



UK Energy in a Global Context

Synthesis Report

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Editors

Paul Ekins, UK Energy Research Centre and University College London
Jim Watson, UK Energy Research Centre

Authors

Mike Bradshaw, University of Warwick
Catherine Butler, University of Exeter
Christina Demski, Cardiff University
Paul Ekins, UK Energy Research Centre and University College London
Nick Eyre, University of Oxford
Rob Gross, Imperial College London
Rob Holland, University of Southampton
Christophe McGlade, University College London
Catherine Mitchell, University of Exeter
Karen Parkhill, Bangor University
Nick Pidgeon, Cardiff University
Jim Skea, Imperial College London
Alexa Spence, University of Nottingham
Jim Watson, UK Energy Research Centre

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Foreword

One of the key objectives of the UK Energy Research Centre's research during the past few years has been to explore in more detail the global context for energy that UK energy policies will need to take into account, if they are to be successful.

UKERC's global energy research has been brought together in a major new book: *Global Energy: Issues, Potentials and Policy Implications* which will be published by Oxford University Press in 2014.

The book lays out clearly the global context within which the supply and use of energy in the UK seems likely to be situated over the next three or four decades. This report complements the book, and discusses the implications of global energy trends for the UK. It elaborates the options and choices for the UK in the light of UK energy issues and trends, and current energy infrastructures, markets and regulation. It also discusses the policies that are intended to determine the direction in which they develop.

This report draws especially on UKERC's research and outputs from the last five years. Although the choice of themes within the report has been influenced by the desire to showcase key UKERC research, the aim is also to present a clear picture of the options and choices facing UK policy makers and other stakeholders (including the public).

There are, of course, still many unresolved uncertainties that will affect how these options and choices develop and play out in the years ahead. Many of these are explored in detail in a companion report: *UK Energy Strategies under Uncertainty* that UKERC is publishing alongside this one.

This report covers issues that are of current or future foreseeable importance, with a particular emphasis on those that have a strong global dimension.

The report starts with a very brief summary of the global context for energy (section 1), before briefly linking together the major issues affecting UK energy choices (section 2), and exploring through futures scenarios how these choices might play out in the years to 2050 (section 3). Section 4 then covers the major issues in more detail: the potential drivers of UK energy demand; how key components of the UK's energy supply could evolve (with a focus on natural gas security and the role of innovation in low-carbon technologies); how public attitudes and values could shape the future direction of the UK energy system; how energy markets in the UK could evolve, in the context of developments within the EU; and what the impacts of energy system change might be on energy costs and bills, and on national and global ecosystem services.

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Contents

1.	Global Energy: Key Issues and Trends	04
2.	UK Energy and Emissions: Options and Decision Timelines	08
3.	UK Energy Futures in a Global Context: Achieving the 2°C Target	13
4.	Challenges for UK Energy Futures	16
4.1	UK energy demand	17
4.2	UK gas security – shale gas, LNG and gas markets	19
4.3	Energy innovation in the UK	22
4.4	UK public attitudes and values related to energy system transitions	25
4.5	Future energy markets and networks in the UK and European Union	27
4.6	Energy prices and bills	29
4.7	Ecosystem impacts of energy technologies: The global impacts of UK energy choices	32
5.	Conclusions and Policy Responses	34
6.	References	39



Global Energy: Key Issues and Trends

by Jim Skea and Paul Ekins

Energy underpins almost every human activity and in 2009 accounted for 3.6 per cent of economic activity in OECD countries reporting this data (OECD, 2011). Liquid petroleum products enable global trade and commerce at the local, national and international levels. Electricity powers lighting systems, office machinery, domestic appliances and electronic goods, as well as enhancing comfort levels in hotter climates, while a shifting balance of fossil fuels and electricity maintains comfort for people living in colder climates. The manufacturing industry depends on the supply of energy.

The energy sector provides major business opportunities ranging from the extraction of mineral energy resources, harvesting renewable energy from sun, wind and water, transforming energy in power stations and petroleum refineries, and marketing energy to consumers while potentially helping them use that energy efficiently through energy service business models.

Primary energy resources are unevenly distributed round the globe and their exploitation, especially of globally traded fossil fuels such as oil, is intimately related to economic development in a number of countries. Those countries that are not well endowed with energy resources are often sensitive to their exposure to imports and their potential vulnerability to supply interruption.

Given the unique role that energy plays, policymakers have neither wanted nor have they been able to play a detached role. For a variety of reasons, they have intervened to incentivise or discourage specific forms of energy, promote energy efficiency and conservation, regulate natural monopolies and market power where it is deemed to be excessive, regulate environmental impacts, set the rules for spatial planning, and stimulate and direct technological innovation. Internationally, energy is the subject of diplomacy both among and between producer and consumer nations.

The energy trilemma

The energy policy challenge is often framed as a 'trilemma' – a balancing of three main policy drivers which are in tension as often as they reinforce each other. Although the term 'trilemma' is recent, the basic concept of a triangle of forces shaping policy trade-offs goes back decades (McGowan, 1989).

The first policy driver concerns the cost of energy to consumers and its impact on a country's competitiveness, now frequently captured in the short-hand term 'affordability'. Major shifts in the price of globally traded forms of energy can have significant macro-economic consequences for both consumers and producers. The oil crises of the 1970s still cast a long shadow over energy policy-making.

The second driver concerns the management of the environmental impacts of energy. The energy sector makes a disproportionately large contribution to environmental problems. For example, it accounts for two thirds of the radiative forcing from human activities leading to climate change. Climate change is a dominant concern both nationally and internationally in current discussions of the energy sector. Energy activities also still contribute disproportionately to air pollution problems such as acid rain and urban smog in low-income countries, although technological solutions have addressed the worst of these problems in most developed countries. There are rising concerns about the interaction of energy activity with water and land especially if the use of biomass for energy develops.

The third driver is 'energy security'. This is perhaps the most nebulous of the three drivers. The term can be used to refer to access to and the price of primary energy resources (e.g. oil, natural gas) as well as to the availability of plant (e.g. power stations) that converts energy into a form suitable for consumption (e.g. electricity). Recent research has made considerable progress in structuring thinking about energy security (Mitchell *et al.*, 2013). Energy security can be threatened by natural disasters, economic disturbances, politically

motivated supply interruptions (whether inside a country or internationally) or simply through inadequate planning. Memories of the 1970s' oil crises mean that an association is often made between the reduction of import dependency and the promotion of energy security. Though the evidence for this link is tenuous at best (e.g. Stern, 2004), the notion helps to legitimise political arguments that are sometimes made for more energy independence.

Different countries have different options, and are likely to make different choices, in relation to these issues, depending on their energy history, culture, resource endowments and international relations. The choices are essentially political, although there are obviously certain irreducible requirements for fuels, technologies and infrastructure if demands for energy services are to be met. The choices made will play out differently in terms of energy security, environmental impact and cost. Because of the substantial costs of the technologies, and the long-lived nature of much of the infrastructure, the economic and political consequences of making the wrong choices are potentially enormous.

The energy system

Figure 1.1 is a schematic illustration of an energy system, which takes energy resources from, and is responsible for emissions to, the natural environment. The resources may be mined, drilled, pumped, grown, felled, using various technologies that produce primary fuels, or captured from

the wind, waves, tides or sun. These are then technologically transformed, converted and transmitted or distributed to businesses and households where they are used by a wide variety of technologies to generate the energy services (warmth, 'coolth', light, mobility, and power for information, entertainment and appliances), the demands for which drive the use of energy. The technologies, of both supply and demand, are continuously subject to processes of innovation and technical change that find new uses for energy, as well improving the efficiency and performance with which energy is produced and energy services are delivered.

This innovation – the development and wide deployment of new technologies – is essential if the environmental dimension of the trilemma is to be adequately addressed while also meeting current consumer expectations in relation to energy security and affordability (see section 4.6). Stimulating this innovation and technological change in a cost-effective way requires a government to strike a sensitive balance between giving economy-wide signals of the direction in which it wishes the energy system to develop (e.g. through carbon taxes if the objective is a low-carbon energy system), developing portfolios of different energy technologies, using different fuels, hoping that diversity in supply can enhance energy security, and encouraging winning technologies to be installed at scale, in order to reap the benefits of experience and economies of large-scale deployment.



2

UK Energy and Emissions: Options and Decision Timelines

by Paul Ekins

There are numerous options on both the demand and supply sides whereby the UK can achieve its objectives of a clean, secure and affordable low-carbon energy system. However, there are profound uncertainties associated with each of these options. Where possible and appropriate, these need to be reduced or better understood as soon as possible to reduce the chance of making inappropriate or unproductive investments.

Energy demand options

In considering energy options it is always worth starting with energy demand, which determines how much supply, and what kind of supply, is required. The level of demand will depend on the growth over time of the UK population and the number of households; the efficiency with which energy services are delivered; and the energy intensity of the activities in which people are engaged. The possible evolution of these variables to 2050 covers a very wide range. Both population and the number of households seem likely to grow significantly, but there is very great scope for increased efficiency in the delivery of most energy services (IEA, 2012), and it may well be that the recent levelling off in the growth of household demand for energy, and in the consumption of road fuels (DECC, 2013a), is indicative of both increased efficiency and moderation in the growth of demand for energy services. The rising energy prices of recent years are also likely to have more than offset any rebound effect (Sorrell, 2007) from increased energy efficiency.

The need for energy, and especially electricity, capacity could also be profoundly affected by the extent to which smart meters, smart grids (Balta-Ozkan *et al.*, 2014) and new energy storage technologies facilitate load smoothing and the reduced provision of peak and back-up capacity. However, it should be remembered that the decarbonisation of the energy system permits only a relatively small role in the future for internal combustion engines using fossil fuels, however efficient they become, and practically no role at all for the heating of homes by natural

gas. Instead, it seems very likely that key new demand technologies will be electric vehicles (with or without fuel cells), which could also be used for electricity storage/load smoothing, and heat pumps, both of which would use almost totally decarbonised electricity, the provision of which would therefore be likely to increase, despite its much more efficient use.

Another possibility, extensively installed in Japan, but less so currently in Europe, is the provision of heat to households through micro-combined heat and power (CHP) hydrogen fuel cells, with the hydrogen initially produced by natural gas, but ultimately by low-carbon electricity. However, all of battery electric vehicles, heat pumps and fuel cells are in substantial need of further development, in particular leading to cost reductions, and their mass deployment raises important issues of consumer and public acceptability, as well as new infrastructure requirements, for example, the strengthening of electricity distribution grids.

Energy supply options

Turning to supply, the most pressing issue related to reducing carbon emissions is the decarbonisation of electricity, so that it may be used to supply low-carbon transport and residential heat, through the electric vehicles, heat pumps and hydrogen mentioned above. Such decarbonisation depends on the development and deployment at scale of some combination of four potentially important low-carbon options: large-scale renewables, small-scale renewables, nuclear power, and carbon capture and storage (CCS).

None of these options can simply be rolled out in an unproblematic manner. All are currently more expensive than the fossil fuel-based technologies they need to replace, and therefore require policy support. In addition to cost, renewables raise additional issues of incentives, deployment, grid connection, planning and public acceptability, market structure and the existence or otherwise of domestic supply chains and storage technologies to address the intermittency associated with some

renewable energy sources. Nuclear power raises additional issues relating to the demonstration of a new generation of designs, public acceptability and risks associated with possible accidents, attack, weapons proliferation, waste, safety, and decommissioning. Finally, CCS has yet to be demonstrated anywhere commercially at scale, so that profound uncertainties remain associated with its feasibility, cost, and the risks of leakage from storage and associated liabilities.

Bioenergy is a renewable energy source that can be used to generate power, raise heat or fuel vehicles, but it also raises a host of thorny issues (Slade *et al.*, 2011). The extent to which it reduces carbon emissions depends on how the biomass is grown, and some means of biomass production seem to produce more carbon emissions than coal. Producing biomass also raises important questions about competing land uses, where bioenergy may either substitute for food production or displace it, resulting in deforestation and the reduction of biodiversity. Finally, as with all issues relating to land, producing bioenergy raises important social questions of power, livelihoods, ownership and control in those countries where the production takes place.

The internationalisation of energy

Internationalisation is another trend that increases the complexity of contemporary energy issues. Of course, oil has always been traded globally, but this now also applies to bioenergy (both solid biomass for combustion and liquid biofuels for transport) and increasingly to natural gas. Although natural gas markets are currently mainly regional rather than global, the growth of shale gas extraction in the US, and the possibility of widespread shale gas extraction elsewhere, including Europe and the UK within it, and the development of liquid natural gas (LNG) technology, mean that global gas markets may develop. Regional markets in electricity are also developing, especially in Europe (ECF, 2010), in part at least to respond to the variability of renewables by integrating electricity grids over a wider area. The decarbonisation imperative is adding another global dimension to energy, as carbon markets become established internationally, while fears that reducing carbon emissions may lead to negative impacts on industrial competitiveness has led to renewed consideration of the possibility of border tax adjustments.

Energy technologies themselves are also part of the global market. Countries are torn between conflicting desires, on the one hand to participate in global networks of research, innovation and technology development, and on the other to gain national competitive advantage from the technologies that result from such processes. This results in an uneasy balance between competition and cooperation in matters relating to energy technologies, while least developed countries demand concessional conditions for technology transfer to them, to permit them to achieve economic development with reduced levels of carbon emissions.

The energy transition 2020-2050

The fact that much energy infrastructure is long lived and expensive, and that different energy options require different kinds and amounts of infrastructure, means that the transition to a low-carbon energy system needs to be carefully sequenced, in the UK as elsewhere. In the years to 2020, the emphasis needs to be on getting initial deployment at scale for those technologies that have already been successfully demonstrated, for example, in meeting the UK's renewable energy targets through onshore and offshore wind, and biomass, and seeing the extent to which the potential cost reductions from this deployment actually materialise.

This is also the period in which the performance of other supply-side options will need to be clarified: the first new nuclear power station will need to be well on the way to completion if its role after 2020 is to be assured; the first demonstration projects for CCS will need to be operational so that there is more clarity about their feasibility than currently (Watson *et al.*, 2012). Much will depend in these cases on the successful incentivisation of these technologies through the Electricity Market Reform put in place in the Energy Act 2013.

In addition, the trajectory of demand reduction will have to be clarified. Has household demand for heating and transport stabilised, so that further efficiency improvements will reduce energy use, or does the most that can be expected from energy efficiency remain a growth rate of energy demand that is lower than it otherwise would be? With the roll out of smart meters to households and businesses, it is also to be hoped that the extent of the benefits from demand response in reducing peak power demands will be clearer.

By 2020, too, it should be clear whether there is a take up of electric vehicles – hybrid, battery or fuel cell – that promises the mass shift to this form of mobility in subsequent decades, or whether motorists remain attached to the internal combustion engines that have served them so well in the 20th century and continue to do so. Similarly it should be clearer whether heat pumps and fuel cell micro-CHP are beginning to mount a credible challenge to gas boilers, and whether much more efficient new buildings and more effective refurbishments can be implemented than in the past.

Finally, 2020 is the year in which a new global agreement on climate change is due to come into effect. How far and how fast the UK is prepared to decarbonise thereafter is likely to be significantly affected by the nature and ambition of that agreement, the framework for which needs to be put in place in Paris at the 2015 Conference of the Parties to the UN Framework Convention on Climate Change.

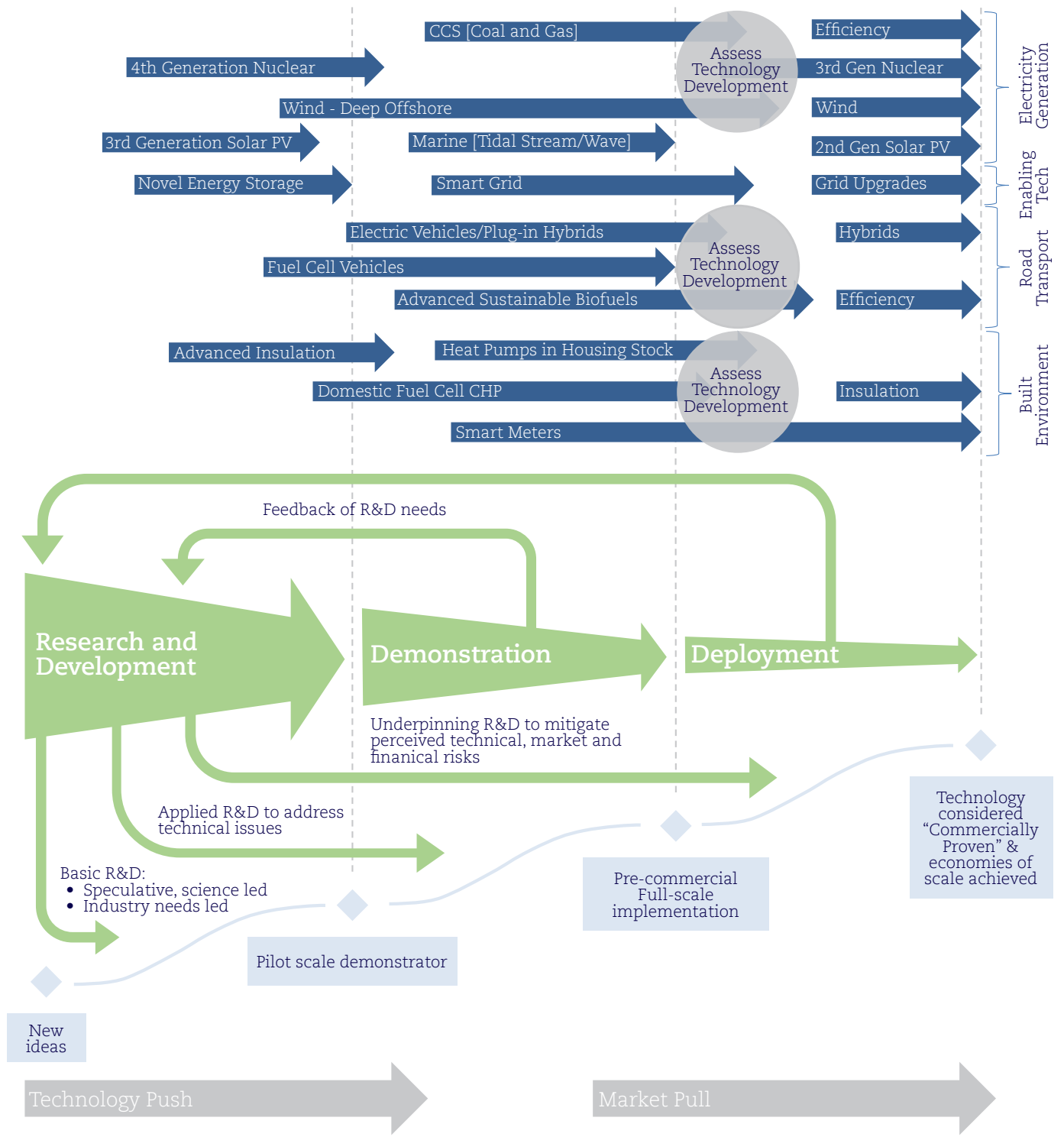
Figure 2.1 shows the pipeline of selected energy technologies and indicates the progress of these technologies that is required by 2020, if the deeper decarbonisation necessary in following decades to limit climate change is to be cost-effectively achieved. In reality, of course, innovation processes are not linear, but are subject to multiple complex feedbacks between the different stages of innovation (as described in section 4.3), so the figure should be interpreted as a snapshot of where different technologies were in 2010, and the kind of progress they would need to make by 2020 if they were going to contribute to the reduction of carbon emissions in subsequent decades, as is often envisaged in scenarios depicting the transition to low-carbon energy systems.

The picture that emerges from this discussion suggests that, during the 2020s, large-scale roll out of mature supply technologies that have already been demonstrated at scale will be required, to the extent required by the new demand patterns that should by then have become apparent. The electricity grid will have to have been substantially redesigned to effectively incorporate the intermittent, less flexible and decentralised low-carbon sources that will be needed by then to supply an increasing proportion, and by 2030 easily the majority, of UK electricity; the carbon intensity of which will need to be no more than 100gCO₂/kWh, compared with around 500gCO₂/kWh in 2000.

There will assuredly be some scope for re-thinking or re-designing some options in light of the lessons and experiences learned from the early and pre-2020s; for example, whether the likely long-term vehicle future is likely to be driven predominantly by batteries or hydrogen fuel cells. Another major issue that will need resolution in these years is the future of the natural gas grid; whether it will be totally converted to low-carbon gas, which could be a mixture of biogas and hydrogen, whether it will be broken up into ‘hydrogen communities’ at the distribution grid level, or whether it will be entirely abandoned in favour of heating largely by heat pumps and biomass district heating. By the end of the decade the scope for large-scale changes in such matters will be much reduced if the deep reductions in carbon emissions that are required from 2030 to 2050 are to be achieved without the costs of un- or under-utilised equipment and stranded infrastructure assets.

By 2050, electricity will need to be almost completely decarbonised, and could be contributing on a large-scale to heat and transport, as well as powering appliances and information and communication technologies. Buildings will be using much less energy for heating and this will come from a mixture of heat pumps, district heating and fuel cell micro-CHP. Vehicles will have very low emissions, and are likely to be mainly ultra-efficient and powered by fuel cells and/or batteries. And industry will also be using low-carbon fuels or fossil fuels with CCS. More detailed scenarios of what a low-carbon UK might look like in mid-century with such changes are sketched out in the next section.

Figure 2.1. Pipeline of selected energy technologies showing progress required by 2020



Source: Adapted from Energy Research Partnership, 2010

3

UK Energy Futures in a Global Context: Achieving the 2°C Target

by Christophe McGlade

The analysis in this section concentrates on an emissions scenario, produced with the global energy system/integrated assessment model TIAM-UCL (McGlade & Ekins, 2014), that provides a 60 per cent probability of limiting the average global surface warming to 2°C. If this is to occur, it is essential for developed countries, including the UK, to lead in ensuring global emissions peak before 2030. However, delaying the peak until then will require drastic year-on-year emissions reductions (an average of 6 per cent per year) that are generally greater than the rates thought able to be sustained alongside further economic growth (estimated to be between around 3-4 per cent annual reduction). The results here therefore suggest that the UK should push for the agreement of a binding global treaty that leads to a peak in emissions within the next ten years.

If an agreement were to be enacted, and systematically implemented, that resulted in global emissions peaking in 2020, results suggest that per-capita GHG emissions in 2050 in the UK, including all international aviation and shipping, fall to 2.5 tCO₂-eq per-capita. This is a drop of 80 per cent from current levels and results in per-capita emissions lower than those currently in Africa. This assumes that there is an overarching global effort to meet the 2°C target, without any regional emissions reductions based on income levels or historical responsibility. Emissions therefore fall in all regions, irrespective of income levels and development status, from 2020 onwards. However, since it is more expensive to decarbonise some sectors in the UK than mitigate a similar level of emissions in other regions, per-capita emissions in the UK also remain slightly above the global average of 2 tCO₂-eq per-capita.

Conversely, if all attempts at emissions mitigation were to be abandoned, resulting in an expected average surface warming of around 4°C by 2100, per-capita emissions in the UK may be expected to grow, though by only 5 per cent from the levels in 2010. This is one of the most modest increases seen in any region (for example, per-capita emissions in the United States and China increase by 15 per cent and 70 per cent respectively).

This suggests that pursuing a low-carbon pathway would be less of a burden on the UK than for many other regions, which is a further strong reason for the UK to take a leading role in the effort to limit the global temperature increase.

In the cost-optimal 2°C pathway, results suggest that the global CO₂ price in 2050 is likely to range from \$120 - \$650/tCO₂ (in 2005 US\$), with an absolute minimum 2020 CO₂ price of \$50/tCO₂. This is around £35/tCO₂ in current prices, illustrating the importance of the carbon floor price announced by the UK Treasury in 2011. This had been due to rise to £30 by 2020 but now seems unlikely to do so, given the decision in the UK's 2014 Budget to freeze the UK's carbon price support element at its 2015 level. It is to be hoped that this decision will be revisited, and the carbon price floor raised, if an ambitious global agreement on climate change emerges from the 2015 negotiations in Paris. However, as explained and emphasised in section 4.3, it should also be recognised that even quite a high carbon price will not be enough by itself to bring about the innovation and deployment of low-carbon technologies that is now required by the UK's carbon targets.

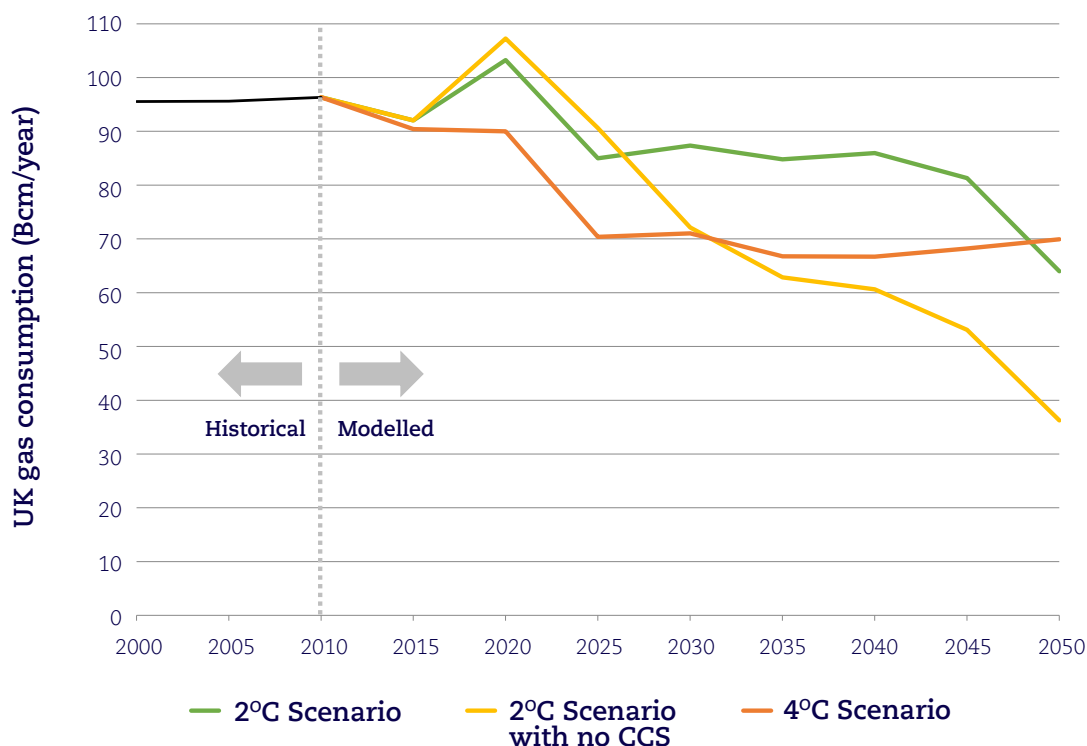
If it does follow the cost-optimal 2°C pathway, in parallel with the global pattern, the UK decarbonises its electricity sector first and to the greatest degree. After 2010 (the beginning of the period examined here), no new major unabated coal plants are constructed and indeed there is negligible unabated coal generation from 2030 onwards. Some unabated gas turbines are constructed but in later periods these are used at very low load factors (15-20 per cent). Gas primarily acts as back-up to the intermittent renewables and to support the increased levels of generation needed in winter months, which is required because 80 per cent of residential and commercial heat has been electrified by 2050.

There are, however, 45 GW of both gas and coal plants equipped with carbon capture and storage (CCS) constructed between 2025 and 2050. This underlines how important it is to demonstrate, commercialise and deploy CCS expediently if the UK is to meet its emissions mitigation goals in the most cost-effective manner. With a continued growth in renewables out to 2050 (at least 2GW of wind and solar are installed annually), the carbon intensity of electricity generation drops to around 50gCO₂ per kWh produced by 2035, staying below this level for the remainder of the modelling period.

There is a much greater utilisation of bio-energy resources than at present, which grow from around 2 per cent to over 15 per cent of primary energy consumption by 2050. Even though there is a high level of demand in all other regions, the UK imports the majority of the bio-energy it consumes. However, given the difficulty and costs of transporting solid biomass or bio-crops, it is predominantly imported as refined products. The conversion process for domestically produced bio-energy is used with CCS, with the resultant products primarily used to decarbonise the transport sector (especially aviation).

Finally, the scenario suggests that there is a good potential for natural gas to act as a transition fuel to a low-carbon energy system on a global scale, with gas substituting for coal; this result is repeated on a modest scale for the UK, in that UK gas consumption before 2050 in a scenario consistent with a 2°C temperature rise (Figure 3.1) is greater than one leading to much higher temperature rise. There are a number of important caveats to this, however, not least that any increases in gas consumption cannot occur alongside an increase in coal consumption. Furthermore, CCS technologies are essential if there is to be anything other than a limited long-term role for gas in a future UK low-carbon energy system.

Figure 3.1. UK gas consumption scenarios to 2050



Source: UKERC modelling using TIAM-UCL model

4

Challenges for UK Energy Futures

This section explores some of the major challenges facing the development of the UK energy system in coming decades. First, section 4.1 discusses UK energy demand in the context of the low-carbon scenario described in the previous section, because this is why the energy system exists in the first place. While UK energy demand is partly influenced by global trends, it is mostly determined by more 'local' factors. Energy supply is more influenced by global factors, as well exemplified by natural gas, the focus of section 4.2. Natural gas is particularly important given the UK's shift from net exporter to net importer in recent years, the rise of shale gas production in the US, and the possible production of shale gas in the UK and in Europe more widely. Innovation, discussed in section 4.3, is also globally influenced, especially when it comes to supply side technologies and networks, but also with respect to end use technologies.

Both supply and demand, and the way in which energy is organised, delivered and paid for is influenced to a large extent by public attitudes and the values that underpin them. This is the subject of section 4.4. This then leads logically to section 4.5 which considers the energy markets and networks through which the UK and wider EU energy systems are organised. There then follows a discussion in section 4.6 of the major influences on energy costs and bills which are currently being delivered by UK energy markets, and how these might develop in the future.

Finally, although much of the environmental discussion in this report has focused on climate change as a result of carbon emissions from the energy system, this is by no means the only environmental impact of the energy system. Section 4.7 looks at the wider impacts of national and global energy trends on ecosystem services, widening the analysis to include both the local and global environmental effects of, and potentially leading to constraints on, the UK energy system.

4.1 UK energy demand

by Nick Eyre

Key drivers of demand

Whereas UK energy supply is dominated by internationally traded fuels and increasingly global technology markets for conversion technologies, many aspects of energy demand are less obviously internationally influenced. With the exception of international shipping and aviation, UK energy demand is, by definition, physically located within the UK, although many of the products consumed in the UK may have been made abroad, with consequent carbon emissions in other countries (Baiocchi & Minx, 2010). Many drivers of energy demand – income, GDP, land use planning, many building techniques and most energy-using practices – have strongly national characteristics.

However, it would be a mistake to conceive of a simple dichotomy in which 'supply is global' and 'demand is national'. In an open economy such as the UK's, the main economic drivers of energy service demands – population, economic activity and energy prices – are increasingly affected by international factors; many energy-using technologies are traded across countries; and globalisation means that even changes in energy-using practices observed in recent decades have been affected by the same trends towards consumerism seen in the rest of the developed, and increasingly in the developing, worlds.

Some of the key policy drivers of UK energy demand have come from EU level, both by direct regulation of products and through Directives that drive targets and other policies. The extent to which this will persist will depend on a number of factors, most importantly any specific targets for energy demand or efficiency in the EU 2030 energy package. National policy, however, remains critical in a number of areas, notably land use, building and fiscal policies, as well as the regulation of the energy sector.

UK energy demand has fallen in recent years. Ensuring that this trend continues is likely to be important for meeting the objectives of carbon emissions reduction and energy security at reasonable cost. The implications of global drivers across the main energy-using sectors of the UK economy leads to the challenges set out below.

Industry

The main energy-using industrial technologies are global with, in many cases, international corporations owning plant in the same sector across the world. There is still significant scope for increases in industrial energy efficiency. However, much has already been achieved, especially in the energy-intensive sectors (Hammond & Norman, 2012), partly driven by a stronger public policy in the 1970s and 1980s (Griffin *et al.*, 2012) and the scope for improvement of current processes is lower than in other sectors. Industrial demand for fossil fuel energy therefore remains a stubborn residual source of carbon emissions in many future scenarios.

Apart from CCS, the only prospect of major emissions reduction is through process or product change. It is difficult to envisage this being achieved solely within the UK, or without a significant increase in energy or carbon prices. In some sub-sectors (notably aluminium) energy prices are a determining factor of investment location; in others there is a smaller effect, but concerns about relative industrial competitiveness are clearly a major driver of wider worries about energy affordability. Securing substantial carbon emission reductions without global agreement or loss of UK manufacturing competitiveness remains a serious challenge.



Transport

Demand for transport is a strong function of land use patterns, aspirations to mobility and social attitudes to lower energy transport modes such as public transport, cycling and walking (Anable *et al.*, 2012). Delivering changes to these modes will require sustained investment in public transport, but also a break from historical patterns of suburbanisation and increased travel. While there are uniquely national drivers of demand, most visions for high-quality/low-energy change that are beginning to influence UK policy and practice come from overseas, notably from elsewhere in Northern Europe.

In contrast the vehicles that dominate current transport use, notably cars, are widely traded across national borders. EU level regulation of fuel efficiency has been the key driver of improved efficiency in the UK, assisted by taxation on fuel, vehicles and company car use. However, there is still huge scope for progress and the technology market is global. Rising oil prices and energy security concerns have increased attention to vehicle efficiency globally, with improvements driven by a combination of engine performance, reduced weight and better aerodynamics.

Asian-based manufacturers have an important market share and have played a key role in introducing new technologies, notably electric hybrids. The key future challenge will be to maintain this progress towards vehicle efficiency and electrification, with innovation in the UK's automotive manufacturing sector being supported by government policy to provide a domestic market for low-carbon transport options (Brand *et al.*, 2013).

Buildings

Electrical appliances, including lights, play an increasing role in energy use in buildings. The market is, in many ways similar to that for vehicles: technology is global and rapidly developing, products are widely traded and EU regulation is the key driver of efficiency in the UK market. For the most rapidly changing product categories (e.g. in information and communication technology (ICT)), timely EU regulation has proved difficult and more global drivers have been important, notably the US 'Energy Star' standard and the IEA 'One Watt' goal for standby power consumption.

Globally negotiated or adopted standards may be expected to become increasingly important. UK policy can help drive adoption, but currently electricity demand reduction has limited policy support compared to low-carbon generation (Eyre, 2013).

Buildings themselves are obviously not traded across borders in the same way. Vernacular architectural traditions remain more important; regulations are national (although increasingly EU policy driven) and the trades that dominate the residential construction and refurbishment sectors are nationally or locally based (Janda & Parag, 2012). Home energy use is therefore less susceptible to global influence, and there is a major challenge for the sector to adopt more advanced insulation and ventilation practices, e.g. from continental Europe. Unfortunately, recent changes to policy have resulted in a reduction in energy efficiency activity (Rosenow & Eyre, 2013).

The commercial building market is more globalised with an international supply chain and design standards. This aids globalisation of technology, even where climatic differences lead to this being energy-inefficient (Janda, 2011), e.g. through the unnecessary adoption of air conditioning in the UK, so the challenge is to avoid a continuing trend to over-conditioning.

Networks

Energy supply networks to final users play a key role in driving end use technologies and practices. In the 20th century, the UK developed universal access to electricity and a very extensive natural gas network. Arguably neither is now fit for purpose for the challenges of modern energy systems. There is broad agreement that some electrification of heating through heat pumps will be required, although the practicability of very extensive change remains debated (Fawcett, 2011).

Advocates of alternative approaches point to much better developed heat networks in other northern countries, but this also remains a contentious topic, with unresolved issues about the cost effectiveness of heat networks for low-energy buildings and the choice of their fuels in a low-carbon economy.

A move to smart grids has begun in the UK, as in many other countries. While there is a clear political and industrial commitment, with potential benefits for suppliers, consumers and network operators, there are significant concerns around data privacy and management.

The most significant benefits are contingent on much higher market penetrations of intermittent renewables and new electricity loads. In delivering on this challenge the UK may be able to learn from countries with earlier high penetration of wind and solar.

4.2 UK gas security – shale gas, LNG and gas markets

by Mike Bradshaw

In the 1990s the UK embarked upon a ‘dash for gas’ as gas production from the UK continental shelf (UKCS) provided an abundant fuel for new power stations, to supply industry, and heat homes. The construction of the interconnector (IUK) between Bacton and Zbrugge (in Belgium) allowed for exports to continental Europe, as well as imports. Demand grew rapidly. The UK’s gas production peaked in 2000 and in 2004 the UK became a net importer of natural gas (see Figure 4.1). Since then, as domestic production has continued to decline, import dependence has rapidly increased. In 2013, according to preliminary data, nearly 48 per cent of UK gas consumption was met by imports.

Security in diversity

The UK benefits from a well-developed gas import infrastructure with 100 billion cubic metres a year (bcma) of pipeline capacity and 50 bcma of LNG terminal capacity, against domestic demand of 80-90 bcma.

In addition to UKCS production, the UK is increasingly served by imports from three sources: first, from the Norwegian continental shelf, via a pipeline system that supplies gas directly to UK consumers; second, from continental Europe via the IUK and the BBL pipeline that connects Balgzand in the Netherlands to Bacton; and third, from three LNG terminals – the Isle of Grain in Essex (National Grid), the Dragon LNG (BG and Petronas) and the South Hook (Qatar Petroleum International, ExxonMobil and Total). Each of these terminals has a distinct and different business model.

These details are important because they demonstrate the increasing globalisation of the UK’s gas supply. Thus, the interconnectors draw the UK into the European market, both in terms of price formation and regulation; while the development of LNG capacity draws the UK into an extended global supply chain.

As Table 4.1 demonstrates, the majority of the UK's LNG cargoes have come from Qatar. The development of these new sources of supply have also required the National Grid to invest in new pipeline infrastructure as gas flows around the country have changed direction and have become more dynamic and complex. This diversity of UK sources of natural gas enhances UK gas security.

A deep and liquid market

The liberalisation of the UK's natural gas industry in the 1990s resulted in the creation of the National Balancing Point (NBP). This is a virtual trading point for the sale, purchase and exchange of UK natural gas. The National Grid manages the physical expression of the NBP through the National Transmission System (NTS) that links physical gas suppliers to consumers. The natural gas price is formed through gas-to-gas competition in this virtual market. This is distinct from continental European gas markets where, until recently, price formation has been dominated by oil indexation and long-term contracts. The NBP is internationally recognised as a benchmark price as it is the deepest and most liquid market in Europe. This is a major source of resilience as it allows prices to attract gas to the UK in times of shortage. Equally, however, if prices are higher on the Continent, then gas will flow from the UK. Because of the UK's ultimate dependence on gas imports, it would not be at all desirable for the UK Government to intervene in the market for energy security reasons.

One way that additional resilience could be provided would be to invest more in gas storage. By European standards the level of UK gas storage is low, but there is currently no business case to support additional investment and the government sees no justification to provide public money. The net result is that while a lot of new storage has planning permission, very little is being built. Consequently, short-term physical security issues –

usually related to technical failures – are resolved via a higher price on the NBP that attracts more pipeline gas from Norway and Europe and LNG from global markets.

Globalising gas security

The geography of gas imports reveals two trends (Table 4.1 and Figure 4.1). First, there is increasing capacity and diversity as new infrastructure has been added to the system. Second, of late, there has been a significant change in the volume and origin of the UK's gas imports. The latter illustrates how developments elsewhere in the world impact on the UK's gas security.

The decision to develop new UK LNG capacity was taken well in advance of the shale gas revolution in North America. However, that import capacity became available just as LNG export capacity – particularly from Qatar – needed a new market. Thus, the UK became a major beneficiary of an LNG glut created by the loss of the US market.

However, after the disaster at Fukushima, the global LNG market tightened as Japan sourced additional LNG supplies. The Japanese utility companies were willing to pay whatever price was needed to attract cargoes. Meanwhile, in Europe recession and growing renewable power generation depressed gas demand. The net result is that far fewer LNG cargoes have found their way to the UK.

At the same time, shale gas production in the US has displaced coal from the power generation mix and coal producers have sought to export that coal. Most recently, in the UK, the high price of gas relative to coal, and the low price of carbon, has meant that power generators have switched to coal. Consequently, late last year gas demand was back at 1995 levels. However, this unexpected and unwanted 'dash for coal' is unlikely to last, as coal power plants are closing in the face of EU air pollution controls. So what happens next?

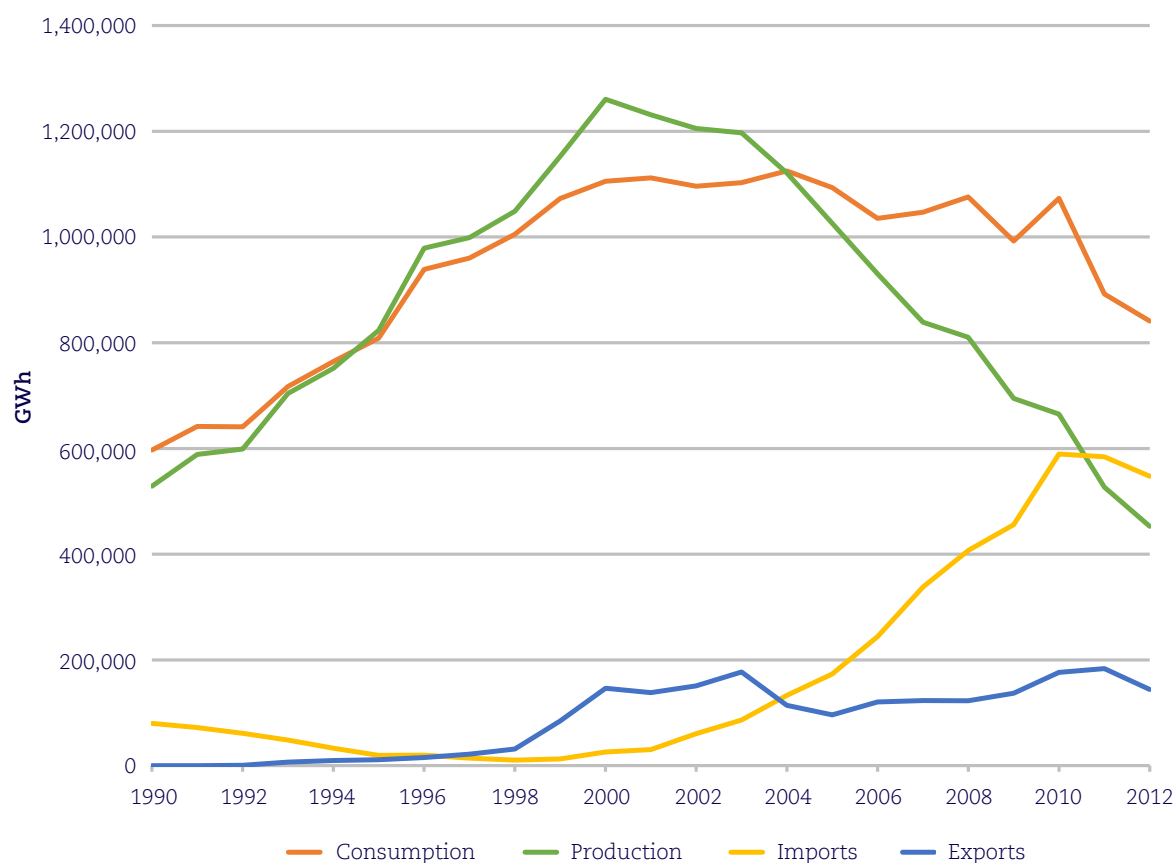


Table 4.1. The Geography of UK Gas Imports (million cubic metres), 2000-2013

	Pipeline Imports			Liquefied Natural Gas Imports		Total Gas Imports	Import Dependence (% of demand)
	Belgium	Netherlands	Norway	Qatar	Total LNG		
2000	270	-	1,031	-	-	1,301	1
2001	367	-	1,158	-	-	1,525	3
2002	611	-	3,392	-	-	4,003	5
2003	401	-	6,327	-	-	6,728	8
2004	2,339	-	8,460	-	-	10,799	11
2005	2,203	-	11,305	-	500	14,008	17
2006	2,788	840	14,003	71	3,442	21,073	29
2007	593	7,107	20,339	247	1,403	29,442	35
2008	1,127	8,440	25,528	-	820	35,915	40
2009	728	6,475	23,478	5,627	10,127	40,808	49
2010	1,245	8,164	25,026	14,565	18,578	53,012	58
2011	368	6,447	21,203	21,153	24,827	52,846	54
2012	1,310	7,297	26,832	13,335	13,667	49,105	61
2013 p	3,307	7,804	27,866	8,607	9,278	48,255	58
% of total imports in 2013	6.9	16.2	57.7	17.8	19.2	100	n/a

p = preliminary
Source: DECC and National Grid

Figure 4.1. UK Natural Gas Trends, 1990-2012



Uncertainty of future demand

Politicians tend to focus on rising import dependence and security of supply as dominant gas security concerns; the reality is that uncertainty about future demand poses a much greater threat. Natural gas will continue to have a major role in the UK's energy mix; the key questions are how much gas, for how long?

The answers lie in a whole system analysis as natural gas, and its associated power generation capacity, currently seem the default cover for any failure to develop new base load (nuclear) and for the intermittency of renewable power generation.

The Government's Gas Generation Strategy (DECC, 2012b) seeks to ensure sufficient gas generation capacity in the future, but expects the load on that capacity to be much lower. However, current market conditions have resulted in existing capacity being mothballed and no appetite to invest in new capacity.

The real concern is that a failure to develop new nuclear in a timely fashion and a slow-down in investment in renewable power, will result in more gas for longer and – in the absence of CCS – higher carbon emissions. Thus, a gas-by-design approach is required, that explores the consequences of this scenario.

As domestic offshore gas production continues to decline, an ever-increasing rate of import dependence may be anticipated (the National Grid's 'Gone Green' scenario forecasts gas demand as 54 bcm/a with 78.5 per cent import dependence by 2035). The Government now justifies its support for onshore development of shale gas in energy security terms. While there are potential benefits in terms of import substitution and balance of payments from shale gas development, it is still very early days and the rate of progress is very slow. It is unlikely that domestic shale gas production at any scale will start until the early 2020s. How much shale gas can be produced in the UK is impossible to know at present; however, it currently seems unlikely to be able to compensate for the decline in offshore production. Thus, how much gas the UK will have to import in the future is dependent on what happens elsewhere in the energy system in relation to both supply and demand.

4.3 Energy innovation in the UK

by Jim Watson

As this report has already argued, the transition to sustainable, low-carbon energy systems will require the development and deployment of a range of new and existing energy technologies. While it is widely accepted that energy efficiency and energy demand reduction have a major role to play in meeting energy policy goals (DECC, 2012a; IEA, 2012), much of the existing research on energy innovation focuses on supply. This partly reflects the greater level of public support for innovation in energy supply technologies (Grubler *et al.*, 2012).

In common with innovation in general, innovation in energy technologies is a complex process that should be analysed from a systems perspective. Innovation is not only concerned with the development of new technologies through research, development and demonstration (R,D&D), it also concerns the deployment of these technologies in markets. Innovation is not a linear process (Rothwell, 1994), and includes frequent feedback loops between the stages of innovation and 'learning by doing'. Onshore wind and solar PV provide clear examples where learning through deployment has delivered substantial cost reductions. However, recent UKERC research also suggests that such cost reductions should not be taken for granted, and that costs do not always fall as expected (see section 4.6 and Gross *et al.*, 2013).

Innovation systems have traditionally focussed at a national or regional level, but there is an increasing emphasis in innovation research on systems that focus on particular groups of technologies (e.g. low-carbon technologies). Furthermore, these systems are increasingly global which poses particular challenges for national innovation policies. Innovation within these systems is not only a technological process, it is also associated with institutional and social changes. For example, smarter electricity networks could create new opportunities for electricity markets to operate in different ways, and change the relationship between consumers and energy suppliers.

Public policy support for energy innovation

Government policies have a particularly important influence over the direction of innovation. Such policies are critical if energy innovation is to be steered in a more sustainable direction. They are often driven by two aims: to accelerate the deployment of cleaner energy technologies and to support a domestic industry to develop and manufacture, install and maintain these technologies.

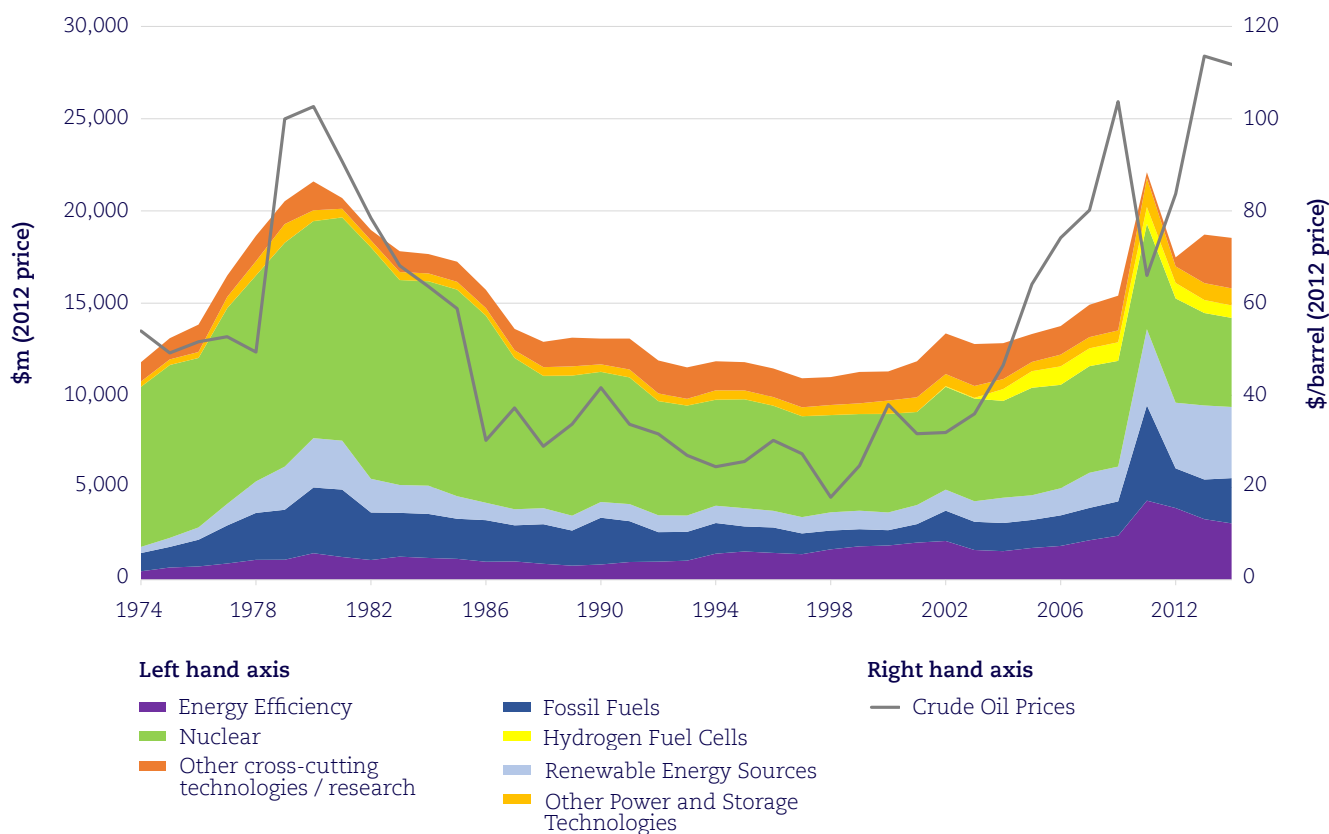
The scale and intensity of government support for innovation world-wide has grown in recent years. Total public spending on energy R,D&D by OECD countries has increased since the 1990s (see Figure 4.2). Spending by large emerging economies has also been significant, including a particularly sharp increase in spending by the Chinese government since the early 2000s (Kempener *et al.* 2010). As the figure shows, these trends in spending have broadly followed movements in global oil prices.

Compared to the spending levels in 1974, spending in 2012 was over 50 per cent higher in real terms. During the last few years, spending has also been boosted by government stimulus packages in response to the global financial crisis of 2008. This has had a particular impact in the United States (IEA, 2013a), but it has also led to spending increases in other countries such as China and South Korea. The balance of spending has also shifted. Spending on renewable energy has dramatically increased by more than 10 times and energy efficiency spending has increased five-fold. At the same time, spending on nuclear power, which used to dominate public R,D&D budgets in many countries, has declined by 45 per cent as the popularity of this technology waned.

Comprehensive data on private sector energy R,D&D spending is not available. Overall, private sector spending tends to track government spending because some of the same drivers apply. Figures from the OECD show that private sector R&D in OECD countries has historically been dominated by spending on nuclear power and oil and gas technologies (Doornbosch and Upton, 2006). More recent data from the European Commission Joint Research Centre based on company reporting confirms a continued focus on fossil fuels, albeit with increasing spending on lower carbon technologies (Skea *et al.*, 2013).

Of course, R,D&D spending is only a partial indicator of innovation. Other indicators include those that seek to track innovation outputs (such as patent applications) and outcomes (such as technology deployment rates). There has been a rapid rise in patent applications since the early 1990s, particularly for non-fossil energy generation technologies and technologies for energy efficiency (OECD, 2013). In general, trends in patenting often track trends in investment and deployment (Lee *et al.*, 2009). Similarly, investment in some energy technologies – particularly renewables – has risen steeply since the mid-2000s (BNEF, 2014).

Figure 4.2. Total government energy R,D&D spending by IEA member countries (1974-2012)



Source: Adapted from IEA, 2013a; BP, 2013

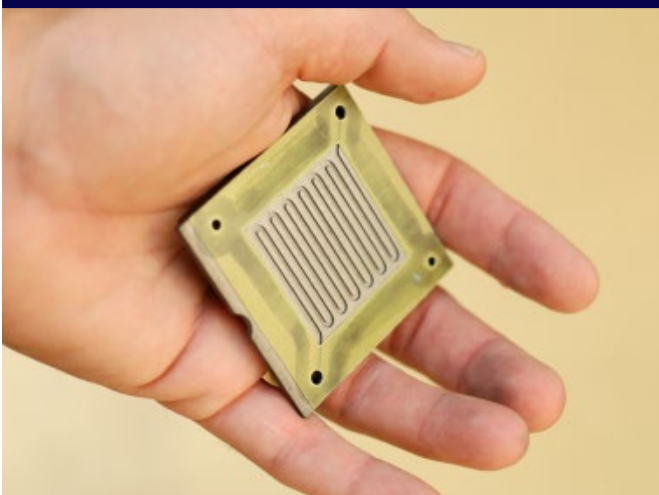
There was some levelling off immediately after the 2008 financial crisis, and a significant drop in 2012 and 2013 due to falls in the cost of solar PV technology and changes in policy frameworks for renewable energy. Alongside this, it is important to remember that global demand for fossil fuels has also continued to rise rapidly. Investment in these traditional energy sources has remained high (e.g. IEA, 2013b), including significant innovation in areas like shale gas extraction and deep water drilling.

Implications for UK innovation policies

Given that many countries are resource-constrained, a situation that has been exacerbated by the financial crisis of 2008, public funding for R&D, technology demonstration and market creation is subject to prioritisation and specialisation. Few countries can afford to support the full range of technologies and the associated organisational, institutional changes to the same degree. The UK is no exception. Furthermore, support for innovation in one country (e.g. through the feed-in tariff policy in Germany) can benefit firms in another country (e.g. solar PV manufacturers in China).

The UK government's approach to low-carbon innovation policy has moved in a positive direction over the last 10 years. As the National Audit Office (NAO) showed recently (National Audit Office, 2013), the government has significantly increased funding for R,D&D since the early 2000s. The vast majority of this funding has been directed to low-carbon technologies. Furthermore, the balance of spending between supply- and demand-side innovations has improved.

Fuel cell.



Demonstration is a particularly risky stage of the innovation process because it requires an increasing amount of investment to be made by a technology developer at a time when the risks of failure remain high. Government policy has an important role to play in supporting technologies across this 'valley of death' between R&D and commercial deployment. The UK's CCS commercialisation programme and the Ofgem Low Carbon Networks Fund (LCNF) are two good examples of UK government funding for this stage of the innovation process. It is not clear in either case whether this funding will help deliver all of the desired outcomes.

However, the UK's innovation policies also have some weaknesses. Four issues are particularly important. First, although public funding for R,D&D has increased from the very low levels seen in the 1990s, this has been inconsistent. There has been a dramatic decline since funding peaked in 2010 – with a one-third reduction in total public spend between 2010-11 and 2011-12 alone. It is not possible to determine how much larger public R,D&D budgets should be because such spending does not guarantee desired outcomes such as industrial development and technology deployment. However, the IEA has suggested an increase to 3-6 times current levels is required (Skea *et al.*, 2013).

Second, there has been a lack of systematic evaluation of past R,D&D programmes, and the inclusion of explicit learning within the design of new or revised programmes. Within these evaluations, there is a need to allow for failures as well as successes, and to learn lessons from both. In some cases, such learning has been undertaken. For example, both DECC and the NAO have reflected on some of the problems encountered in attempts to fund full-scale CCS demonstrations (National Audit Office 2012). While progress with the demonstration of CCS technologies has been slow and frustrating (Watson *et al.*, 2012) lessons learned have then been incorporated into the design of the current phase of the CCS commercialisation programme.

Third, co-ordination across public sector bodies and agencies may not be effective enough. There have been some recent improvements led by the Low Carbon Innovation Co-ordinating Group (LCICG, 2014). This Group has been successful to some extent in improving co-ordination and taking a 'high level' strategic view of priorities. However, co-ordination could be more effective at the level of individual technology areas. For example, a number of initiatives are supporting smarter electricity and heat networks including the Energy

Technologies Institute smart systems and heat programme, the LCNF and a proposed new Energy Systems Catapult (funded by the government's Technology Strategy Board). There is significant scope for a greater level of information sharing, and joint learning across these initiatives.

Fourth, the understanding of innovation in energy systems – and policies to steer innovation processes – need to pay more attention to the history and momentum of these systems. It has been argued that because of this momentum, energy systems in the UK and other industrialised countries are 'locked-in' to the use of fossil fuels, and hence high carbon emissions (Unruh, 2000; Unruh, 2002). This means that if markets are left to themselves, energy systems tend to change slowly. Transitions such as the historical shifts in the UK from wood fuel to coal have taken many decades (e.g. Pearson & Fouquet, 2006). The systemic innovation required to shift energy systems in a more low-carbon and sustainable direction is likely to include political challenges to existing, unsustainable technologies and their associated actors and interests.

4.4 UK public attitudes and values related to energy system transitions

by Nick Pidgeon, Christina Demski,
Catherine Butler, Karen Parkhill
and Alexa Spence

Despite the very obvious human, social and cultural drivers of both climate change and global energy security, proposed solutions to such issues are largely dominated by the physical sciences, technology, and economics. Scenarios of future energy system change, whether within the UK and EU or other regions of the globe, often embed assumptions that new technologies fostered through appropriate market instruments or financial incentives will be sufficient to ensure transition to a low-carbon and resilient energy system. Such approaches typically overlook the important role that people and communities will play in transforming future energy systems (Spence & Pidgeon, 2009).

The diversity of public attitudes on energy

On the supply side of this equation, it is known that some people hold very strong objections to particular technologies such as nuclear power (Butler *et al.*, 2013a). Accordingly, where nuclear also plays an important role in low-carbon policy scenarios (for the UK see, for example, DECC, 2011), gaining public trust and acceptability must be factored into decision-making.

New proposals such as for biofuels, unconventional gas, or innovative bulk energy storage are likely to raise similar questions in the public mind. Even when a technology, such as onshore wind, has very favourable general evaluations in national surveys, this does not preclude it encountering substantial opposition at a local level. Local contestation can arise because of competing notions over the 'appropriate' use of local spaces, as well as concerns over the fairness of processes for public consultation and engagement (Woods, 2003; van der Horst, 2007; Pidgeon & Demski, 2012).

People and communities are equally important for proposed demand-side changes, since many existing scenarios envisage considerable behavioural change, alongside the social acceptability of interventions. Modelling undertaken for both the UK (UKERC, 2009) and the USA (Dietz *et al.*, 2009) suggests that very significant energy savings can be achieved in developed nations through altered lifestyles. However, this would require changes such as substantial uptake by existing home-owners of modern insulation systems, and new social norms promoting more efficient home appliances and vehicles, as well as different ways of using them. Anticipating public responses to such changes creates an additional layer of uncertainty and indeterminacy, over and above the technological and economic uncertainties more typically considered in national and global energy scenarios (Butler *et al.*, 2014).

In addition, energy systems involve a complex assemblage of resources and supply technologies, demand technologies and associated behaviours, energy infrastructure, 'softer' system elements such as regulation and policies, and the various actors and institutions involved. Public views about the future will be dependent upon the way such changes occur as a whole, while people might also judge the acceptability of individual elements of the system differently when considering options in the light of different governance arrangements or the different overarching policy frames of climate change targets and long-term sustainability, energy affordability, and energy security (Corner *et al.*, 2011).

The UKERC Public Values and Attitudes project sought to explore public perspectives in the UK; looking at the interconnected set of system changes as a whole, synthesising findings across innovative deliberative (Butler *et al.*, 2013b) and survey-based approaches (Demski *et al.*, 2013). Many of the results give particular pause for thought.

The public participants overwhelmingly and enthusiastically endorsed a need for radical change to the energy system in the future – an important conclusion given the often repeated stereotype of a public that is intractably opposed to any form of change. Interestingly, some technologies which are central to decarbonisation scenarios for the UK and other nations evoked quite ambivalent preferences, as when carbon capture technologies were viewed by participants as a ‘non-transition’ – that is a change that simply perpetuated an already undesirable dependence upon fossil fuels and existing energy system trajectories.

Research in other countries has begun to explore similar issues using portfolios of energy technologies (see de Best Waldhober *et al.*, 2009; Fleishman *et al.*, 2010; Hobman *et al.*, 2012; Scheer *et al.*, 2013) or locally-based scenarios (Trutnevyte *et al.*, 2011). A key innovation in the Public Attitudes and Values project was the attempt to go beyond such studies by building an understanding of the deeper values and concerns underlying people’s preferences (see Parkhill *et al.*, 2013). While specific preferences (i.e. for individual elements of system change) might not yet be fully formed, or be highly conditional on other elements of change being realised, a more meaningful insight into public perspectives was deemed to come from examining what values and worldviews people bring with them to the engagement process, because it is these that they draw on to understand new information and concepts as well as to construct responses.

The importance of values

The values emerging from this research were underpinned by two fundamental ideas: the view (a) that society should in the long term be moving away from the exploitation of finite (typically fossil fuel) resources in favour of renewable technologies coupled with (b) greater efficiencies and a reduction in energy use as a whole.

Avoiding waste, the protection of nature and the environment, providing security and reliability, equity of impacts, a degree of autonomy for individuals and communities, and technological improvement embedded within a long-term view of system change were also values that were desired and ones that people felt would help to meet the two more fundamental ideas outlined above.

Values are being used here to refer to guiding principles in life which, as relatively durable entities, are ‘measures not of individual preference but an index of support for a morally right or just society’ (Chan *et al.*, 2012). As such values cannot always be simply traded-off with each other, but may require a careful negotiation of moral principles. To clarify how such values operate, solar power may be taken as an example.

The public view solar power in a highly favourable light in many countries in part because it is a renewable energy. However, it may be imagined that a solar energy installation supplying the

Three energy technologies – nuclear power, onshore wind, fracking – which have been subject to public controversy.



UK but residing in North Africa is revealed as causing local environmental contamination and land-use territorial disputes. This version of solar deployment would not fit the general positive public preference for solar energy as in this instance it would no longer be seen as 'fair', 'just' or 'clean'. As such, public importance is attached to meeting renewable, clean, just and affordable values in future energy systems, and not just to solar energy technology itself.

A global dimension to attitudes and values

Although the main focus of UKERC's research has been people's views on the energy system of the UK, participants in the qualitative workshops frequently situated UK changes in terms of their global dimensions (Butler *et al.*, 2013b). Fundamentally, the participants recognised not only the importance of linkages within the UK's energy system but also, as their discussions around UK 'energy security' illustrated, how we are all now part of a global energy system. In this regard, they reflected on how the impacts of our national, group and individual choices are often felt at global spatial scales and across different times. In addition to this, while there was concern about climate change and the polluting nature of many industries, there was also an awareness that emissions were still being created but had simply been relocated to other countries. This logic led participants to conclude that in the shifting of manufacturing from the UK to other countries the principal issues of pollution and climate change were not being adequately addressed, while at the same time this meant that much needed jobs for the UK were being reduced.

Engaging with values in policy

UKERC research has also demonstrated how a varied cross-section of UK publics are perfectly capable of deliberating complex issues of energy policy and technology with which they have little day-to-day familiarity given the right tools, information and opportunity. Approaching energy system change through exploring values rather than simple expressed 'preferences' adds to our understanding of the core reasons for public acceptance or rejection of different energy system aspects. Public perspectives, in the UK but also in other nations and regions of the globe, are never solely about technology, but are ultimately about what the technology symbolises and represents, as well as people's views on the actors, institutions and processes embedded in system change.

A clear policy conclusion of the research, then, is that these social dimensions must always be considered alongside other more technical elements of system change. When engineers, businesses or policy makers judge the potential for acceptability of any particular proposed future energy system change it would make good sense to think first about the derived value set and whether any change is compatible (or alternatively incompatible) with it, rather than to focus simply upon the observable 'risks' and 'benefits' of the technology *per se*. While doing so would not guarantee the absence of contestation and debate, engaging with the value set may enable both the UK and the wider global society to develop smoother transitions to alternative energy futures.

4.5 Future energy markets and networks in the UK and European Union

by Catherine Mitchell

The European Union (EU) is committed to creating broad, integrated regional markets for electricity (and at some time in the future for natural gas) by implementing what is referred to as the EU target model of market coupling. In effect, market coupling requires that regional, and no longer exclusively national, supply and demand for electricity (and gas) will establish energy market clearing prices. This pan-European vision of market trading builds upon current European energy-only electricity or gas markets, which consist of power exchange-based short-term energy markets, longer-term bilateral trades between individual buyers and sellers, and real-time balancing services administered by the system operator.

By design, the EU target market model optimises cross-border flows to reflect energy-only price differentials between the coupled markets (Baker and Gottstein, 2013). Therefore the rules and incentives of future energy markets have to both deliver what is needed in a Member State, but also fit with the requirements of European laws. As noted earlier, current energy policy objectives revolve around decarbonisation, security and affordability. These objectives, particularly the first, have led to technological change and new, more integrated ways of thinking about energy system operation.

The decarbonisation arc is initiating a shift from a low capital cost, high fuel cost energy system to a high capital and low / zero fuel cost energy system. The energy system is therefore broadly moving from a centralised energy system of a few supply technologies and one-way networks to one which is made up of multiple different types

of supply, demand and operational technologies which together enable the efficient and integrated running of the system. Cost reductions in the former type of system mainly come from economies of scale. Cost reduction in the latter energy systems will also derive increasingly from the efficient integration, operation and use of energy.

At the same time, policies on decarbonisation (e.g. smart grid development, storage, interconnection and so on) have become central to shaping market conditions, for limiting/increasing uncertainty and for encouraging/discouraging investment. As noted in section 4.3, policies to reduce emissions and/or energy demand have major implications for current energy incumbents, and their current businesses, as well as for investors. These policy decisions are made outside what is currently seen as the market framework yet these are central to market outcomes.

While it is clear that low-carbon technologies are required if carbon emissions are to be reduced, increasing R,D&D and deployment support related to clean energy – supply, demand and management technologies, across global supply chains, is making the relative prices of different low-carbon solutions highly volatile over the short and medium term. The fall in solar electricity prices due to Chinese investment is a graphic example of this (REN21, 2013). As a result, energy policy delivery, and policy success or otherwise, has become a major driver of market and technological uncertainty, and this is feeding into investment concerns, and then into energy security concerns.

With respect to electricity, much has been written about the theoretical concerns of adding renewable electricity to the energy system. Most of that literature has been overly negative and/or conservative about the consequences, meaning that the costs to the system of greater levels of variable renewable power have been overestimated (e.g. Milligan & Kirby, 2010; Borggrefe & Neuhoff, 2011; IEA, 2011; SSRENIPCC, 2011). However, evidence from electricity systems where there is a high proportion of variable renewable electricity has shown that there are three serious market or operational challenges which need to be addressed.

Firstly, increasing proportions of high capital cost and low (nuclear power) or zero (variable renewable electricity) fuel cost technologies are able to bid in low or zero marginal costs to conventional electricity markets. This effectively shifts the electricity supply curve to the right, bringing down both average and peak prices (Bauknecht *et al.*, 2013; Cochran *et al.*, 2013).

An increasing share of nuclear power and renewable electricity in the absence of increased demand means that conventional generators will be displaced more often by low or zero marginal cost electricity sources and sell electricity at lower prices when they are selected – and they therefore will run at lower and less predictable capacity factors and therefore earn less revenue.

Secondly, as more countries have policies and targets for low-carbon or renewable electricity, the investment risks for fossil generation are increasing. Investors in a fossil power plant have to be confident that they can sell their power plant output for enough years at a sufficient price to make their investment worthwhile. As more and more low-carbon or variable renewable power comes on the system, so there is less and less market demand to be met by fossil generation and the average system marginal cost may fall. Just as individual fossil generators are questioning their economics in electricity systems with high proportions of variable power, so the availability of flexible capacity and suitable ancillary services becomes even more important in order to complement the increasingly inflexible and uncertain output of nuclear and renewables.

Thirdly, a further challenge to conventional electricity systems is that related to balancing. Conventional electricity systems balance uncertain demand (i.e. customers around the system turning their lights, appliances and load requirements on and off with more or less unpredictability) with certain supply to match it (i.e. supply from firm, dispatchable coal and gas plants). As greater proportions of variable, or relatively inflexible, power are introduced into the electricity system, the system operator and/or balancer has to balance the uncertain demand with more uncertain supply. This is a fundamental change in the operation of the electricity system, and has major knock-on effects for the economics of the wider energy system (Riesz *et al.*, 2013). Making the demand side more flexible by a greater use of storage and demand side response mechanisms in markets, including load shifting via smart grids, is becoming of increasing importance and value.

The rules and incentives of electricity markets and networks, and their regulation have a fundamental impact on the way electricity systems work, and on their outputs such as carbon dioxide. Future markets will have to alter rules and incentives so that they overcome the challenges outlined above, responding to technological and market uncertainty, encouraging investment, and incentivising capabilities markets (one dimension of which is capacity) to ensure appropriate flexibility to back up variable power and utilise the demand side effectively (Borggreffe & Neuhoff, 2011; IEA, 2011; Hogan, 2012; Bauknecht *et al.*, 2013; Cochran *et al.*, 2013; Hurley *et al.*, 2013; Keay-Bright, 2013; Riesz *et al.*, 2013).

At its most simplistic the regulation of such markets will comprise electricity rules and incentives which support system-orientated solutions for renewable electricity rather than solutions for single plants; and that incentivise and reward storage, the demand side, smart grids, and technical flexibility in general via capability markets at a system-wide level (Gottstein 2011; Gottstein & Skillings, 2012; Hogan, 2012; Baker & Gottstein, 2013; Keay-Bright, 2013). Such regulation must encourage and help to create large, liquid markets with the ability to aggregate services across large balancing areas, including through transmission and storage investments, interconnection and inclusion of the demand side, which can mitigate internal congestion and constraints, which otherwise usually lead to wasted renewable electricity or enforced curtailment of demand.

The European target market model, mentioned earlier in this section, aims to create an efficient European energy system where the optimal balance of maximising 'local' energy as well as system wide operational attributes is reached. It is reasonably clear what the goals of individual Member States should be for their market rules and incentives. Implementing the rules and incentives which deliver the type of markets will be more or less difficult for the different Member States depending on their geography and natural resources; the state of development of their energy systems; and their institutional and political arrangements (Lockwood *et al.*, 2013). Many European countries have already significantly moved towards the target market model – for example, Germany, Denmark, Spain, Italy, Austria, Sweden, Norway and Portugal. There are a great many lessons, and examples of best practice, that can be learnt from these European countries and elsewhere in the world (for example, US and Australian regional markets).

Increasingly individual Member States are being affected by other Member States policies. For example, large German utilities no longer wish to invest in nuclear power because of the German decision to shut down all nuclear power plants. These types of cross-Member State impacts can only increase further and all countries, including the UK, will find themselves increasingly driven towards market rules and incentives which fit with wider European policies.

4.6 Energy prices and bills

by Rob Gross and Paul Ekins

The cost of energy, to businesses and households, is a major source of public debate in the UK. This section discusses some of the factors that feed into these costs, with an emphasis on their international drivers and implications. Many of the factors that influence the costs of energy for UK consumers are at least partly international in nature. Fossil fuel markets are global or regional, and the costs of supply and demand side technologies and measures are subject to international drivers. Furthermore, as noted in section 4.5, many of the utilities that dominate UK electricity and gas markets are international – and their strategies are not solely determined by the dynamics of the UK energy market. The section also returns to the theme of innovation (following on from section 4.3) and discusses one of the most important future drivers of energy bills: the costs of low-carbon electricity generation technologies.

The affordability of UK energy

The present and potential future cost of decarbonising UK energy has been the subject of much public debate and some confusion. The confusion, at least, has been unnecessary because the Committee on Climate Change (CCC) has set out very clearly (CCC, 2012) the relative impact of different factors that have contributed to recent electricity and gas bill increases, and how their recommendations for future decarbonisation are likely to affect bills to 2020. DECC has conducted a similar analysis, which reaches broadly similar conclusions (DECC, 2013b).

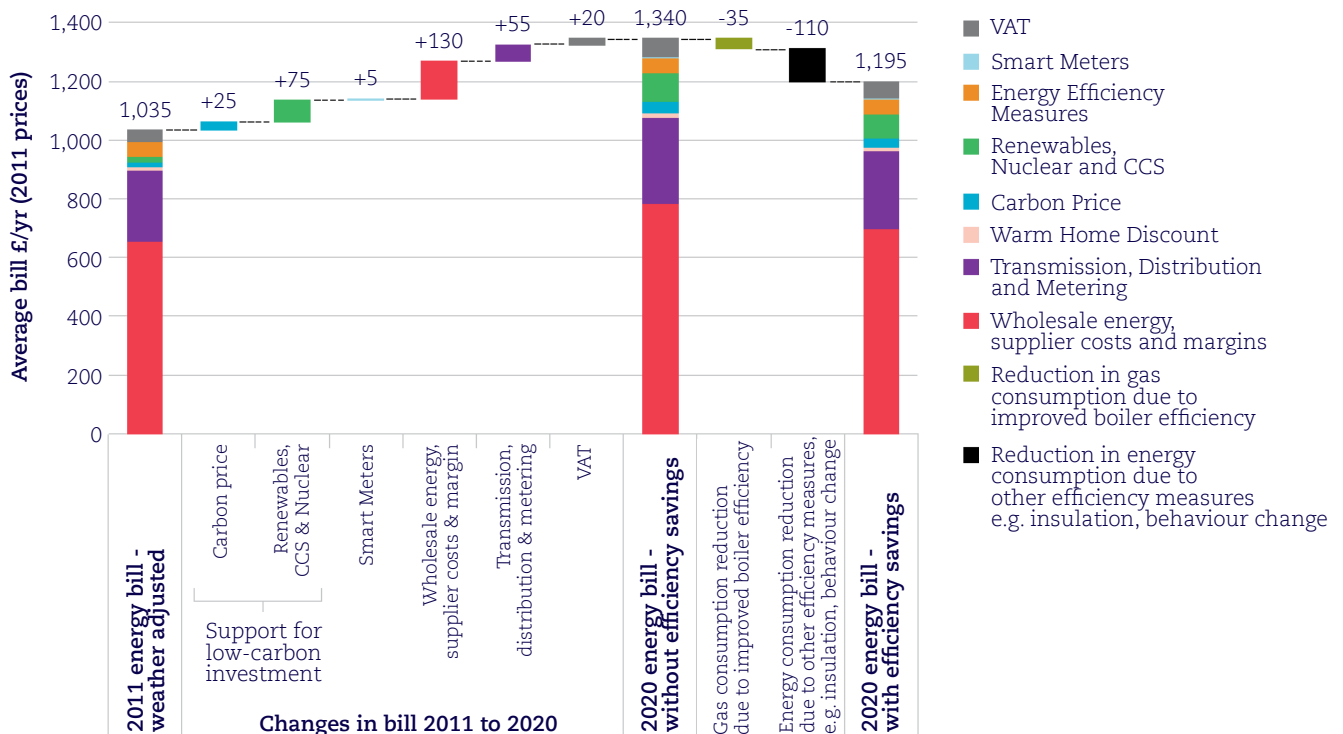
The CCC analysis is illustrated in Figure 4.3, which breaks down the average dual-fuel bill (for the 86 per cent of UK households who are connected to both the electricity and gas networks) into the different components of which it is comprised. This shows that in 2011 over 60 per cent of such bills derived from wholesale energy and supplier costs, over 20 per cent came from transmission, distribution and metering, and just 4.5 per cent (£45) came from investments in energy efficiency, which may be presumed to have reduced bills below what they would otherwise have been, and 3.5 per cent (£35) came from support for low-carbon energy supply, mainly renewables. A significant proportion of current energy costs are therefore not solely within the control of UK policy makers or UK-based energy companies. As noted above, fossil fuel prices are partly determined by international markets. The costs of current and new energy technologies depend partly on international factors such as the extent of deployment in other markets, innovation by international firms and currency exchange rates.

The CCC further estimates that by 2020 support for low-carbon supply (in this case renewables, CCS and nuclear) will have added a further £100 per household per year, as shown in Figure 4.3, with wholesale and supplier costs having increased

by £130 and transmission and distribution costs (including costs associated with upgrading the electricity grid and providing back-up generation to support more intermittent generation) having added a further £55, while it is estimated that energy efficiency investments over this period will reduce average bills by £145 below what they would otherwise have been. Clearly these projections are subject to a number of uncertainties – particularly the future trajectory of electricity generation costs (see later in this section), the price of fossil fuels (particularly natural gas – see section 4.2) and the extent of progress with energy efficiency (see section 4.1). But, given the warnings of climate science, £135 per household per year (the 2011 plus the 2020 costs) does not seem an excessive amount for a relatively rich country like the UK to pay to make a fair contribution to preventing dangerous man-made climate change.

The CCC (2012) report provides a similar analysis for industrial energy costs as it does for households, with broadly similar results. However, it acknowledges that, while these average costs may be affordable for most households and businesses, without greatly affecting their welfare or competitiveness, this may not be true for households vulnerable to fuel poverty or energy-

Figure 4.3. Change in Average Residential Energy Bill – Gas and Electricity (2011 and projected in 2020)



Source: Adapted from CCC, 2012

intensive sectors. Households in this category and businesses in these sectors may therefore need special arrangements to ensure that the former can get access to the energy they need to keep warm, and the latter can continue to compete internationally, at least until such time as it is clear that energy-intensive sectors outside the European Union (EU) are facing similar carbon emission reduction costs to those prevailing in the EU.

Case study: forecasting the costs of low-carbon power generation

Many analyses of the costs of decarbonisation, including analysis conducted by the CCC, present an expectation that the costs of low-carbon technologies will reduce through time. Yet since the mid-2000s the price of building power stations in the UK has gone up – for conventional gas power stations and some (though not all) renewables. Estimates of the expected costs of building new nuclear and carbon capture and storage plants also increased (Gross *et al.*, 2013). Many of these increases in costs and prices were not anticipated and stand in sharp contrast to a widely shared view that costs tend to fall over time, particularly for emerging technologies.

There is a rich international literature on the sources of cost reduction in all technologies, and how best to estimate future cost-trends. The principal approaches can be characterised as ‘engineering assessment’, and ‘learning’ or ‘experience’ curves (e.g. Klaassen *et al.*, 2005; Neij, 2008). Engineering-based approaches offer advantages for early stage technologies with very limited market exposure, since the absence of historical cost and deployment data militates against the use of experience curves. The potential to consider sources of cost reduction ‘parametrically’ – to break down the costs of a technology into a set of component parameters – also allows for sensitivity to key cost changes to be assessed. Engineering assessments may also help to identify discontinuities or innovations that learning curves cannot anticipate.

Learning curves chart the relationship between market growth and cost reduction, an empirical phenomenon that has been identified for technologies in numerous sectors of the economy. The literature both applies learning curves to particular technologies and discusses their usefulness and limitations. Some complexities associated with learning curves include: whether learning rates vary through time and as technologies mature; the presence of ‘cost floors’; the difficulties associated with projecting deployment; divergent costs and prices; system

boundary issues; and alternative sources of learning (such as learning by researching).

A recent UKERC report on electricity generation costs conducted detailed case studies of several technologies: nuclear power, gas-fired combined-cycle gas turbines (CCGTs), carbon capture and storage, onshore and offshore wind and solar PV (Gross *et al.*, 2013). It concluded that the costs of electricity generation can indeed fall through time and as deployment rises. However, market growth is a necessary but not sufficient condition for learning and cost reduction. There are many dimensions involved in both projecting future costs and creating the conditions for costs to fall. The literature highlights the learning potential of spill-overs from research, indicating that continued attention to R,D&D (see section 4.3) is an essential accompaniment to market enablement.

Fuel and commodity prices, which are partly driven by global markets, can also have large impacts on costs: these are largely unanticipated by most cost forecasters. Escalations in the prices of both fuels and essential raw materials overwhelmed downward cost trends previously seen in several technologies and anticipated in others. In addition, cost reductions from learning can be overwhelmed in the short term by supply chain bottlenecks, build delays and ‘teething troubles’ as new technologies are going through their early stages of development. There are historical precedents for technologies deployed in the power sector to demonstrate cost increases before supply chains and learning from experience are firmly established.

Because of these and other factors, cost reduction projections are difficult and challenging. Analysts and policy makers should not be surprised if forecasts turn out to be wrong. However, projections do need to make uncertainties and assumptions clear. In particular there is a need to make a distinction between different types of uncertainty, and recognise that some categories of uncertainties cannot be resolved. Some uncertainties are exogenous, inherently unpredictable and may exhibit high volatility. Others are endogenous, ‘known’ and therefore lend themselves more readily to future projection.

Despite uncertainties, recent studies of energy technology costs show improved ‘appraisal realism’. The scope of cost estimates (for example what is and what is not included) and the assumptions regarding other key variables (such as the discount rate) tend to be well documented in recent analyses undertaken for the government and bodies such as the CCC.



Oilseed rape is widely grown for biofuel production, which is traded internationally.

4.7 Ecosystem impacts of energy technologies: the global impacts of UK energy choices

by Rob Holland

The last few decades have seen a growing recognition of the contribution that the natural world makes to human wellbeing through the provision of what are termed ecosystem services. Commonly grouped into four categories (provisioning, regulating, supporting and cultural) ecosystem services flow from the world's natural capital, that comprises the living and non-living components of nature. These ecosystem services have significant value, both in terms of their monetary worth and through benefits to the physical, mental, spiritual and emotional wellbeing of individuals and to society.

Major studies such as the Millennium Ecosystem Assessment (2005) and the UK National Ecosystem Assessment (UK NEA, 2011) have highlighted the pressures that many ecosystem services are under. With the setting up of the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), an institution comparable to the IPCC, the international community will increasingly be required to take action to both address greenhouse gas (GHG) emissions and the degradation and loss of biodiversity and ecosystem services. It is within this context that the implications of differing energy technologies and future strategies for ecosystem services need to be examined.

The unifying theme that emerges from such an examination is the need to consider both the national and international implications of energy policy on the provision of ecosystem services. Analysis using consumption-based techniques and life cycle assessment has demonstrated that failure to account for impacts beyond national borders may lead to a significant underestimate of the true implications of UK choices of energy technologies for ecosystem services globally (Barrett *et al.*, 2013; CCC, 2013; Scott *et al.*, 2013). These assessments, together with a growing literature that has emerged in recent years, suggest that developing countries may be most significantly affected by demand pressures from overseas, yet it is within these developing countries that the greatest reliance on ecosystem services may exist.

The relationship between energy technologies and ecosystem services has been a major focus of work for UKERC (see review in Hinton and Holland, 2014). To explore the global implications of energy technology four contrasting energy systems (nuclear, gas, wind and biomass to CHP) were examined using an ecosystem services assessment method based on systematic reviews and expert knowledge (see Papathanasopoulou *et al.*, in prep). These technologies were chosen as they feature strongly in many scenarios of UK energy futures, and represent a range of carbon emission and other environmental intensities that encompass both the marine and terrestrial environments.

The analysis provided a number of insights for the UK energy sector. In particular, while much of the published research focuses on the fuel cycle or operational stages, which tend to take place in the UK, such information as exists on upstream activities (associated with extraction and processing of raw materials for construction of infrastructure) suggests that these have significant impacts on ecosystem services, with much of the activity and associated impacts being outside the UK.

Linking such findings to future energy scenarios provides a mechanism to explore the implications of energy policies for the provision of ecosystem services, and ultimately the impacts that such choices will have on individuals and society, both in the UK and more widely. Across the technologies examined, the stage in the life cycle, and the location where this activity is occurring, define the impact of each technology and so represent key factors to be incorporated in the decision making process. The increasing availability of global geographic data, and models describing the flows of goods and materials around the world, present real opportunities to incorporate such knowledge in the decision making process, so contributing to the sustainability of energy production.

As the perceived value of ecosystem services differs among individuals and communities, understanding the impact of different energy strategies represents a major challenge, and one that has profound implications for human wellbeing and for the decision making process. Exploration of future energy scenarios was based on broad-brush global patterns of impacts, with an outstanding challenge being to refine our understanding down to sub-national scales. For example, research that traced one supply chain, that of Brazilian ethanol supplied to the UK, demonstrated the importance of including the social context for understanding implications of technologies.

Social life-cycle assessment revealed significant benefits within the producer region in Brazil and negative implications for consumers in the UK, challenging many common assumptions associated with this technology. Such work demonstrates that combining community knowledge with coarser-scale understanding of the potential impacts of energy technologies on ecosystem services can provide a powerful tool to guide policy, and should increasingly be used in the energy debate.

Energy technologies are incredibly diverse, and this diversity interacts with regional variations in climatic, social, political and economic conditions to affect the sustainability issues experienced. Although implications for climate remain a key driver shaping global energy policy, work highlighted here demonstrates the importance of considering the full range of ecosystem service consequences when developing future energy strategies. Given the importance of these services for human well-being, failure to do so may lead to a significant underestimate of the true implications of choices of energy technologies.

As impacts may often be displaced overseas, with the potential to affect individuals and communities with high reliance on ecosystem services, there is a compelling case to assess impacts of energy production in a way that considers the global context. The techniques that such work highlights are amongst a suite of emerging tools that enable the global costs and benefits associated with different energy pathways to be examined and more informed policy guidance that can consider these issues to be produced, in turn allowing improved strategies to meet future energy requirements to be designed, which reduce overall social and environmental costs.

5

Conclusions and Policy Responses

by Paul Ekins and Jim Watson

UK energy policy has been extraordinarily innovative over the past two decades, as the imperatives associated with the energy trilemma have come to be perceived as increasingly pressing, and the solutions increasingly difficult to negotiate. This brief concluding section can do no more than hint as to how government might seek to address the various challenges and issues discussed above, with the policy directions suggested needing much further development. In what follows the three elements of the trilemma are discussed in turn. The order of their discussion does not represent their priority, because one of the features of the trilemma is that, as will hopefully emerge from the discussion, either all three elements will be successfully addressed, or none of them will be.

Decarbonisation

The Committee on Climate Change (CCC) has, on a number of occasions, called for a 'step change' in policy ambition on carbon emission reduction (e.g. CCC, 2009; CCC, 2012) if its carbon budgets, and the overall statutory 2050 carbon emission target, are to be met. While UK carbon emissions, at least if those emissions arising from the products the UK imports are ignored, have certainly fallen substantially since 1990, the major causes have been the substitution of gas for coal for power generation in the 1990s, the recession following the financial crisis in 2008-09 and, in some cases such as household energy efficiency, the impact of government policies. However, the CCC's call for a step change in policy ambition is still valid.

First, the policies need to ensure that the near-term targets to which the UK is legally committed, namely the second and third carbon budget through to 2023, and the 2020 renewables target, are actually achieved. The signs here are reasonably hopeful, but achievement of the renewables target depends crucially on the success of the continuing Renewables Obligation (RO), the Contracts for Difference (CfD) feed-in tariffs that will take over from it in 2017, the Feed-in Tariffs (FiTs) for smaller-scale generation, and

the Renewable Heat Incentive (RHI), actually delivering the renewables deployment for which they were designed. Apart from keeping the level of incentive under review, to ensure that it is adequate, but not excessive, the government needs strenuously to avoid giving conflicting signals as to future policy direction, or adopting confusing or inconsistent policies. If £100 billion or more private investment is required in the UK energy system, as is sometimes estimated, then government will need "to provide the support and policy certainty needed" (HMT, 2013). While significant progress has been made in recent years – particularly with respect to renewable electricity deployment – there is a very long way to go.

Because the renewables target is expressed as a percentage of energy demand, reducing this demand through efficiency measures, while countering the rebound effect, will reduce the quantity of renewables that need to be supplied for the target to be met. It will also reduce the need for other low-carbon technologies to meet electricity, heat and transport demand. Because, as widely agreed, increasing energy efficiency is cheaper than providing new sources of energy supply, and because energy efficiency actually reduces the costs of delivering a given level of energy service, the greater the contribution to meeting the target that comes from energy efficiency, the lower will be resulting increase in energy bills.

By reducing the quantity of energy required, energy efficiency also contributes to increasing energy security, thereby showing itself to be one of the few means of positively addressing all three components of the trilemma. In this context, the government decision at the end of 2013 to slow down the rate of installation of household energy efficiency measures was perplexing. If it was felt politically essential to relieve the pressure on energy bills, then it would surely have been possible within the overall total of public spending to have found an extra £1 billion per year of investment in the UK building stock in order to reduce its energy demands into the long-term future.

Security

As discussed in section 2 of this report, energy security is perhaps the most complex dimension of the energy trilemma. That makes policies to maintain or strengthen energy security particularly challenging. One problem for policy makers – or indeed for individuals and communities – is that the potential risks to energy security are numerous. Some risks are international, and are often outside the control of government and other actors in the UK. In principle, risks originating from within the UK are more amenable to control. But in practice, they can be equally hard to predict.

Policy and industry discussions of UK energy security tend to focus on two issues: the possibility that the UK will not have the necessary infrastructure – mainly but not only power stations and transmission and distribution networks to distribute their electricity – to provide energy to consumers when they need it; and the possibility that the UK will not be able to import the primary energy it needs for power generation, heat and transport. While this focus is understandable, it is partial.

As discussed in section 4.2, UK gas security is critically important for the UK – and is likely to remain so for the foreseeable future. Yet there is much less attention to the low levels of gas storage in the UK than there is on the potential for inadequate electricity generation capacity.

Given the unpredictable nature of energy security risks, it makes sense to pursue a strategy of energy resilience. This means implementing strategies that make the energy system robust to a range of risks, many of which cannot be precisely known in advance.

Three elements of resilience strategies are particularly important. First, policies are required to ensure investment in electricity and gas infrastructures, including power generation capacity and gas storage. Second, policies should encourage diversity in electricity generation and in gas and oil supplies. As discussed in section 4.2, the UK's gas supplies currently include significant amounts of diversity – including a range of sources and supply routes for gas. Third, there should be a strong emphasis on energy efficiency and demand reduction (see above) so that any increases in prices due to energy security risks will have a lower impact on households and businesses.

All three of these strategies imply a major role for government. Investment in sufficient electricity generation capacity – including a diverse mix of technologies and fuel sources – can only be addressed if policies are in place to ensure that energy companies can earn the going return from investments in new generation plant. Similarly, if the UK is to increase the amount of gas storage capacity, government will need to provide gas companies greater incentives to invest.



The current turmoil surrounding energy companies and markets hardly gives confidence on this score, particularly for electricity. This is contributing to tighter capacity margins that could be problematic if the winters of 2015-16 or 2016-17 are really cold. The capacity mechanism in the Energy Act 2013 is intended to reassure energy companies that their existing or new plants (particularly those that are gas-fired) will be economically viable. However, the mechanism will not have an impact until later this decade – and National Grid has had to step in with short-term measures in the meantime.

Current market conditions for gas-fired generation are not propitious, with cheaper coal squeezing out gas (and increasing carbon emissions) on the one hand, and zero marginal cost renewables, when available, doing the same on the other. Of course, the rapid advances in renewables deployment, and their zero fuel costs, should be celebrated. They can have a positive impact on energy security where they reduce the need for fossil fuels. But intermittent renewables such as wind power can also lead to new energy security challenges, though only when they account for a more significant share of the electricity generation mix than they do now (see section 4.5).

It is often argued that domestic energy sources are likely to be better for energy security than those that are imported. While the empirical evidence for such claims is thin, arguments for UK-based energy resources and infrastructures are often made in these terms. There are, of course, some advantages to the UK economy of reducing imports of fossil fuels due the impact on the balance of payments. However, it is important to remember that such imports sometimes bring economic benefits by allowing UK consumers to access cheaper resources from abroad and/or by improving the diversity of supplies.

Such arguments have come to the fore recently in the debates about shale gas. As discussed in section 4.2, whether the UK becomes a major producer of shale gas is currently very uncertain. In principle, UK shale development could help strengthen UK energy security by diversifying the sources of gas for UK consumers – but it is unlikely to have a significant impact on energy prices and bills because the UK is closely integrated with the large European gas market. However, shale gas is extremely controversial in the UK. As this report has argued (see section 4.4), UKERC's research has found that the development of new sources of fossil fuel such as shale gas could conflict with one or more underlying values about the kind of energy system publics wish to see.

A key lesson from this research is that any plans to develop new forms of energy such as shale gas should not be taken for granted by government. They should be subject to genuine consultation and public engagement – and should be discussed in the context of broader energy system change.

Affordability

Low-carbon energy is currently more expensive than fossil fuels, although the price gap has recently narrowed substantially for, especially, onshore wind (in respect of the wholesale price) and solar photovoltaics (in respect of the retail price). For this price reduction to continue, and for it to spread to other technologies such as offshore wind, the widespread deployment of these technologies will need to be sustained.

Inevitably, this will put costs on energy consumers or taxpayers in the short to medium term. But, as noted above, the projected costs associated with low-carbon energy are estimated to be only around £135 per household per year in 2020, about the same as the average house insurance, as the current Chairman of the CCC has pointed out. As section 4.6 explains, this estimate depends on a number of assumptions, not least that government policies for energy efficiency will be strengthened. But viewed as insurance against the risks associated with climate change, most recently expressed by the IPCC in its report on projected climate change impacts (IPCC, 2014), this should be considered to be very good value.

For poorer households and trade-exposed energy-intensive businesses, however, the extra costs of low-carbon energy may represent a significant challenge, and this challenge needs to be seriously assessed and properly addressed. The means of doing this effectively, and without undesired unintended consequences, are likely to be complex and the details cannot be explored here. It is certain that energy efficiency measures will be a major part of the solution, as noted above, as will direct reductions of energy bills for vulnerable households (the Warm Home Discount). For businesses, rebates with Climate Change Agreements will also continue to be important. There is considerable international experience in this area which can inform UK policy.

It should be emphasised that the affordability challenge is likely to be time-limited if current plans for a low-carbon transition are realised. 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 added to current energy bills could come to be regarded as one of the best investments in both secure and affordable energy that this country could make. As this would also mean the UK making a fair contribution to reducing global carbon emissions and thereby mitigating climate change, these investments would in addition be globally beneficial beyond the UK. The investments would mean that the UK is playing its full part in global efforts to reduce emissions. It would also be an act of global leadership, and would substantiate the aspirations of successive governments for the UK to make the transition to a low-carbon society.



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