation in the face of powerful incentives to defect and free ride.
- **Energy demand is rising:** Even if the most optimistic forecasts for the upscaling of low-carbon energy supply are exceeded, increases in energy consumption will blunt their impact. Decarbonisation of energy supply must be combined with a break with the historically observed relationship between energy consumption and economic growth. If the rate of decarbonising energy supply is less than anticipated by the more optimistic scenarios, climate targets will only be achieved through greater efforts to reduce energy demand or the deployment of negative emission technologies. Given the uncertainties associated with the latter (Anderson and Peters, 2016), reducing energy demand must be a priority.
- **Societies are disinclined to change:** Energy demand is shaped by large-scale, capital-intensive and long-lived technologies and infrastructures (e.g. transport systems, buildings) that constrain the feasible rate of change. This inertia is reinforced by the entrenched habits and social practices that develop alongside these technologies and infrastructures, together with powerful political interests that resist change (Rosenbloom and Meadowcroft, 2014). For example, policies aimed at reducing automobile dependence face a backlash from motorists whose work and leisure patterns are built around the private car, and from motor and fossil fuel industries whose economic interests are threatened (Dudley and Chatterjee, 2011). For this reason, energy- and carbon-intensive forms of energy service provision continues to dominate and will be difficult to dislodge.
- **Carbon pricing is insufficient:** Carbon pricing can encourage reductions in energy demand and carbon emissions but is unlikely to be sufficient by itself. Carbon prices remain much lower than required to meet ambitious climate targets and attempts to raise them must overcome formidable political obstacles (Loftus *et al.*, 2015). Carbon pricing can encourage organisations and individuals to pursue energy efficiency, but many are

locked in to energy-inefficient systems and practices, with the costs of switching to more efficient systems frequently offsetting the financial benefits of lower energy consumption (see Gillingham *et al.*, 2012). Moreover, the economic theories underpinning carbon pricing provide a poor guide to real-world individual and organisational behaviour (Brown, 2001; Wilson and Dowlatabadi, 2007).

- **Current policies neglect innovation:** Energy demand reduction requires rising energy/carbon prices alongside policies to reduce the economic barriers to improved energy efficiency (Sorrell *et al.*, 2004). It requires interventions that encourage individuals and households to adopt *existing* energy-efficient technologies and practices, alongside support for *new* energy-efficient technologies throughout all stages of the innovation chain. But many policy measures are underrepresented in the current policy mix (e.g. innovation support) while others are confined to relatively incremental improvements (e.g. insulation). Thus, in the face of multiple barriers, current policy approaches appear insufficient.

Two things are clear from the preceding discussion. First, to reach our climate change targets, we must significantly reduce energy demand relative to business-as-usual scenarios, and possibly also in absolute terms. Second, the pathways to doing so defy simple or straightforward solutions. This brings us to the challenge of finding the most effective approach, and to the contribution of a 'sociotechnical' perspective on energy demand.

Perspectives on reducing energy demand: the sociotechnical approach

The challenge of reducing energy demand has been approached from many different theoretical perspectives including neoclassical economics (focusing on economic barriers to energy efficiency), social psychology (focusing on cognitive, emotional and affective influences on energy-related choices) and social practice theory (focusing on how habitual behaviour and social norms shape energy demand). Each approach offers valuable insights, but also has blind spots and weaknesses – particularly in relation to achieving more radical reductions in energy demand. This book therefore proposes a complementary *sociotechnical perspective* that can overcome some of these limitations. The sociotechnical approach is well established in the academic literature but has rarely been applied to energy demand.

A distinguishing feature of the sociotechnical approach is the expansion of the unit of analysis from individual technologies to the *sociotechnical systems* that provide energy services such as thermal comfort and mobility. Sociotechnical systems are understood as the interdependent mix of social and technical entities that function collectively to deliver specific energy services. They include physical artefacts (e.g. infrastructures, conversion technologies, passive systems), social arrangements (e.g. firms, supply chains, markets, regulations)

and intangible elements such as skills, habits, routines, expectations and social norms (Geels, 2004). The sociotechnical system associated with electricity, for example, includes: physical artefacts such as power stations and transmission lines; social arrangements such as electricity markets, technical standards and industry associations; and intangible elements such as electrical engineering skills and the social practices associated with electricity provision and use (Hughes, 1983). Sociotechnical systems develop over many decades and the alignment and co-evolution of the different elements leads to mutual dependence and resistance to change (Geels, 2002). Since the configuration of sociotechnical systems shapes the level, nature and pattern of energy demand, significant reductions in energy demand requires not just changes in individual technologies, but far-reaching changes in the sociotechnical systems themselves. We term such changes *sociotechnical transitions*.

The sociotechnical perspective has its roots in the study of innovation but differs from more conventional approaches to innovation by: first, focusing on broader systems and processes of long-term change in those systems; and second, understanding innovation as both a technical and social process that necessitates complex relationships between a range of actors (including firms, researchers, policymakers and consumers). These actors develop strategies, make investments, learn, open up new markets and develop new routines. As an example, a sociotechnical account of transitions in the electricity system would include the changes within and interrelationships between: public policies and industry regulators; the strategies of generation, network and supply companies; the practices of electricity consumers; and the cognitive, normative and regulative rules that underpin different elements of the system (Geels, 2002; Hammond *et al.*, 2013).

This book investigates how transitions in sociotechnical systems occur and their potential contribution to reducing energy demand. We assume that such transitions centre around particular *low-energy innovations* – defined as technologies or social practices that differ significantly from existing technologies and practices and have the potential to radically improve energy efficiency and/or reduce energy demand. An example would be the central role of heat pumps in a transition from gas to electric heating systems. We seek to make a distinctive contribution to the energy demand literature by developing a sociotechnical understanding of the emergence, diffusion and impact of such innovations. We aim to uncover the processes and mechanisms through which different types of low-energy innovation become (or fail to become) established, identify the role of different groups, explore the resulting impacts on energy demand and other social goals, and develop practical recommendations for both encouraging the diffusion of such innovations and maximising their long-term impact.

Our approach rests upon two assumptions. First, innovations must be situated and studied within broader sociotechnical systems, particularly when their diffusion is associated with fundamental changes in those systems (sociotechnical transitions). Second, to have a significant impact on energy demand, such innovations should be technologically radical, socially radical, or a combination

of the two – what Dahlin and Behrens (2005) term ‘systemically radical’. Radical innovations disrupt established sociotechnical systems – in this case the dominant energy- and carbon-intensive systems – and lead to far-reaching changes in the nature and functioning of those systems (see Chapter 2).

UK policy on energy demand

This book focuses primarily on the UK, one of a small number of countries that have made significant progress in reducing energy demand. Between 2001 and 2017, UK GDP grew by 31 per cent and population grew by 11.7 per cent, but primary energy demand fell by 19 per cent. These reductions have partly been achieved by the diffusion of low-energy innovations – such as energy-efficient lighting, appliances, boilers, electric motors and vehicles – and these in turn have been encouraged by policies such as building regulations, appliance standards and energy efficiency obligations. But demand reductions have also resulted from economic restructuring and the ‘offshoring’ of energy-intensive manufacturing to other countries. In this regard, reductions in UK energy use and emissions have been offset by increased energy use and emissions elsewhere. While such reductions may contribute to UK climate targets, they do little to address global climate change. Barrett *et al.* (2013) estimate, for instance, that while the UK’s territorial greenhouse gas (GHG) emissions fell by 27 per cent between 1990 and 2008, its ‘consumption-based’ emissions increased by ~20 per cent as a consequence of imported consumer goods displacing (more energy efficient) domestic production.

The UK has set long-term, legally binding targets for reducing GHG emissions and has established an independent Committee on Climate Change (CCC) to set intermediate targets and oversee progress. But the CCC (2018) warns that the UK is not on course to meet its ‘carbon budgets’ and that urgent action is required to both bring forward new policies and to reduce the risk of existing policies failing to deliver. Despite the UK’s progress to date, new measures are urgently required to deliver deeper and faster improvements in energy efficiency, particularly in ‘more difficult’ sectors such as domestic heating (Shove, 2017; Staffell, 2017).

The UK has long history of energy efficiency policies and several of these have been very successful – including the series of obligations on energy suppliers to improve household energy efficiency (Mallaburn and Eyre, 2014) and the EU standards on the energy efficiency of domestic appliances. But there have also been notable failures, including the flagship Green Deal policy that was intended to deliver large-scale energy efficiency retrofits but was terminated only two years after its launch (Rosenow and Eyre, 2016). The IEA observes that UK energy efficiency policy has neglected security of supply and other concerns (IEA, 2006, 2012b; Kern *et al.*, 2017), the CCC criticise the large-scale decline in investment after 2013 and the current dearth of policy initiatives, and Hardt *et al.* (2018) highlight the slow-down in the rate of efficiency improvement in industry and the limited scope for further energy savings through offshoring.

Overall then, the UK serves as both an exemplar of successful measures and a cautionary tale. While offshoring is clearly unsustainable in terms of reaching global emissions goals, the UK provides some good examples of what can be done, as well as what should be avoided. Several of these cases are covered in this book² and provide lessons that are relevant to a range of contexts.

About the book

This book is based upon research by the Centre on Innovation and Energy Demand (CIED), a five-year, social science research centre funded by the UK Research Councils. Focusing primarily on the UK, the book uses a sociotechnical approach to explore the challenge of reducing energy demand. The book includes theoretical discussions, literature reviews and a series of empirical case studies organised around the themes of *emergence*, *diffusion* and *impact* of low-energy innovations. The chosen cases include both new technologies (e.g. smart meters, vehicle automation and district heating) and new organisational arrangements (e.g. integrated policy mixes) that either have or could have significant impacts on energy demand. The book has the dual aim of improving the academic understanding of sociotechnical transitions and energy demand and providing practical recommendations for public policy.

Structure

This book is structured around the themes of emergence, diffusion and impact – introduced in full in Chapter 2. We do not argue that all innovations follow a linear progression between these stages (which often overlap), but instead present them as a useful framework for conceptualising the innovation journey.

Emergence: The term *emergence* does not refer to the initial invention of new ideas (e.g. from scientific research), but the introduction of those ideas into society. Emerging technologies, behaviours, institutional arrangements and business models struggle to become established against more dominant systems and can easily fail. Before innovations can break through into broader markets, space needs to be created for learning and improvement, for the building of social networks and for stabilisation around a dominant configuration or design. The chapters on emergence examine these processes for specific low-energy innovations and uncover the conditions for their success.

Diffusion: Innovations spread when their performance improves and costs fall as a result of network, scale and learning economies; when public policies support their adoption; and when they become aligned with people's expectations and behaviours. Diffusion does not happen into an 'empty' world, but in the context of existing sociotechnical systems that provide barriers and active resistance. Many low-energy innovations are not intrinsically attractive to the majority of consumers since they are often (initially) more expensive and perform less well on key dimensions. The chapters on diffusion explore the mechanisms driving this process for selected low-energy innovations, and

examine how infrastructures, business models, social norms, values and public policies need to change for such innovations to succeed.

Impact: The diffusion of low-energy innovations will only contribute to climate goals if they lead to significant reductions in economy-wide energy consumption. But research on innovation and sociotechnical transitions has paid relatively little attention to the ultimate impact of innovations on energy demand or other social goals. More generally, the links between economic growth, energy efficiency and energy consumption remain poorly understood. The chapters on impact therefore employ both orthodox and novel methods for estimating the historical impacts of low-energy innovations and for projecting their potential future impacts.

Chapters

Across each chapter, *Transitions in Energy Efficiency and Demand* moves from contextually-specific first principles through to empirical research in selected areas and, finally, to ideas for how these systems can be most effectively be changed. While each chapter is structured differently, they all include specific policy recommendations.

The first section of the book, ‘Analytical perspectives’ provides a conceptual and normative orientation to the problem of reducing energy demand. Chapter 2, provides a theoretical primer on the problems addressed by this book, and the potential contribution of the sociotechnical approach. This includes an overview of the ‘multi-level perspective’ on sociotechnical transitions and a survey of key debates relevant to emerge, diffusion and impact. Chapter 3 adds an ethical dimension to this discussion, considering the broader normative problems of energy provision through a case study of fuel poverty in the UK.

Chapter 4 begins the section on ‘The emergence and diffusion of innovations’ by considering visions of personal transport futures in the UK and the role of electric vehicles therein. It argues that policymakers would benefit from engaging with a variety of future visions, including the possibility of disruption and shocks and the failure to meet emission reduction targets. Chapter 5 then examines the experimentation with automated vehicles that is underway in several UK cities. It points to the highly managed processes of these experiments (e.g. where and when experiments occur, who is included/excluded, what counts as an experiment), which limit the opportunity for second-order learning and surprises. Chapter 6 explores the evolution of the UK smart meter rollout, including the obstacles faced and the potential implications for energy justice and consumer vulnerability. Lastly, Chapter 7 investigates the mammoth task of comprehensively upgrading UK residential buildings, highlighting the need for consistent and ambitious policy targets; the importance of new business models and finance mechanisms; and the role of intermediary actors in supporting policy implementation.

Moving on to the ‘Societal impacts and co-benefits’ section, Chapter 8 explores the importance of energy for economic growth and summarise a number of recent studies which suggest that efficiency improvements are key driver of growth and

that the rebound effects from those improvements can be large. Chapter 9 is more forward-looking, using macroeconomic modelling to explore the economy-wide impacts of UK household energy efficiency improvements. They show how these can stimulate economic activity, leading to increased employment, investment and savings, and argue that a focus on rebound effects can obscure the wider economic and social benefits of improved energy efficiency.

The section on ‘Policy mixes and implications’ considers the policy frameworks for facilitating low-energy innovation. Chapter 10 uses a series of historical cases studies to investigate how policymakers can deliberately accelerate sociotechnical transitions – highlighting the importance of ‘disarming’ resistance from incumbent actors, popular support for the transition and the level of maturity of the core innovation. Chapter 11 goes on to discuss the challenge of delivering energy efficiency policy in the UK, arguing that political sensitivities about energy prices, neglect of the social benefits of energy efficiency and rigid adherence to neoclassical economic theory have hampered effective policy. This feeds directly into Chapter 12 on policy mixes for energy demand reduction. This chapter draws on the emerging policy mixes for energy transitions literature and highlights the comparative neglect of energy efficiency policy mixes. It goes on to summarise the empirical findings conducted as part of CIED with a view to both: (1) drawing out overall insights and avenues for future research and (2) establishing policy reflections on design principles for policy mixes in which energy efficiency plays a key role. Closing this section, Chapter 13 reviews the literature on Strategic Niche Management (SNM), identifying some lessons for both researchers and policymakers working towards low-energy transitions.

The conclusion (Chapter 14) summarises and elaborates the contributions of each chapter and develops a summative list of conceptual and policy principles for accelerating energy demand reduction. Taken together the chapters provide a comprehensive, sociotechnical account of the energy demand challenge and provide both new empirical results and practical suggestions for achieving meaningful change. We hope you enjoy!

Notes

- 1 This is a higher rate of reduction than assumed in many scenarios, since it excludes the possibility of temporarily overshooting the 2°C target and compensating subsequently through the use of negative emission technologies.
- 2 Although we also reference Denmark, Japan, Finland, New Zealand and the Netherlands, for example.

References

- Anderson, K. and Peters, G. (2016) The trouble with negative emissions. *Science* 354(6390): 182–183.
- Barrett, J., Peters, G., Wiedmann, T., Scott, K., Lenzen, M., Reolich, K. and Le Quéré, C. (2013) Consumption-based GHG emissions accounting: A UK case study. *Climate Policy* 12(4): 451–470.

- Bloomberg New Energy Finance (2018) *New Energy Outlook 2018*. Bloomberg, London, UK and New York, USA. Available at: <https://about.bnef.com/new-energy-outlook/#toc-download>.
- Brown, M.A. (2001) Market failures and barriers as a basis for clean energy policies. *Energy Policy* 29(14): 1197–1207.
- CCC (2018) *Reduce UK Emissions: 2018 Progress Report to Parliament*. Committee on Climate Change, London, UK. Available at: www.theccc.org.uk/publication/reducing-uk-emissions-2018-progress-report-to-parliament/.
- Cullen, J.M. and Allwood, J.M. (2010) The efficient use of energy: Tracing the global flow of energy from fuel to service. *Energy Policy* 38(1): 75–81.
- Dahlin, K.B. and Behrens, D.M. (2005) When is an invention really radical? Defining and measuring technological radicalness. *Research Policy* 34(5): 717–737.
- DECC (2011) *Planning Our Electric Future: A White Paper for Secure, Affordable and Low-carbon Electricity*. Department of Energy and Climate Change, HM Government, London, UK.
- DTI (2003) *Energy White Paper: Our Energy Future – Creating a Low Carbon Economy*. Department of Trade and Industry, London, UK.
- DTI (2007) *Meeting the Energy Challenge: A White Paper on Energy*. HM Government, Department of Trade and Industry, London, UK.
- Dudley, G. and Chatterjee, K. (2011) The Dynamics of Regime Strength and Instability: Policy Changes to the Dominance of the Private Car in the United Kingdom. In: Geels, F.W., Kemp, R., Dudley, G. and Lyons, G. (Eds) *Automobility in Transition? A Socio-Technical Analysis of Sustainable Transport*. Routledge, London, UK, 83–103.
- Frankfurt School–Centre/BEFT (2018) *Global Trends in Renewable Energy Investment*. Frankfurt School of Finance & Management gGmbH, Frankfurt, Germany.
- Geels, F.W. (2002) Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy* 31(8–9): 1257–1274.
- Geels, F.W. (2004) From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy* 33(6–7): 897–920.
- Geels, F., Sorrell, S., Schwanen, T., Jenkins, K. and Sovacool, B.K. (2018) Reducing demand through low-energy innovation: A sociotechnical review and critical research agenda. *Energy Research and Social Science* 40: 23–35.
- Geels, F., Sovacool, B.K., Schwanen, T. and Sorrell, S. (2017) The socio-technical dynamics of low-carbon transitions. *Joule* 1(3): 463–479.
- Gillingham, K., Harding, M. and Rapson, D. (2012) Split incentives in residential energy consumption. *The Energy Journal* 33(2): 37–62.
- Hammond, P.G., Howard, R.H. and Jones, I.J. (2013) The energy and environmental implications of UK more electric transition pathways: A whole systems perspective. *Energy Policy* 52: 103–116.
- Hardt, L., Owen, A., Brockway, P., Heun, M.K., Barrett, J., Taylor, P.G. and Foxon, T.J. (2018) Untangling the drivers of energy reduction in the UK productive sectors: Efficiency or offshoring? *Applied Energy* 223(1): 124–133.
- Hughes, T.P. (1983) *Networks of Power: Electrification in Western Society, 1880–1930*. John Hopkins University Press, Baltimore, Maryland, USA.
- IEA (2006) *Energy Policies of IEA Countries: The United Kingdom 2006 Review*. International Energy Agency, Paris, France.
- IEA (2012a) *World Energy Outlook 2012*. International Energy Agency, Paris, France.

- IEA (2012b) Energy Policies of IEA Countries: The United Kingdom 2012 Review. International Energy Agency, Paris, France.
- IEA (2015) World Energy Outlook Special Report 2015: Energy and Climate Change. International Energy Agency, Paris, France.
- IEA (2017) Perspectives for the Energy Transition: Investment Needs for a Low-carbon Energy System. International Energy Agency, Paris, France.
- IEA (2018) Global Energy & CO₂ Status Report 2017. International Energy Agency, Paris, France.
- Kern, F., Kivimaa, P. and Martiskainen, M. (2017) Policy packaging or policy patching? The development of complex energy efficiency policy mixes. *Energy Research and Social Science* 23: 11–25.
- Loftus, P.J., Cohen, A.M., Long, J.C. and Jenkins, J.D. (2015) A critical review of global decarbonization scenarios: what do they tell us about feasibility? *Wiley Interdisciplinary Reviews: Climate Change* 6: 93–112.
- Mallaburn, P.S. and Eyre, N. (2014) Lessons from energy efficiency policy and programmes in the UK from 1973 to 2013. *Energy Efficiency* 7(1): 23–41.
- Rosenbloom, D. and Meadowcroft, J. (2014) The journey towards decarbonization: Exploring socio-technical transitions in the electricity sector in the province of Ontario (1885–2013) and potential low-carbon pathways. *Energy Policy* 65: 670–679.
- Rosenow, J. and Eyre, N. (2016) A post mortem of the Green Deal: Austerity, energy, efficiency, and failure in British energy policy. *Energy Research and Social Science* 21: 141–144.
- Shove, E. (2017) What is wrong with energy efficiency? *Building Research and Information* 46(7): 1–11. DOI: 10.1080/09613218.2017.1361746.
- Smil, V. (2010) *Energy Transitions: History, Requirements, Prospects*. Praeger/ABC-CLIO, Santa Barbara, USA.
- Sorrell, S. (2009) Jevons' Paradox revisited: The evidence for backfire from improved energy efficiency. *Energy Policy* 37(4): 1456–1469.
- Sorrell, S. (2015) Reducing energy demand: A review of issues, challenges and approaches. *Renewable and Sustainable Energy Reviews* 47: 74–82.
- Sorrell, S., Schleich, J., O'Malley, E. and Scott, S. (2004) *The Economics of Energy Efficiency: Barriers to Cost-Effective Investment*. Edward Elgar, Cheltenham, UK.
- Sovacool, B.K. (2016) How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Research and Social Science* 13: 202–215.
- Staffell, I. (2017) Measuring the progress and impacts of decarbonising British electricity. *Energy Policy* 102: 463–475.
- Steckel, J.C., Brecha, R.J., Jakob, M., Strefler, J. and Luderer, G. (2013) Development without energy? Assessing future scenarios of energy consumption in developing countries. *Ecological Economics* 90: 53–67.
- UNFCCC (2015) *United Nations Framework Convention on Climate Change*. United Nations, New York, USA.
- Wilhite, H., Shove, E., Lutzenhiser, L. and Kempton, W. (2000) The Legacy of Twenty Years of Energy Demand Management: We Know More about Individual Behaviour But Next to Nothing about Demand. In: Jochem, E., Sathaye, J., Bouille, D. (Eds) *Society, Behaviour, and Climate Change Mitigation. Advances in Global Change Research Vol. 8*. Springer, Dordrecht, Germany.
- Wilson, C. and Dowlatabadi, H. (2007) Models of decision making and residential energy use. *Annual Review of Environment and Resources* 23: 169–203.