From: [redacted]
To: Cleve Hill Solar Park
Cc: [redacted]
Subject: Deadline 3 - Response to discussion on Need
Date: 31 July 2019 12:32:13
Attachments: [redacted]

Dear Hefin,

Please find attached an additional submission on Need, together with supporting information. We hope to have the opportunity to discuss this at a further hearing on this topic in September.

There is also some information about the 15% loss of energy when panels are positioned east-west rather than south from the Sheffield Solar website: https://www.solar.sheffield.ac.uk/panel-data/comparison-of-east-west-arrays/ .

Please let us know if you require any further information.

Kind regards,

Lut and Marie

Response to discussion at the Special Issue Hearing on Need
Dr Ralitsa Hiteva
Energy expert for GREAT
July 2019

Several key claims made in the Statement of Need which were then developed or subject to comments from the Applicant during the special issue hearing are unfounded. This short document is intended as a written reply to those claims. I would like to highlight the following points:

***Firstly*, there is no need for large scale solar PV to bridge a gap in supply in the UK in the immediate, medium or long term**. UK policy documents and energy institutional reports such as the CCC's "Net Zero report" (2019); and the two most recent Future Energy Scenario's reports by the National Grid (2018; 2019) are consistent in highlighting the importance of small-scale solar PV, at household and community level. Furthermore, the CCC report (2019, p.157) points out that scenarios with significant emission reductions (discussed in Chapter 5) involve deploying large scale solar PV in other parts of the world, where the cost will be lower and the technology will be more efficient, because of land availability and higher levels of solar irradiation.

The most up-to-date scientific evidence on energy demand clearly shows that UK energy demand has been steadily decreasing and is projected to continue to do so at a rate which places it as a "first fuel". The Aurora report from May 2019 (page 10, which uses National Grid Initial Transmission System Demand Out-turn data) puts the reduction in energy demand at 21% over the past 10 years. This means that meeting energy demand will increasingly be the result of a combination of energy demand management, flexibility of the energy system and renewables such as offshore wind, with high load factor and for which the UK has a natural environmental disposition. Investment in small-scale solar PV plays a key role in both energy demand management and flexibility.

***Second*, large-scale solar PV such as the Applicant's proposed project will block grid capacity and reduce diversity of the renewable mix at the distribution level.** The Applicant's team argued for the importance of a diverse mix of renewables being developed and argued that large-scale solar PV projects (such as CHSP) are part and parcel of such diversity. Large-scale solar PV (albeit at a smaller than the proposed Cleve Hill capacity) has been part of the renewables mix so far (while the case for renewables in general was being made). However, with the increase of renewable capacities installed, grid constraints mean that the strategic emphasis across the wider industry has shifted towards more self-generation from domestic, commercial, industrial, and community solar PV projects and offshore wind. This shift is reflected in the withdrawal of the Renewable Obligation and Feed in Tariffs for large scale solar PV in the UK. Subsidised large-scale solar PV capacities already in operation will continue to contribute towards meeting the energy need for the UK, but encouraging new large-scale PV projects is not an energy industry and policy focus. If diversity is important in the future mix of renewables, the solar PV contribution can and will be from smaller projects than Cleve Hill.

In fact, a large-scale solar PV capacity connected to the grid at the wrong place (a congested part of the transmission and distribution network) and time (when trials for battery storage services providing flexibility to the grid have just started at some parts of the network) will have the opposite effect. It will effectively block a diversity of renewables projects at the DNO (distribution network) level. This argument was detailed in Chapter 7 of the expert report prepared for GREAT, which unfortunately was misinterpreted by the Applicant in its verbal argument. DNOs will only entertain new connections for smaller projects connected at the distribution-level where National Grid has confirmed the impact on the transmission grid. Blocking the transmission grid with a plant such as Cleve Hill will automatically restrict distribution-level connections without significant new works (paid for by the new distribution-connected generators through a "statement of works").

Furthermore, large-scale energy battery storage (such as the one proposed at Cleve Hill) which is not committed to specific demand customers and relies on the Capacity Market is likely to operate at low levels of efficiency because of the significantly lower than expected clearing prices of the Capacity Market for flexibility services.

***Third*, an argument for the project as an example of how large-scale solar PV capacity can "stand on its own two feet" doesn't take into account the cost of transmission and distribution connection and reinforcement, which will be passed on to consumers**. If the proposed project is financially viable (and our argument is that it is unlikely to be, when all costs are taken into account) it will be because the cost for grid reinforcement will be paid for consumers and government. Despite the large costs of transmission and distribution reinforcement which connecting such a large capacity will incur, connection to the grid is presented by the Applicant as non-problematic. For the Applicant these costs are indeed not problematic as they will be passed on to current and future consumers and will be partly covered by government investment which comes in the form of innovation stimulus packages like the Low Carbon Network Fund (£500 million between 2010 and 2015).

Thus, although the generation of large-scale solar PV is subsidy free, its transmission and distribution are not and these costs are "hidden" by current market arrangements. They are obscured from the planning process because while applications for connection are made to and granted by the National Grid at the transmission level, they also create congestion and costs at the distribution level, which need to be addressed by the DNOs. The costs of the project to the distribution part of the grid are as important as those to the transmission part of the grid. The relationship between the three could be compared to that of pollution upstream in a river which is then carried on downstream obstructing the water flow.

A connection offer from the National Grid is not "supportive" of a project. When National Grid makes a connection offer, they do so because they are required to make capacity available (under a statutory obligation to make an offer for connection and to design a suitable connection in the absence of competition on a first come first served basis). An opinion from the relevant DNO (UK Power Networks) is missing and the lack of recognition by the Applicant of the impact of the project on the distribution network is worrying. However, the Applicant is aware of these costs, as evident from the Statement of Need document which concedes that "*Electricity consumers, either directly or indirectly through their energy bills, pick up all of those costs related to market inefficiencies, economic decision making, asset investments, balancing actions, and transmission and distribution system enhancements*".

These costs are inherent to large-scale solar PV projects with battery storage under the current market conditions but are excluded from the economic assessment of the project represented as the Levelised Cost of Energy (LCOE). Furthermore, these costs are in addition to other significant costs to consumers and the energy system stemming from the inefficiencies of solar technology in the UK, its limited load factor and high levels of risk and uncertainty due to lack of policy support, as evidenced in the expert report. Approval of the project will effectively pass on these costs to consumers and the system. The Applicant has argued verbally that National Grid is "supportive": no evidence was provided to substantiate this contention and if National Grid are working with the Applicant on progressing the project, it is because National Grid are required to by statute, not because they consider it is a valuable addition to national generating infrastructure.

***Fourth*, the proposed project is not presenting an important opportunity to work toward developing a more flexible energy system in the UK**. Key energy documents, such as the 2019 National Grid "Future Energy Scenarios" illustrate the importance placed on promoting flexibility at the transmission and distribution level of the system at the short, medium and long-term. However, the battery storage system is not core to the CHSP application: there is limited specific detail about what technology will be used, and there are no concrete plans for its operation (outside of the Capacity Market which has effectively oversupply flexibility capacity from battery storage). Furthermore, the Applicant admitted at the hearing that the project can go ahead without the battery storage, and will likely do so, as flexibility is not part of the economic case of the project. The battery storage element is included to make a more convincing argument for connecting such a large-scale inefficient capacity to a constrained part of the grid but will make a limited material difference to National Grid's requirement for flexibility in managing energy balance and system security.

***Finally*, refusal of the application will not cause the UK to "lag behind" in meeting decarbonisation targets**. In fact, the "Net Zero" CCC report, The Clean Growth Strategy and the National Grid "Future Energy Scenarios" are unanimous that investment in energy demand reduction, engaging consumers with wide uptake of domestic and community scale solar PV, and ramping up of offshore wind capacity is a way forward and least regret option for decarbonisation. The CCC report calls for an additional 35GW of renewable capacity by 2030 to meet the UK decarbonisation target, and the Offshore Wind Sector Deal signed by the Government in May this year will provide for an additional 30 GW of renewable capacity from offshore wind by 2030.

In conclusion, a large-scale solar PV project like CHSP is going to be:

- expensive, risky and inefficient in meeting key objectives of the UK energy system,
- redundant in meeting security of supply,
- expensive and inefficient as a way of decarbonisation,
- counter-productive for decentralisation of energy, and
- will make a limited material contribution to flexibility should it proceed with the battery storage component.

Panel Data

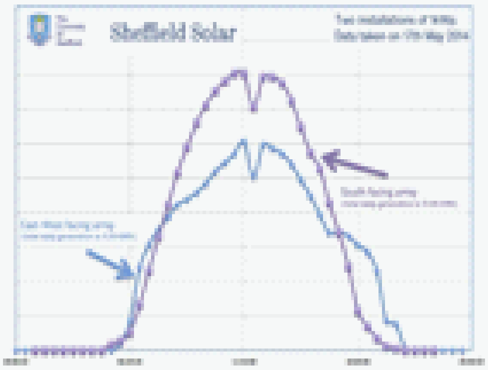
- Azur Space GaAs Double Junction Test Cell
- Azur Space Solar Power Cell
- Comparison of East-West arrays
- Copper Indium Gallium diSelenide (CIGS) ME60 Module
- Fuji 52W Thin Film Flexible Module
- Kyocera KD135SX-1PU Polycrystalline module
- Module offline
- Phono Solar 190 at 13 degrees inclination
- Phono Solar 190 at 30 degrees inclination
- Polysolar PS-CT-Series Transparent Module

Comparison of East-West arrays

In the UK, most of the installed PV panels face due South, in order to maximise the feed-in-tariff. However, this results in a peak generation of electricity around midday, when all solar panels are generating together. In order to reduce this peak generation, it is best to vary the azimuth of the installations, i.e. to encourage the installation of 'off-south' arrays. As an example, we have taken data from two installations within Sheffield Solar's Microgen Database: one faces close to South, the other has two arrays which face almost East and West (arrays are installed on opposite eaves of a roof). The results are shown in the graph below.

The result is that the peak generation at midday is spread more evenly throughout the day. This aids an excess load on a local grid network if many installations are close by, but also generates more useable energy for the household. It should be noted that the total energy generated on that day for both systems was similar, resulting in a similar FIT income. Over an annual period, the generation (and therefore income) will be affected however, due to the reduction of daylight hours in winter. This effect is minimised by the majority of energy being generated in Summer.

Click image to see higher resolution.



Donate your PV Data →

Our Microgen site records PV generation in the UK by collecting data from volunteers.

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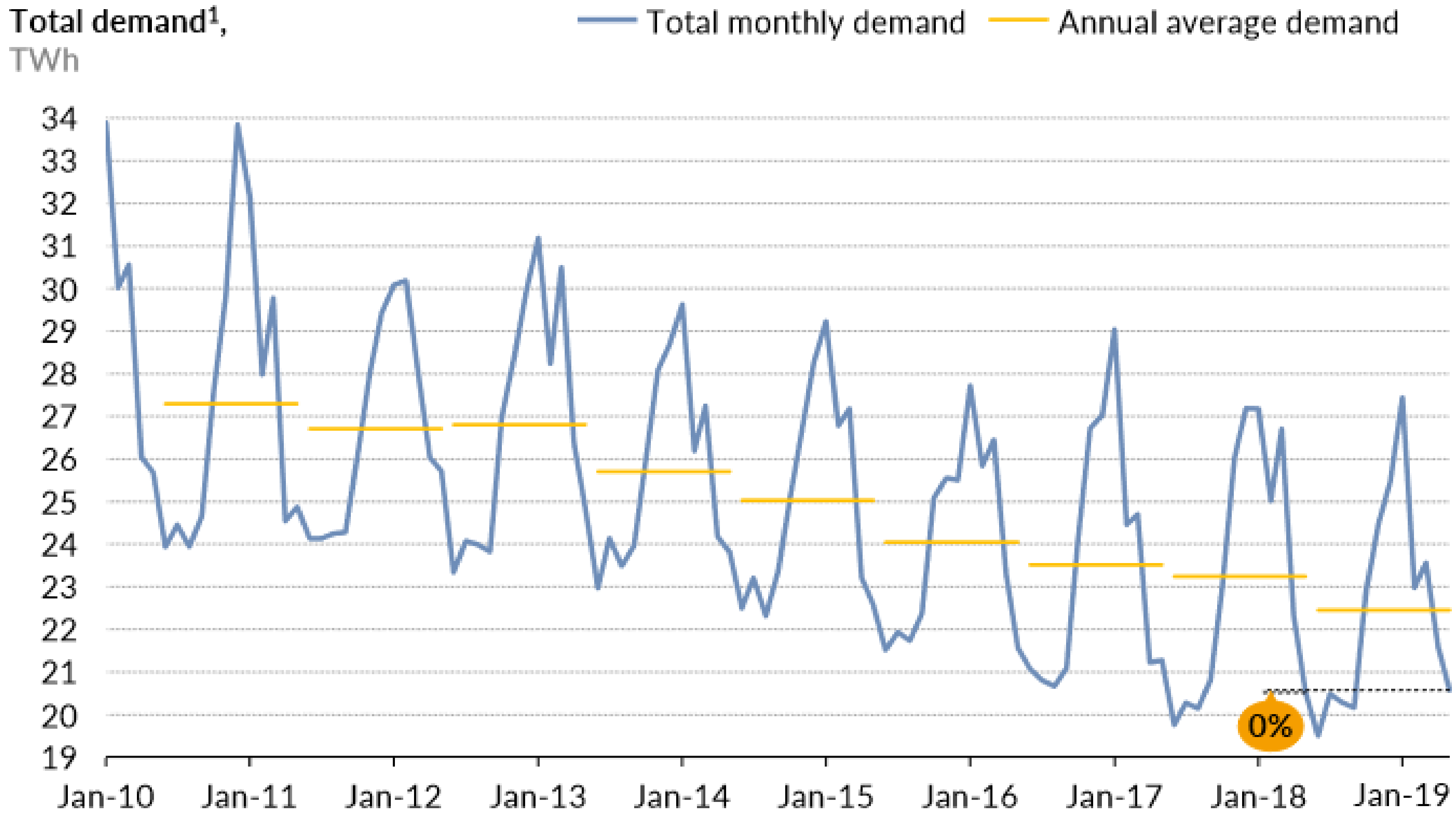
Monthly historical demand on the transmission system



1, Demand data presented here is Initial Transmission System Demand Out-Turn, and includes station transformer load, pumped storage demand and interconnector demand, but does not include embedded demand.

Source: National Grid

Shifting the focus: energy demand in a net-zero carbon UK

July 2019

Editors: Nick Eyre & Gavin Killip

About this report

Reviewers

Sections of the report have been reviewed internally, by chapter authors and the following colleagues in the CREDS consortium: Stanley Blue, Phil Coker, Clare Downing, Mike Fell, Sarah Higginson, Kay Jenkinson, Bob Lowe, Greg Marsden, Elizabeth Shove, Stefan Smith, Steve Sorrell, Peter Taylor and Marina Topouzi.

We are also grateful for comments by external reviewers from Green Alliance: Dustin Benton and Libby Peake; and from the Committee on Climate Change: Ellie Davies, Adrian Gault, Aaron Goater, Jenny Hill and Sarah Livermore.

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Frequently used acronyms

BEIS	Department for Business, Energy & Industrial Strategy
CCC	Committee on Climate Change
DCLG	Department for Communities and Local Government, now Ministry of Housing, Communities & Local Government
DECC	Department for Energy and Climate Change, now incorporated into BEIS
Defra	Department for Environment, Food & Rural Affairs
DfID	Department for International Development
DfT	Department for Transport
DIT	Department for International Trade
FCO	Foreign and Commonwealth Office
HMT	HM Treasury
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
MHCLG	Ministry of Housing, Communities & Local Government

Cover photograph by Erik Odiin on Unsplash.

Introduction to CREDS

The Centre for Research in Energy Demand Solutions (CREDS) was established as part of the UK Research and Innovation's Energy Programme in April 2018, with funding of £19.5M over 5 years. Its mission is to make the UK a leader in understanding the changes in energy demand needed for the transition to a secure and affordable, low carbon energy system. CREDS has a team of over 90 people based at 13 UK universities.

The aims of the Centre are:

- to develop and deliver internationally leading research, focusing on energy demand;
- to secure impact for UK energy demand research in businesses and policymaking; and
- to champion the importance of energy demand, as part of the strategy for transition to a secure and affordable low carbon energy system.

This report

Shifting the focus: energy demand in a net-zero carbon UK is CREDS' first major publication. It builds on research undertaken by members of the CREDS consortium over many years to address the question "What can changes in energy demand contribute to the transition to a secure and affordable UK energy system that is compatible with net-zero carbon emissions?". It examines the most recent comprehensive statement of UK Government Energy policy – the Clean Growth Strategy. Drawing on expertise in the CREDS consortium across the buildings, transport, industry and electricity sectors, the report sets out a vision for the role of energy demand changes and develops detailed recommendations for action.

Shifting the focus: energy demand in a net-zero carbon UK

Foreword by Chris Stark, Chief Executive, Committee on Climate Change

Delivering net-zero greenhouse gas emissions depends critically on changing energy systems. Every analysis, globally and in the UK, shows that there will need to be rapid and extensive change to energy supply and energy demand. The UK has achieved major changes in complex systems before, but not at the scale that the Committee on Climate Change has now recommended to reach net-zero in the UK.

For most people, their main interaction with the energy system is through using energy, at home, at work and in transport. We've become accustomed to these interactions being simple – rarely something that we consider actively – even as the UK has achieved substantial reductions in emissions from electricity supply. As we look forward to a zero carbon future, the technologies that manage and consume energy will change, affecting people's experience and even their behaviour. This makes changing energy demand a controversial topic, but an important one. Consumers must become more engaged in the next stage of the energy transition.

Public support for changing the way energy is used is essential. Reducing energy demand saves money for households and businesses, of course, as well as reducing emissions. And importantly, it can have other benefits – improving air quality, improving our homes and public spaces, and creating employment across the UK.

Over the last 15 years, reduction in demand for energy has been an important contributor to lowering UK carbon emissions. However, in recent years, the downward trend in demand has begun to falter, largely due to weakening of Government policy. Our analysis at the Committee on Climate Change is that stronger policy to reduce demand is urgently needed. And we know that the policies that might influence energy demand are very different to those for supply – policies that are often made outside of Westminster, making this a fascinating public policy challenge overall.

Photo by Andrew Haimerl on Unsplash

I therefore welcome this report from the Centre for Research into Energy Demand Solutions (CREDS). As a major research consortium focusing on energy demand, CREDS brings together many researchers who have individually contributed to the work of the Committee over several years. We look forward to working closely with them over the coming years to better understand the challenges of changing energy demand.

The report draws on CREDS researchers' expertise. It sets out the key changes in energy demand that can contribute to carbon emissions reduction and the other energy policy challenges of the UK. Taking the Government's Clean Growth Strategy as its starting point, it highlights where more specific policies are needed to deliver the Government's ambitions and where ambitions can be increased. It is a welcome contribution to the net-zero debate.

Chris Stark

Chief Executive, Committee on Climate Change

Contents and authors

Report Editors: Nick Eyre, Gavin Killip

Summary of recommendations

The complexity of energy demand means there is no 'silver bullet' solution or policy: a range of policy instruments is required to meet energy policy goals. These involve many sectors, institutions and stakeholders, with a range of different timescales for action. We list a large number of recommendations in this report, and bring them together in Chapter 9. They can be considered under the following six broad headings.

1. Prioritise energy demand solutions

Energy demand change can support all the key goals of energy policy – security, affordability and sustainability – with more synergies and fewer trade-offs than supply-side solutions. For this reason, treating demand reduction as 'the first fuel' is already the policy of the International Energy Agency (IEA) and the European Union. Demand-side solutions also form a key part of implementing zero carbon sustainable supply, through using zero carbon fuels and enabling greater use of variable renewables. In UK energy policy, there has been a tendency to focus on energy supply options rather than a systemic approach. We recommend that this is reversed, and that demand-side solutions are given at least equal weight.

2. Consider and promote all the benefits of demand-side solutions

UK policy with respect to energy demand tends to focus on the benefits of lower carbon emissions and lower bills for energy users, often using the latter as an argument for minimal intervention. Reduced demand, improved energy efficiency, greater flexibility and decarbonised fuels have a much wider range of benefits, notably for health and employment. Addressing energy demand is generally more likely to promote sustainable development than increasing energy supply. As importantly, recognising all the benefits is more likely to motivate action. We recommend that all the benefits of demand-side solutions are considered in developing and promoting policy.

3. Scale up policies that work

UK energy demand policy has featured numerous policy changes in the last decade. In some cases, such as Carbon Emissions Reduction Target, the Carbon Reduction Commitment and the proposed Zero Carbon Homes standard, policy instruments that were well-designed and effective have been modified, or much reduced in scale. This has significantly reduced the effectiveness of UK energy policy. We recommend greater consistency in demand side policymaking and, in particular, scaling up policies that have been shown to work.

4. Develop long term plans for demand-side innovation

There has been a tendency in policymaking to see the demand side as having the potential to provide quick wins, but not to have a fundamental role in the transition. Our analysis indicates that this is unhelpful. Energy demand reduction, flexibility and decarbonisation will need to play a critical role and this should be recognised in energy innovation policy. We recommend that Government should develop long-term plans for demand-side innovation.

5. Build effective institutions for delivery of demand-side solutions

Energy using activities are diverse, and therefore the policy agenda set out above involves influencing a wide range of stakeholders, including both specialists and the general public. Doing this effectively will require a major increase in activity in demand-side policy delivery in Government at a range of levels. This will require better coordination across departments, with more capacity and clearer responsibilities for specialist agencies, devolved governments and local government departments. We recommend that Government should reform the existing delivery structures and develop an institutional framework designed for delivering the energy transition.

6. Involve a wider range of stakeholders to build capacity across society

A transformation in the way that energy is used needs to be led by Government, but cannot be delivered by Government alone. There is some good practice on which to build, but there needs to be a concerted effort to engage, enthuse and empower stakeholders across business and civil society. We recommend that Government should develop a strategy for involving a wider range of stakeholders to build capacity across society.

1. Introduction: why energy demand is important to a low carbon transition

Nick Eyre (University of Oxford), Tim Foxon (University of Sussex) and Gavin Killip (University of Oxford)

The aims of this report

This report sets out the critical role that needs to be played by changes to energy demand in delivering the ambitious goals of UK energy policy – a secure and affordable, low carbon energy system. Our analysis draws on current knowledge from the UK energy demand research community. We take as our starting point the ambitious goals of UK Government policy set out in the Clean Growth Strategy (BEIS, 2017), the Government's most recent statement on the energy transition. In particular, this report considers the aim to accelerate the pace of clean growth, and we seek to build on the comprehensive, quantitative analysis of the Strategy done by the Committee on Climate Change (CCC, 2018). We agree with the Strategy that major improvements in energy productivity in businesses, transport and homes are crucial to achieving this goal. We set out a broad vision for how this might be achieved, and show that this requires attention to technical, social and institutional factors that drive energy demand. We argue that a stronger focus on demand will be required to address the greater action implied by a net-zero carbon target (CCC, 2019). We set out recommendations on the changes in policy required to deliver the goals of the Clean Growth Strategy, in relation to energy use.

The key role of energy demand

Energy use has been a key driver of economic and social development, by enabling production and consumption of goods and services and allowing people to lead comfortable and enjoyable lives. The industrial revolution began in Britain in the late eighteenth century, by harnessing first water power and then fossil fuels to provide heat and power. Energy use has driven the development of modern societies, and is critical to most aspects of our lives in homes, businesses and transport. Figure 1 shows the breakdown of energy use in the UK – broadly an even split between households, workplaces (industry and other) and transport.

Photo by Christopher Burns on Unsplash

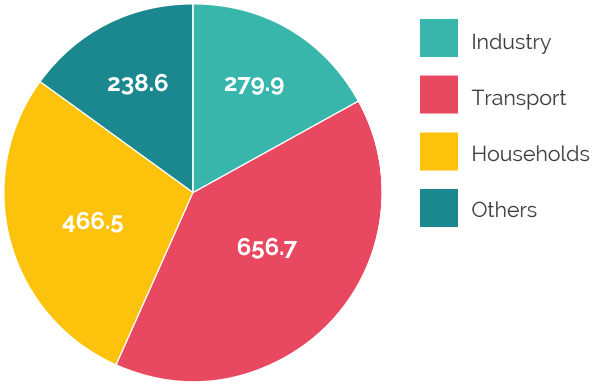

Figure 1: Energy use in the UK by sector in 2017 (TWh). CREDS calculations based on BEIS (2018)

However, the widespread use of fossil fuels has also driven major environmental problems, which has required action to mitigate by households, industry and Government. Although the worst excesses of urban air pollution have been addressed in industrialised countries, energy related pollution remains a major cause of ill health, even in the UK. In addition, a range of evidence has shown that stabilising the global climate will require the elimination of fossil fuel use within a few decades (IPCC, 2014, 2018). The UK has led the world in adopting a strategic approach to doing this through the 2008 Climate Change Act. This sets progressively tighter carbon budgets for national emissions for successive five-year periods, at least 15 years in advance. Good progress has been made to date, with a 43% reduction in emissions since 1990 by 2017. However, the Clean Growth Strategy provides a clear warning that more needs to be done: "In order to meet the fourth and fifth carbon budgets (covering the periods 2023–2027 and 2028–2032) we will need to drive a significant acceleration in the pace of decarbonisation and in this Strategy we have set out stretching domestic policies that keep us on track to meet our carbon budgets" (BEIS, 2017, page 9). At the UK Government's request, the Committee on Climate Change has recently concluded that even more stringent budgets will be needed as 2050 is approached, for the UK to reach net-zero greenhouse gas emissions and make its fair contribution to the goals of the Paris Agreement (CCC, 2019).

Addressing this challenge of achieving further and faster carbon reductions will require both widespread deployment of clean energy sources to replace fossil fuels, and reducing total energy demand, whilst continuing to deliver the services that people and businesses need. This requires much better understanding of the role of demand-side solutions in mitigating climate change (Creutzig *et al*, 2018).

Changes to the way that energy is used are critical to the development of a secure, affordable and sustainable energy system. In recent decades, more than 90% of the progress in breaking the relationship between carbon emissions and economic growth globally has come from reducing the energy intensity of the economy (IPCC, 2014). By comparison, reducing the carbon emissions per unit of energy has, to date, been a relatively minor effect. Similarly, in relation to energy security, the International Energy Agency (IEA, 2016) showed that, in leading energy-importing countries, energy efficiency improvements have played a major role in reducing dependence on imported fuel.

These trends have been seen strongly across northern Europe, including the UK, where the decoupling of energy use and economic activity has been reflected in absolute reductions in energy demand. Primary energy demand in the UK has fallen by 20% since 2003. This has confounded official projections made at the beginning of this period, which projected slow but steady energy demand growth (McDowall *et al*, 2014). This decoupling has a longer history, with an annual improvement of the GDP/energy ratio averaging 2.5% since 1970, reducing current energy demand to one third of what it would have been with no improvement.

These changes in energy demand have been driven by a combination of three factors:

- economic restructuring (away from energy intensive manufacturing and towards services)
- technical energy efficiency improvements, and
- a slowing in the growth of demand for many of the services provided by energy.

To some extent, the first of these factors is linked to the movement of manufacturing activity out of the UK, in particular to East Asia. This offshoring of economic activity has reduced UK industrial energy demand; its effect has been broadly similar in scale to that of technical improvements in industrial energy efficiency (Hardt *et al*, 2018). The Clean Growth Strategy aims to halt this trend of offshoring by retaining industrial activity in the UK. This implies that further reductions in industrial energy demand would need to come from technical or process changes that reduce energy demand per unit of material produced, or wider structural changes that reduce the demand for these materials, for example, through a greater focus on resource efficiency.

It is difficult to exaggerate the impact of the historical decoupling of energy demand from economic activity. It has contributed more to carbon emissions reduction than the combined effects of the UK's programmes in nuclear, renewable and gas-fired power generation. It has made energy services more affordable to households and businesses. It has improved UK energy security, both by reducing energy imports and enabling peak electricity demand to be met with less generation capacity. Much of this impact has been driven by public policy. It is recognition of this effect across the world that has led to the International Energy Agency (IEA) to call for energy efficiency to be treated as 'the first fuel' in energy policy (IEA, 2016).

Given this important role of energy demand, it features surprisingly little in public discourse about energy. The importance of demand is recognised in the Clean Growth Strategy, but the UK Government has not published an updated Energy Efficiency Strategy since 2013. Despite the evidence, many people still think that energy demand is inexorably rising and references to 'increasing energy demand' remain common in the mass media. This misapprehension applies even in parts of the energy sector, including, in one case, a serving Government Energy Minister (Carrington, 2015).

Another frequent misunderstanding is that energy efficiency is a short-term issue and that its potential for improvement will soon be exhausted. Historical evidence (NAS, 2010) is that the potential for cost effective efficiency improvement has remained relatively stable over 40 years. As efficient technology has been deployed, technological and organisational innovation has enabled new potential to be developed at broadly similar rates. Some options that are now widely used, such as LED lighting, represent a step-change in efficiency improvement, but were not even considered in analyses done 20 years ago. Energy using technologies and practices are still very far from their theoretical optimum (Cullen & Allwood, 2010). Moreover, as we discuss below, future energy supply-side changes will increase opportunities for improvement.

The Clean Growth Strategy provides a major opportunity to implement approaches to energy efficiency improvement that have already been shown to be effective, either in the UK or elsewhere in the world. This will involve a substantial shift in UK Government policy, which has become less effective in recent years (e.g. Rosenow & Eyre, 2016).

Energy demand in the UK energy transition

Delivering a secure, affordable and sustainable energy system, and particularly the goals of the Paris Agreement, requires an energy transition on the scale, for example, of the industrial revolution. Energy transitions are often described in terms of the change in dominant fuel (e.g. wood to coal, coal to oil), but this is a shorthand. Transitions have always been associated with major shifts in energy-using activities and therefore with wider patterns of economic development and social change (Foxon, 2017). There is no reason to think that the sustainable energy transition will be any different; it will not simply be a shift from unsustainable fuels to renewables, but also a change in how, when and where those fuels are used and what human activities they enable and support. Policy to promote the transition will need to take this into account.

Thus, the energy transition cannot be properly conceptualised without reference to questions about what energy is used for. People and businesses demand energy services (e.g. thermal comfort, mobility and industrial materials) rather than energy *per se*. Total energy demand is a function of this demand for energy services, as well as the efficiency with which that energy is used. The amount of energy needed to meet the demand for any given service therefore depends not only on the technologies used, but also on the wider social systems involved, including the user practices, business models, institutions and infrastructure associated with that service (Foxon, 2011).

This is why understanding energy demand is critical. But it is also complex. Active measures to change the demand for energy services can be controversial. In particular, in international climate negotiations 'demand reduction' can be interpreted to mean reducing the demand for basic services and therefore 'pulling up the ladder' on social development for developing countries. Similar issues apply to people living in fuel poverty in the UK. However, in advanced economies like the UK, improving human welfare no longer relies on massive expansion of energy intensive activities.

Not all consumption is useful: car dependence, unhealthy diets, over-heating and over-cooling of buildings; and use of new, rather than recycled materials, are obvious examples. So reducing the demand for energy services is a part of the agenda for change.

Achieving more significant energy demand reduction needs a focus on both efficiency and service demand. It is estimated that improvements in energy productivity, i.e. economic output per unit of energy used, of at least 3% per annum are needed to help achieve global carbon targets (ETC, 2017) by decoupling energy demand from economic output.

However, in the context of the energy transition, reducing demand is no longer the only issue. As the Clean Growth Strategy acknowledges, there are at least two other demand-side issues which need to be addressed – demand flexibility and decarbonisation of energy sources used at the point of demand.

Variable (intermittent) sources of electricity, such as wind and solar, will play the key role in decarbonising the electricity system, in the UK and globally. This will make balancing electricity supply and demand increasingly challenging. Integrating increasing levels of variable renewable energy focuses attention on temporal issues. A zero carbon electricity system will only be possible if demand is more flexible. Technologies and services for demand-side flexibility will be major growth areas in electricity markets. Demand response (shifting the timing of energy demand) will be important. The Clean Growth Strategy recognises the potential benefits and the role of a smart grid in delivering them. It focuses largely on opportunities based on energy storage, and therefore somewhat underplays the potential role of increasing the temporal flexibility in the demand for energy services.

Most analysis of the energy transition shows that electricity will be a key form of energy supply for heating and transport uses, as well as for power. But there is increasing recognition that it is unlikely to be a complete solution, as some categories of end use, notably industrial processes, freight transport and space heating, are difficult to electrify. In these sectors, other approaches to decarbonisation will be needed using other energy vectors. The best combination of options is not yet clear, and therefore there currently is no convincing storyline for complete decarbonisation. This implies development of solutions that deploy other zero carbon energy vectors and associated storage, notably hydrogen.

These multiple aims for demand change in the energy transition – efficiency, reduction, flexibility and a switch to sustainable fuels – cannot effectively be analysed separately. A sustainable, affordable and secure energy system will require all of them. Figure 2 sets out a simple representation of how we see them contributing to energy system transformation.

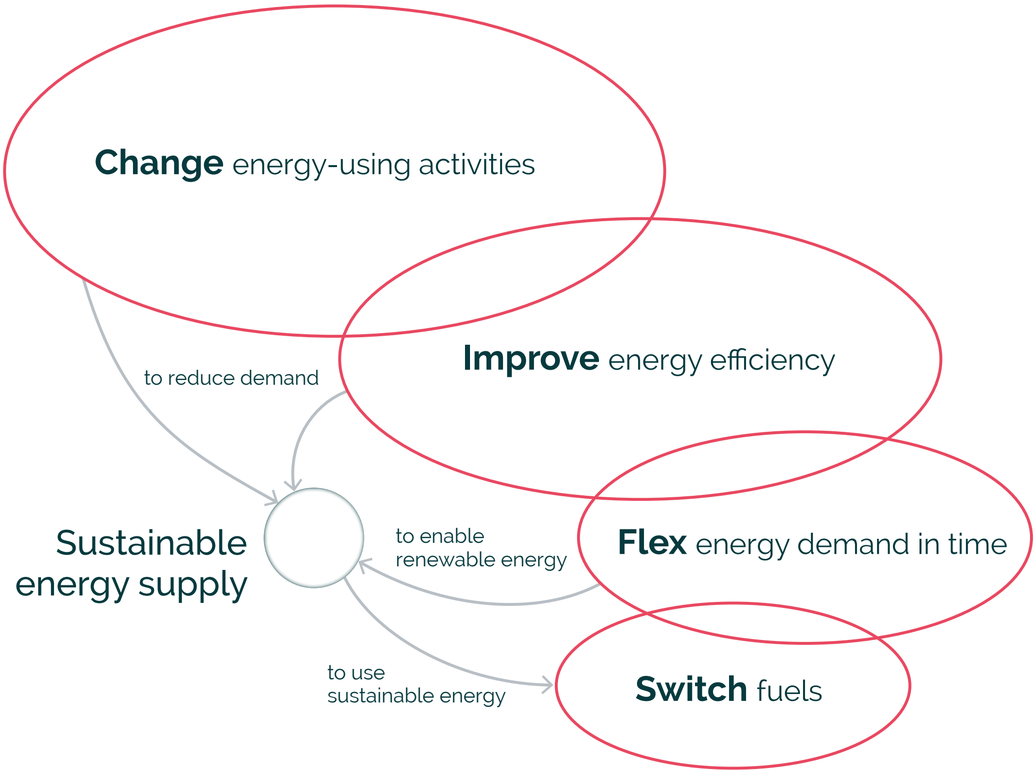

Figure 2. Contributions of the demand side to energy sustainability.

Thinking systemically about the role of energy demand

In the context of this complexity, a systems approach is useful in understanding the role of energy demand in a transition to a sustainable low carbon society. Insights from past energy transitions suggest that systemic change involves not only new forms of energy supply, but also changes in the way that energy is used. In this report, we discuss in more detail the types of change needed in buildings, industrial processes and transport.

In contrast to micro-economic and behavioural approaches that focus on individual responses to incentives, a systems approach focuses on interactions between individual and societal choices and wider systems that both enable and constrain those choices. For example, energy use in a car-dominated system of personal transport depends not only on the technological features of the car, but also on occupancy of vehicles, the choice between car use and other modes and the need to travel (which is influenced by factors such as commuting distance and virtual communications options). In turn, these features and choices depend on wider systemic features, such as car and fuel supply networks, road infrastructures and traffic systems, patterns of land use, institutions and regulations governing car use, engineering skills and knowledge, political power of relevant interest groups, routine practices of users, and wider cultural norms associated with car use and other forms of transport (Geels *et al*, 2012). Changes to these systemic elements combine to create significant changes in energy demand needed to meet mobility or other service requirements.

None of this implies that user decisions do not matter, indeed the recent analysis of the Committee on Climate Change shows that changing technology alone is insufficient for most of the carbon emissions reduction required to reach a net-zero target (CCC, 2019). A systems approach argues that individual choices cannot be considered separately from the socio-technical system in which they are embedded (Schot *et al*, 2016). For example, choices as to whether to make a journey by private car, public transport or by cycling or walking depend on the availability, cost, convenience and safety of different alternatives. While it will require considerable change for socially 'normal' activities to be different in future, there are plenty of precedents (e.g. smoking in public buildings). Thinking systemically about energy supply and demand together points to new opportunities for interventions to achieve the goals of a low carbon, secure and affordable energy system. This report highlights some of these opportunities in relation to meeting demands for energy services in the built environment, industrial processes, mobility and electricity systems.

Innovation

Socio-technical systems thinking also applies to innovation. It is not only about new technology, but also about the context of broader economic and social change. Innovations are only successful to the extent they are consistent with that broader change. The Clean Growth Strategy rightly emphasises the importance of investment in innovation, including to develop new technologies and bring down the costs of clean technologies. Energy innovation often focuses on supply technologies, but there are also major opportunities for innovation to deliver energy and resource efficiency improvements, in industry, buildings and transport, as well as to deploy low carbon end-use technologies.

However, we argue that this needs to be embedded in a wider understanding of the drivers of energy demand and the potential for changes in demand. Much research in recent years has argued for the need to think systemically about innovation and transitions, and that this can inform the difficult policy choices relating to demand reduction, flexibility and decarbonisation. If the goal of innovation is reframed from technological change to how those service demands can be met in a more sustainable way, we need to consider not only innovation in technologies, but also innovation in how energy is used, the business models for providing energy services and the institutional and regulatory frameworks that govern these systems.

Changes in energy use interact with wider social and technological changes, not least those associated with new technological and business opportunities created by smart systems and the digital economy. The increasing deployment of information and communication technologies (ICT) could enable economic value to be delivered in less energy intensive ways, but could also lead to the creation of new service demands (such as on-demand entertainment) that increase energy demand. Greater use of ICT linked to more distributed forms of energy generation could open up new market structures, such as via peer-to-peer energy trading, but this could create challenges for existing regulatory frameworks.

Recent research shows that ICT has large energy savings potential, but that realising this potential is highly dependent on deployment details, user behaviour and indirect effects that could either offset or amplify direct energy savings (Horner *et al*, 2016).

Implications for policy

It is well-established that demand reduction can support all three pillars of energy policy objectives – security, affordability and reductions in greenhouse gas emissions. Improving energy efficiency can play a major role in the goals for productivity, competitiveness and employment that are set out in the Clean Growth Strategy. Indeed, our analysis is that the goals of the Strategy are unachievable without a significant refocusing of policy effort towards energy demand.

Energy demand involves many actors – from households to major corporations and Government; it occurs where we work and where we live, it underpins the goods and services we purchase, the ways we travel and the public services we rely on. So addressing energy demand effectively will involve many technologies and stakeholders. Therefore we endorse the analysis of the Clean Growth Strategy (p59) that the move to a low carbon society needs to be a "shared endeavour between Government, business, civil society and the British people".

Framing the challenge of changing energy demand in this way points to a move away from individualist and incremental policy approaches towards an approach more focused on long-term systemic change. This implies recognising that policy also needs to consider changes in infrastructures, institutions and practices, as well as the traditional instruments of energy efficiency policy such as price incentives, product regulations and information programmes. There are also multiple potential benefits from a greater focus on demand in areas not usually considered in energy policy (IPCC, 2018), for example in cleaner air, more comfortable buildings, less waste and more liveable urban environments.

Government has a critical and unique role in setting the vision for this shared endeavour. The Climate Change Act and proposals to increase the stringency of targets to 'net-zero' provide a good starting point. The commitment of Government, supported by an overwhelming majority in Parliament, sets the framework for the more detailed policy development by Government, but also provides the foundation for action by other actors – for corporate planning, and for the wider public discourse on energy systems and personal commitments.

Policy analysis traditionally relies heavily on cost benefit analysis. In energy, there are good reasons for this, as the energy system is a major, capital intensive infrastructure, with significant cost implications for households, businesses and Government. Limiting the costs of delivering any desired outcome obviously matters. However, many of the benefits of demand reduction (e.g. health) are uncertain and difficult to value, and therefore often excluded from analyses. Moreover, aggregate costs and benefits are not the only issue for two reasons.

First, the distribution of those costs also matters, both because it is an important outcome in its own right, and because perceptions of fairness constrain political feasibility. Secondly, as set out above, changes to energy service demands drive the energy system. These are determined by infrastructures, institutions, preferences and practices that lie outside the usual scope of incremental cost benefit analyses. A more pluralistic approach is required to these challenges.

This report aims to contribute to that approach. The CREDS team looks forward to working further with a wide range of stakeholders to examine how the ideas proposed in this report could be implemented, in order to contribute to the achievement of a sustainable net-zero energy transition.

Report structure

The following sections of the report set out our analysis, based on research evidence, of some key energy demand issues. These are structured along the lines of the major sections of the Clean Growth Strategy in which energy demand plays an important role, as follows:

- **Section 2** considers how we might reduce and decarbonise energy demand in buildings;
- **Section 3** looks at decarbonising industrial processes and using material resources more efficiently;
- **Section 4** covers travel demand and low carbon transport;
- **Section 5** addresses the role of shifting demand as time-of-use becomes more important because of increasing generation from variable renewable sources;
- **Section 6** looks at the challenges associated with demand for, and use of, zero carbon fuels;
- **Section 7** considers the governance and policy approaches that may be required; and
- **Section 8** draws together our conclusions.

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2. Reducing energy demand from buildings

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This chapter sets out the trends and drivers of energy demand in buildings. It also sets out the policy for buildings in the UK and recommendations for government policy and CREDS work.

Energy demand trends and drivers

Buildings are central to our lives because they provide us with shelter and comfort at home, enable us to carry out productive activities at work and to provide other services, such as warehousing. Heating, cooling, lighting and appliances dominate the use of energy in both domestic and non-domestic (commercial and public) buildings.

There are 27 million dwellings and 2 million non-domestic (industrial, commercial and public) buildings in the UK. Together they are responsible for around 698 TWh or 43% of total delivered UK energy of 1642 TWh[1] (BEIS, 2018a), and 29% of UK CO_2 emissions (Committee on Climate Change, 2018).

Energy demand trends for buildings come with several caveats. The weather, in particular external temperature, influences demand, but adjustments to official numbers to take account of this can be hard to interpret. There are also gaps in the official record, and variations in how buildings are categorised, particularly for non-domestic buildings, which can appear as industry, service or 'other'. Also, some energy vectors like electricity are not disaggregated by sector. Disaggregating industrial process use from building use is challenging in some non-domestic sectors. Most importantly drivers of demand such as floor area and heating demand and efficiency have not been consistently monitored and are instead modelled with many assumptions.

However, with these caveats, a number of trends in delivered energy can be identified for both domestic and non-domestic buildings.

1 Original data units (mtoe) have been converted to TWh.

Trends and drivers in domestic buildings

Overall, non-temperature corrected domestic energy consumption was 466.4 TWh in 2017, 8.8% higher than in 1970. Demand reached a peak of 573.4 TWh in 2004 and has since fallen by around 19%. Natural gas and electricity dominate domestic energy consumption with 64% and 23% respectively, with the remainder coming from solid fuels, biomass, petroleum and external sources of heat.

Gas consumption rose by 280% from 1970, to a peak of 396.6 TWh in 2004 before falling by 25%. Gas is used for heating (76%), hot water (23%) and cooking (1%).

Electricity consumption rose by 60% from 1970, peaking at 125.6 TWh in 2005 and then reducing steadily by 12%. Electricity is used mainly for appliances (59%), heating (17%) and lighting (13%).

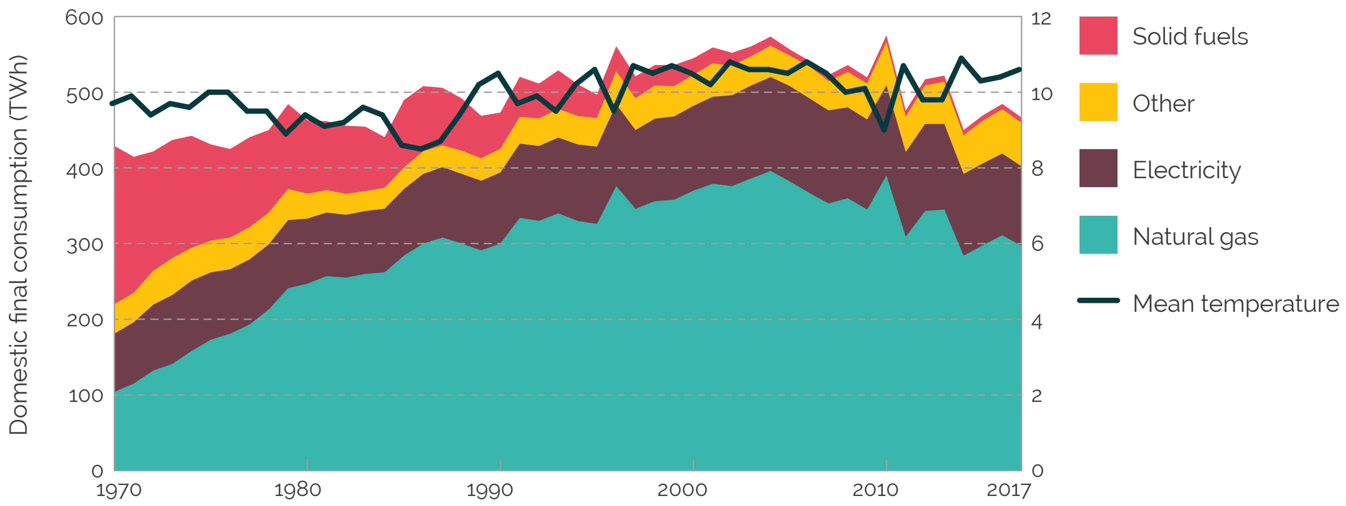

Figure 3: Final domestic energy consumption by fuel. Source: Energy Consumption in the UK, BEIS 2018.

The main factors increasing demand are the number of households (up by 50% from 18 million in 1970 to 28 million now), rising demand for heating and hot water (our homes are thought to be 4°C warmer now than in 1970 (DECC, 2013)), reductions in fuel prices (gas dropping in real terms by 41%, electricity by 32%, between 1983 and 2000) and increased electricity use from additional lights and appliances.

The rapid market penetration of energy efficiency measures has made a significant contribution to the fall in demand since 2003. Condensing boilers have become the dominant form of heating since they became mandatory in 2005, double glazing is in over 80% of homes now compared to 10% in 1983 and some degree of loft insulation is approaching market saturation (Committee on Climate Change, 2018). However significant potential remains: the Committee on Climate Change estimates that around 4 million cavity walls remain to be insulated (Committee on Climate Change, 2018).

For electricity the significant rise in the number of appliances in use has been offset by improvements in both operational and stand-by energy efficiency.

Between 2005 and 2012, gas prices more than doubled (+116%), and electricity costs increased by 42%. The Government considers that this, coupled with the economic downturn in 2008 and falling disposable income, is likely to have reduced energy demand over the period. However, there is no direct evidence for this.

There are some signs that the downward trend in domestic energy demand may be reversing, with 2016 and 2017 both showing temperature-corrected rises. However, is it too soon to predict any shifts in consumer behaviour.

Trends and drivers in non-domestic buildings

Overall service sector energy demand, of which around 93% comes from non-domestic buildings, was 238.4 TWh in 2017, which is 10% higher than 1970 (216.3 TWh) (BEIS, 2018a). The main energy consuming processes were space heating, lighting, catering, chilled storage and IT, detailed below.

- Commercial buildings dominate the sector with 67% of total demand. This has risen by 71% since 1970 (159.3 TWh in 2017 compared with 93 TWh in 1970). The main categories are industrial buildings, retail, leisure and hospitality.
- Public sector buildings accounted for 28% (65.1 TWh) of demand, which is 38% down on 1970 (101.2 TWh). The main categories are health, and central and local government.
- Agriculture accounted for 7% (17.4 TWh) which is 22% lower than in 1970 (22.0 TWh).

The upward trend in overall energy demand masks three sets of influences. Commercial sector activity has increased significantly as the UK has moved to a service-based economy. This has been largely offset by a 63% drop in energy intensity across the sector as a whole, although this intensity trend began to reverse in 2014 and has since risen by 11%. The improvements in efficiency in the commercial sector are thought to be due to higher densities of occupation, improved heating, cooling, ventilation and lighting efficiencies.

Policy principles and challenges

Policies for reducing energy demand in buildings have been well characterised in the academic literature, Government reports and by the work of Committee on Climate Change, most recently on the domestic sector (Committee on Climate Change, 2019). The main policy approaches are set out below.

1. Reducing demand and avoiding waste, e.g. heating fewer rooms and turning off lights and appliances. This is referred to as behaviour change and is a complex socio-technical phenomena involving interaction with control systems and new emerging uses of energy, sometimes stimulated by efficient technologies or building design.
2. Efficient conversion of delivered energy to useful energy by using more efficient heating systems, lighting and appliances.

3. Avoiding heat loss or heat gain by increasing fabric insulation, controlling ventilation and solar gains and integrating measures so that they work effectively together.
4. Integrating energy generation into buildings, for example solar thermal, passive heating via glazing, solar photovoltaics, or heat pumps. Although generation is not strictly demand reduction, it is hard to disaggregate unless it is separately metered and reported.

Buildings present many of the same barriers to change seen in other sectors. However, buildings, by nature and use, are highly diverse, which can make upgrading existing buildings difficult. As a result, policy has tended to focus on new buildings, and easier-to-install, more cost-effective interventions on existing buildings, such as like-for-like more efficient boiler replacements.

A wide variety of policy measures has been employed to do this: standards for building fabric and services e.g. Part L of the 2010 Building Regulations in England; performance standards for other technology used in the building (e.g. lights and appliances); and financial incentives, energy management standards and training, and feed-in tariffs or tax breaks to accelerate the market deployment of efficient and renewable generation technologies.

These policies have succeeded in reducing, or at least stabilising emissions. However, with 'low- hanging fruit' such as condensing boilers reaching market saturation, policy now needs to address the more difficult 'high hanging fruit' (also known as 'coconuts') such as heat pumps and solid wall insulation. A number of policy approaches can be used to accelerate the deployment of these technologies where the barriers to deployment are lower, for example installing heat pumps off the main gas grid (Cohen & Bordass, 2015).

However new buildings are a very small proportion of the stock: around 0.7% pa of the total UK commercial floor area (Property Industry Alliance, 2017) and 0.92%pa of dwellings in England (MHCLG, 2019). Sixty-five per cent of the existing UK non-domestic stock was built before 1991 and 24% before 1940 (BEIS, 2016). As a result, policy to deliver in the short- to medium-term such as the 5th Carbon Budget, needs to focus on existing buildings. However, in doing this policymakers face three significant challenges.

- The actual energy performance of a building can be twice as bad as predicted at the design stage (Cohen & Bordass, 2015). This performance gap is caused by a combination of poor modelling, deviations between design and build, and occupant behaviour (Carbon Trust, 2011). It is a problem for all buildings but is particularly well-characterised in non-domestic buildings (Innovate UK, 2016a & 2016b).
- Rented properties suffer from the so-called 'landlord/tenant divide': a principal-agent barrier where the landlord is reluctant to invest in energy efficiency measures (and as a result, respond to policy interventions) when the tenant benefits from the resulting lower energy costs.

- The construction sector faces significant supply-side barriers (Low Carbon Innovation Co-ordination Group, 2016; Zero Carbon Hub, 2014), such as fragmented supply chains, especially for large companies relying on outsourcing, unhelpful contractual conventions, poor management practice, a lack of the skills and capacity needed to specify and commission novel technologies and systems, and a general reluctance to try new approaches without prior demonstration.

A number of international policies and programmes are attempting to overcome these issues, and particularly the performance gap, by regulating operational energy performance as well the predictive approach used by conventional building codes. The Australian commercial building labelling scheme NABERS (The National Australian Built Environment Rating System) is a good example, although similar programmes are operating in the US and Singapore.

These programmes are attracting research attention because they are clearly transforming their markets. They appear to be doing this by raising the strategic important or 'salience' of energy savings by exploiting the value of other, non-energy 'multiple benefits' such as productivity, reputation, health, comfort or amenity (Mallaburn, 2016). However it is not yet clear how these processes work in detail or how this success can be replicated in a UK market or regulatory context.

Buildings policy in the UK

The UK was the first European country to introduce energy efficiency policies following the oil shocks in 1973 (Mallaburn & Eyre, 2016). Energy efficiency obligation policies were pioneered in the UK and used as a model for similar EU programmes in the late 1990s (Fawcett *et al*, 2018). However policy in recent years has stalled.

This section briefly outlines the recent history of buildings policy in the UK and the EU, sets out the current situation and assesses how the Clean Growth Strategy addresses the more serious policy gaps and shortcomings.

History

The period 2000-2010 saw a range of policies affecting buildings:

- Significant new funding for households through the Energy Saving Trust and (in 2001) a new Carbon Trust to support businesses and the public sector.
- An amendment to the England and Wales Building Regulations[2] requiring all domestic boilers fitted after 1st April 2005 to be condensing.
- A gradual tightening of the energy efficiency requirements of the Building Regulations, particularly in the 2006 revision in England and Wales[3].

2 Part L (England and Wales) has equivalents in Scotland (Part J) and Northern Ireland (Technical Booklets F1 and F2) – the exact dates of changes do not coincide.

3 Part L (England and Wales) evolved between 2002-2010 to make distinctions between residential / non-residential buildings and between new-build / existing buildings.

- The 2007 Carbon Reduction Commitment (CRC), requiring large non-energy intensive organisations to measure, disclose and manage their energy use.
- The 2008 Carbon Emissions Reduction Target (CERT) significantly ramped up the energy efficiency obligation on energy companies to subsidise energy efficiency measures.
- A 2008 requirement that all new buildings would need to be zero carbon from 2016 (households) and 2019 (commercial).
- Smart meters, and their roll-out by the Smart Meter Implementation Programme, established under the 2008 Energy Act.

At the EU level:

- The 2010 Energy Performance of Buildings Directive (EPBD) required Energy Performance Certificates (EPCs) to be provided at sale or lease to benchmark the theoretical energy performance of most buildings and give advice on energy efficiency options. Display Energy Certificates (DECs) measure actual energy performance in non-domestic buildings and must be prominently displayed in public buildings over 1000m^2 in floor area.
- EU product policy regulates the energy performance of technologies not regulated by the EPBD, mainly lighting and appliances. The two main measures are 2017 Energy Labelling Framework Regulation that governs the familiar A to G product labels and the 2009 Ecodesign Directive that sets minimum performance requirements to remove poorly performing products.

Current UK buildings policy

The UK and EU policies described above made a significant contribution to emissions reductions in the last 20 years, particularly in households (Committee on Climate Change, (2017). However, the Government's enthusiasm for buildings policy has waned since 2010 with many programmes being wound down or deprived of funding. This stop-start approach has been a characteristic of UK policy for over 40 years.

Policy for commercial buildings, which was never a UK strength, is now particularly weak, with a number of initiatives held back by industry lobbying or Government concerns about excessive burdens on business through the over-enthusiastic implementation or 'gold plating' of EU Directives (DCLG, 2015).

In 2012 direct, publicly-funded support for both business and household energy efficiency, estimated at around £100m pa, was removed from the Energy Saving Trust and the Carbon Trust (DECC, 2011). Conversely, support for public sector energy efficiency funding through Salix Finance has been maintained and, in 2017/18, significantly increased.

In 2013 the CERT energy efficiency obligation was replaced by the Energy Company Obligation (ECO) which stopped subsidies for better-off households and instead focused on the fuel poor.

In the 'able-to-pay' sector, CERT funding was replaced with the Green Deal, a repayable loan-based system aimed at overcoming up-front capital investment barriers. It was originally intended for both households and businesses, although most activity centred on the domestic sector.

The introduction of the Green Deal was widely recognised as a disaster both in emission reduction terms and, in combination with the removal of previous subsidies, by severely disrupting the retrofit market (Rosenow & Eyre, 2016). As Figure 4 shows, cavity wall and loft insulation rates have fallen dramatically compared to pre-Green Deal levels.

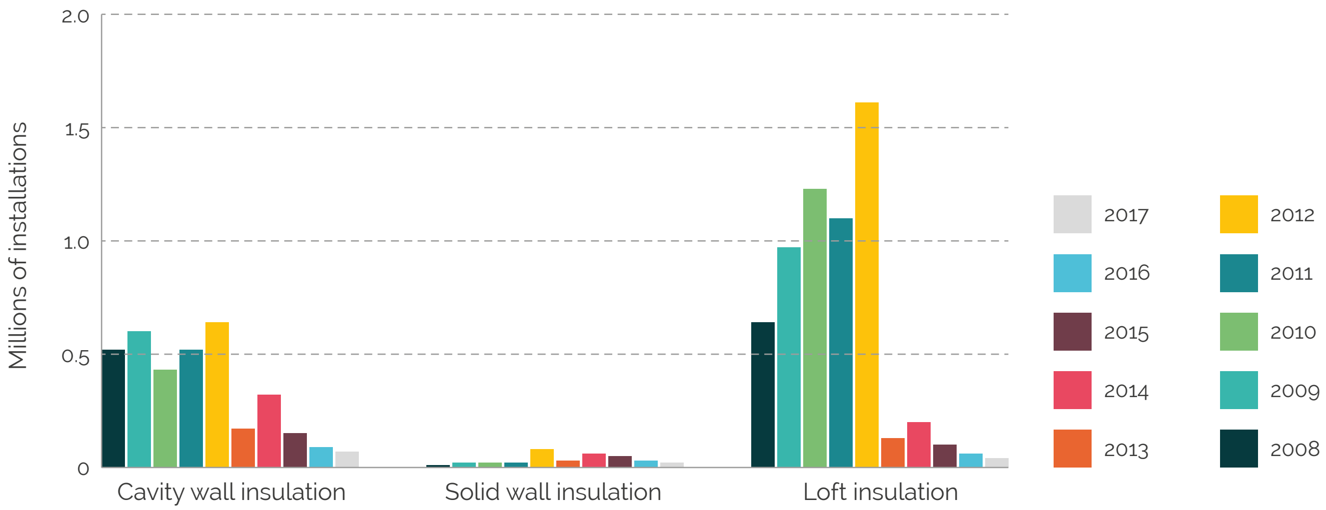

Figure 4. Annual insulation rates 2008-2017. Source: Reducing UK emissions. 2018 Progress Report to Parliament (Committee on Climate Change, 2018).

Zero carbon targets for both domestic and non-domestic buildings were abolished in 2015. The CRC Energy Efficiency scheme was fiercely resisted by businesses, progressively reduced in ambition and abolished in April 2019. Enhanced Capital Allowances for energy efficiency equipment will be abolished in April 2020 and the savings used to support a new industrial energy transformation fund for energy intensive companies.

Some new policies have been announced or enacted. For new buildings, in May 2018 the Prime Minister announced a 'Buildings Mission' to reduce energy use by 50% by 2030 (BEIS, 2018d). In the 2019 Spring Statement (HMT, 2019) the Chancellor announced a new Future Homes Standard which from 2025 effectively bans fossil fuel heating in new homes.

For existing buildings, the UK is developing its own operational energy performance scheme. From April 2019 all rented buildings are subject to minimum energy efficiency standards (MEES) under the Energy Efficiency (Private Rented Property) (England and Wales) Regulations 2015[4]. Rented properties must have an EPC rating of E or better unless the landlord registers an exemption. However, as discussed in the next section, the value of the EPC as a policy tool is open to question.

The grant regime under the Low Carbon Building Programme was replaced by feed-in tariffs under the Renewable Heat Incentive in 2011 where businesses and householders were paid according to the renewable energy they exported to the grid.

Several voluntary schemes are also under development for non-domestic buildings. The Soft Landings programme (BSRIA, 2012), developed by BSRIA, the buildings services trade body, aims to build capacity in the sector by providing guidance and support. The Design for Performance programme (Better Buildings Partnership, 2018), run by the Better Buildings Partnership, is piloting energy performance labelling, based on the Australian NABERS experience, in several large UK building developments.

Buildings in the Clean Growth Strategy

The Clean Growth Strategy (CGS), and subsequent initiatives related to it, proposes a number of new initiatives specifically aimed at households and non-domestic buildings.

Domestic buildings in the CGS

The key policy aim is to bring as many existing households as possible up to EPC band C by 2035 (where "practical, cost-effective and affordable") and 2030 for fuel poor and privately rented homes. This is an ambitious target, but the CGS does not explain how it will be delivered or funded. Also, there are no targets for new homes beyond the current Building Regulations. And finally, there are also significant concerns about the use of EPCs as a policy benchmark (Jenkins *et al*, 2017).

- A band C target is a blunt instrument. For hard-to-install measures such as solid wall insulation it may be more cost effective in the long run to upgrade to EPC band A or B at a relatively lower marginal cost compared with further intervention later.
- There are serious accuracy and reliability issues between different assessors, between different property types and within the same property type.
- An EPC uses annual fuel cost and annual carbon emissions as the main metric of evaluation. However, as we decarbonise energy supply this might become a less useful metric for managing demand compared to other metrics such as load flexibility at peak times.

4 MEES applies in England and Wales only. In January 2016, the Scottish Government published a draft of the Assessment of Energy Performance of Non-domestic Buildings (Scotland) Regulations 2016 which came into force on 1st September 2016.

- There is compelling evidence that regulatory bodies are not enforcing current EPC rules (Environmental Industries Commission, 2018) or indeed Building Regulations more widely (Zero Carbon Hub, 2014).

The Hackitt Review of Building Regulations and Fire Safety (MHCLG, 2018), commissioned following the Grenfell fire, will significantly affect the regulatory environment in the UK. It is essential that this cultural change happens not only to fire and safety, but also energy performance. Several of the review recommendations, if implemented, would address the performance gap.

- A new Joint Control Authority separating enforcement from the interests of supply chain actors, including clients, designers and contractors.
- A stronger change control process that requires more robust record-keeping of changes made to plans during the construction process.
- More rigorous enforcement powers and penalties including requirements to change work that did not meet Building Regulations.

The use of regulations, if implemented correctly, can have significant benefits. Condensing boiler regulations are considered to be an exemplar. In 2003 they were in around 7% of UK houses. Once they were made mandatory in 2005, this rose to 50% in 2011 and is now approaching 100%, saving 11 MT CO_2e pa (Elwell *et al*, 2015) or 17% of total household gas consumption. There is potential for further savings at minimal cost such as managing flow temperatures and balancing heating systems. This latter measure can increase the efficiency of the system by 10% (Sustainable Energy Association, 2016).

Non-domestic buildings in the CGS

A Call for Evidence (BEIS, 2018b) estimated that the package of measures set out in the CGS would deliver £6bn in cost savings and 22Mt of non-traded CO_2 emission reductions, split 45% from existing policies, 40% from buildings and the remainder from industrial processes and heat. This, if implemented, would make buildings the single biggest new policy element for delivering the 5th Carbon Budget.

In common with domestic sector proposals the CGS is thin on actual policies to deliver this target. Only three are mentioned: a new energy performance reporting framework, an industrial energy efficiency scheme and tightening of the MEES standards. Key issues are deferred to future consultations: on advice for SMEs, the energy services and finance markets and the role of the UK Energy Savings Opportunity Scheme (ESOS) and Climate Change Agreements (CCAs).

Non-domestic buildings attract almost no specific policy attention at all: just 4 paragraphs, compared to 11 pages for households. There is no substantive analysis of the nature and scale of the problem or of the specific policies and measures that might be needed.

The Government's response to the Call for Evidence on business policies, published in March 2019, promises a review of Part L of the Building Regulations in 2019 and recognises the importance of focusing on operational performance, but also promises further consultations. It is fair to say that the Government does not have a non-domestic buildings policy.

There are some encouraging signs. The CGS recognises the central role of regulation coupled to demand-side drivers, building on research into corporate strategic or 'salience' drivers (DECC, 2012) and the International Energy Agency's 'multiple benefits' approach (IEA, 2014).

The Government recognises that policies to deliver their objectives must combine market solutions with strong Government intervention. This is important because the lessons from successful overseas policies (van der Heijden, 2017) show the value of a hybrid policy approach, where carefully managed government/industry partnerships are exploiting the multiple benefits of improved energy performance to transform markets (Mallaburn, 2018).

Recommendations

Recommendations for Government policy

HMT, BEIS, MHCLG and devolved administrations:

Develop an overall policy framework for the building sector that unifies the existing fragmented, stop-start policy approach and provides a clear signal of Government ambition and intent in the medium and long-term that will deliver the buildings element of future carbon budgets. If business is to invest in delivering this long-term strategy and develop new models it needs long-term Government commitment.

BEIS and MHCLG:

Ensure that the implementation of the Hackitt Review addresses the energy efficiency performance gap on the evolution of and compliance with buildings standards and in the development of skills, standards, procedures and capacity within the building industry sector.

BEIS and MHCLG:

Broaden overall policy on to the actual, real-world 'as-built' energy performance of buildings. Shifting to a performance-based culture will allow tenants and householders to choose energy efficient buildings and enable the market to accelerate their uptake.

- For households, regulatory policy needs to focus on actual rather than modelled heat loss from the buildings, based on the principles set out in the recent BEIS Smart Meter Enabled Thermal Efficiency Ratings (SMETER) project (BEIS, 2018c).
- For non-domestic buildings the Government should introduce a performance-based policy framework based on successful overseas experience.

BEIS:
Introduce measures to deliver rapid, low-cost emission reductions from existing technologies and systems, for example using product labels to reflect the real-world, operational boiler efficiency based on the Government's 'Boiler Plus' approach (BEIS, 2017).

BEIS:
Produce credible roadmaps for new and existing buildings on the deployment of emerging technologies such as heat pumps, district heating and solid wall insulation, identifying sectors to be used to reduce costs and build supply-chain capacity, for example heat pumps installed in properties off the gas grid.

Recommendations for CREDS and BEIS working together

Continue to develop and build national, long-term energy performance datasets. Policymakers and researchers need reliable, real-world, in-use energy performance data. Significant progress has been made in recent years by both Government and researchers, but many areas need urgent attention.

- For households, we need a national longitudinal survey building on existing data and monitoring, such as the EPSRC Smart Meter Research Lab and the MHCLG/BEIS English Housing Survey and its Energy Follow-Up Survey. Together these can provide a coherent platform to develop the national tool for domestic policy, the National Household Model.
- EPCs for the twenty-first century. EPCs are the main currency for delivering building energy efficiency and cost millions to implement. However, the implementation is poor in part because the latest computational, digital and data practices are not utilised.
- For non-domestic buildings we need a national data strategy to bring together and rationalise the various official datasets and studies building on the work of 3DStock and SimStock.

Maximise the value of research and demonstration investments. UK Research & Innovation, Government and industry have funded several major projects such as the EPSRC Active Building Centre and the Energy Systems Catapult Smart Systems and Heat programme. It is important that maximum value is extracted from these investments, for example to help develop data and modelling tools.

Deepen our understanding of how to exploit the value of the multiple benefits of energy efficiency. We need to understand how they enhance the salience of energy demand measures, how salience varies between organisations, sectors and individuals and where the key, practical policy 'intervention points' lie.

- For households we need systematic ways of capturing the value of multiple benefits in policy evaluations, for example based on HIDEEM modelling of the health benefits of energy efficiency (Hamilton *et al*, 2015), used for fuel poverty policy appraisal (BEIS, 2016).
- Develop methodologies to characterise and better understand the relationships between the thermal performance of buildings and indoor environmental quality (IEQ – air quality, over-heating and noise).
- For non-domestic buildings we need to understand how energy productivity and other 'multiple benefit' policy approaches can transform the buildings and construction sectors by, for example, exploiting value drivers and building market capacity and skills.

Develop a long-term collaborative hybrid policy framework to decarbonise buildings based on successful experience overseas and the latest research that sets out the respective roles of industry and Government over a 10–15 year timescale.

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3. Industry, materials and products

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Introduction

Industry ultimately provides all the goods and services demanded by UK households, from major infrastructure to mobile phones. This clearly uses energy that leads to greenhouse gas (GHG) emissions. In fact, UK industry accounts for 16% of total final energy demand and 23% of the UK's GHG emissions (BEIS, 2017a; CCC, 2018). Since 1990, industrial GHG emissions have nearly halved, with 85% of this reduction occurring between 1990 and 2010. The reductions since 2010 have been more modest, with emissions actually increasing by 1% in 2017 (BEIS, 2017b). The reduction in emissions has been due to a complex mixture of structural change within UK industry, greater reliance on imports to meet the demand for energy intensive industrial products, changing demand for industrial products, and improved energy efficiency (Hardt *et al*, 2018; Hammond *et al*, 2012).

Industry is a diverse and heterogeneous sector and there are numerous ways to describe its structure and to identify opportunities to improve energy efficiency. For example, Griffin *et al*, (2016) identify 350 different combinations of technologies and sectors relating to industrial energy demand. This makes it challenging both to identify appropriate options and to propose generic solutions. Other studies consider industry from a resources and materials perspective, such as steel, cement and paper for example (Owen *et al*, 2018; BEIS, 2015[5]). When identifying mitigation options it can be misleading to treat industry as a single sector. Instead, it is necessary to disaggregate by subsector and identify current and available technologies, material and product outputs, trade patterns and infrastructures (Barrett *et al*, 2018).

5 Industrial roadmaps for a number of industrial sectors are available from: www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050

Direct GHG mitigation options for industry are often grouped into four categories: improved energy efficiency, fuel switching, electricity decarbonisation and carbon capture and storage (Griffin *et al*, 2016). Clearly, there is role for all these options, however this chapter focuses on the role of energy efficiency in industry itself, plus broader measures to reduce energy demand from changing the mix of, and demand for, materials, products and services.

We achieve this by identifying the historical trends in UK industrial energy demand and explaining the reasons behind them. We review the current UK Government policy approaches as outlined in the Clean Growth Strategy and then consider whether there could be a more ambitious role for both industrial energy efficiency and broader options for reducing energy demand such as material efficiency. Before proposing some recommendations to reduce industrial energy demand, we explore the level of ambition needed in UK industry in relation to internationally agreed climate targets.

Recent trends in industrial energy efficiency and demand

A simple examination of historical trends in UK industrial energy demand suggests a major success story. While UK GDP has grown by ~70% since 1990, industrial energy demand has fallen by ~40% – indicating an absolute decoupling between the two (see Figure 5).

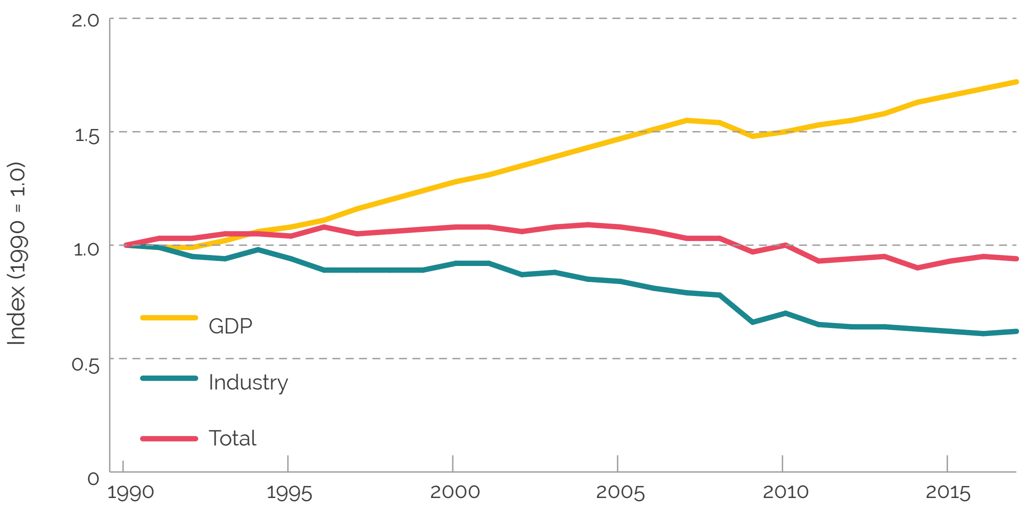

Figure 5: Industrial Energy Demand and UK GDP (1990 to 2016). Source: BEIS, 2017b with industry data added from BEIS, 2017a.

Reductions in industrial energy use have been greater than the average for all sectors in the UK. One of the reasons for this is a decline in the amount of energy used per unit of industrial output – known as energy intensity. Sometimes this metric is used as a proxy for energy efficiency, but this is misleading. It is influenced by a range of factors, including changes in the mix of industrial sectors and industrial products. For example, a shift away from heavy industry and towards consumer electronics would tend to reduce energy intensity. Hence, reductions in industrial energy intensity are not only a result of improvements in the technical efficiency of industrial processes.

Hardt *et al,* (2018) estimate that between the period of 1997 to 2013 half of the reduction in industrial energy intensity can be attributed to improvements in technical energy efficiency, with the rest being due to structural change and other factors.

Structural change, in turn, includes both changes in the mix of industrial sectors, and changes in the mix of domestically-produced versus imported goods and services. Since 1990, there has been a trend towards 'offshoring' industrial production to other countries, meaning that a smaller share of the goods and materials consumed in the UK are produced in the country. Figure 6 demonstrates that offshoring was the most important factor along with energy efficiency improvements between 1997 and 2013. While the offshoring of industrial energy use helps meet national GHG emission targets, it fails to deliver a global reduction in emissions.

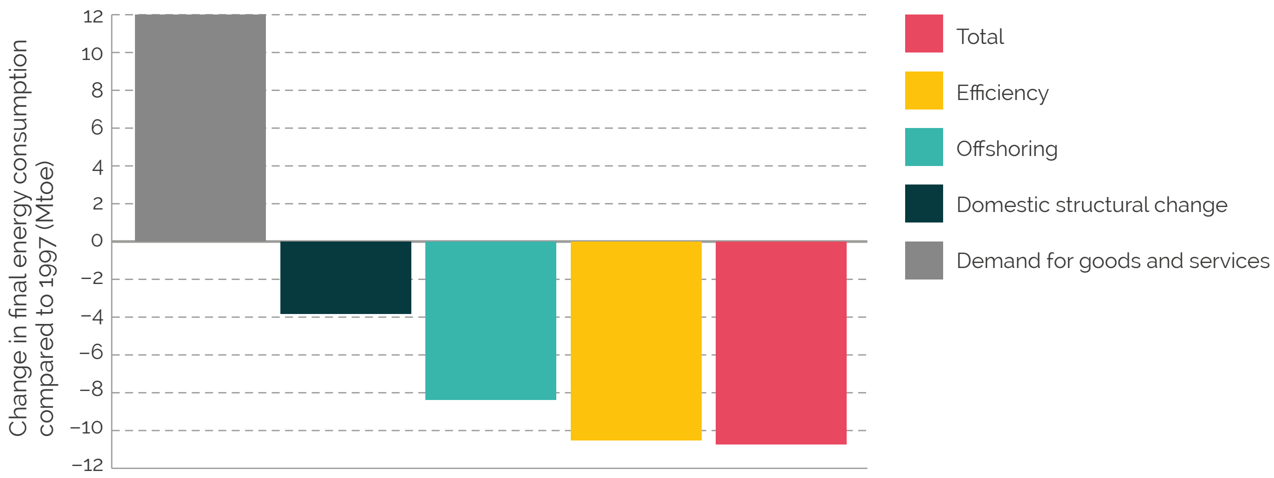

Figure 6: Decomposition analysis of UK industry, 1997–2013. Source: Hardt *et al*, 2018.[6]

In the more recent period from 2007 to 2013, the growth in demand for goods and services from industry resulted in increased energy demand. This increase was only partly offset by a reduction in energy demand from improved energy efficiency over the same time-period. Therefore, without the reductions from domestic structural change and offshoring, industrial energy demand in the UK would have been marginally higher in 2013 than in 2007.

6 Technical energy efficiency is very difficult to separate from other factors and could include both technical changes in processes along with structural changes within sectors which would not be captured in the assessment of structural change between sectors. Therefore, the assessment of the contribution of technical energy efficiency is an over estimate.

Current approaches to delivering industrial energy demand reduction

The Clean Growth Strategy (CGS) sets out a range of strategies to help decarbonise industry, including not only energy efficiency and demand reduction but also fuel switching and other abatement options. On energy efficiency, it sets a high-level goal for improvement across business and industry of at least 20% by 2030 and outlines a number of strategies to deliver this. From an historical perspective, this represents a 'business as usual' ambition with the level of improvements being similar to those seen in the past.

The CGS analysis (BEIS, 2017b) shows that overall industrial emissions savings in the region of 45MtCO_2 are technically possible by 2050 compared to baseline emissions in that year (CO_2 emissions being 123MtCO_2 from industry in 2015). This 37% reduction would be mainly achieved through carbon capture, usage and storage (CCUS) and fuel switching, with a very small role for energy efficiency of 5MtCO_2 (4% of 2015 emissions).

It is unclear when these reductions would be delivered and the issue of timing is extremely important when considering cumulative emissions, and therefore impact on climate. The Committee on Climate Change (CCC) however suggest that this 5Mt reduction relates to energy efficiency that could be achieved by 2030. However, this 5 Mt emissions saving may not be the total contribution to GHG reduction from energy efficiency, since the BEIS baseline projection already incorporates some energy efficiency improvements – based on extrapolating past relationships between energy use and GDP. This makes it difficult to assess what the total contribution by 2050 from energy efficiency might be. However, the impression given in the CGS is that the role of energy efficiency is expected to be minimal compared to other options.

The CGS and numerous other publications identify multiple economic barriers to achieving energy efficiency improvements such as split incentives, asymmetric information and high transaction costs. Therefore, it is difficult to reduce energy demand without some policy intervention as the business case for further improvements is weak, especially in the energy intensive sectors. A number of strategies are therefore outlined in the CGS to meet the high-level energy efficiency goal, building on the 'Industrial Decarbonisation and Energy Efficiency Action Plans' (BEIS, 2017c), and the earlier roadmaps (BEIS and DECC, 2015). The proposed strategies include: an Industrial Energy Efficiency Scheme providing support for large companies to invest in energy efficiency; increasing the Climate Change Levy rates after 2019; improving and reforming the Energy Savings Opportunity Scheme (ESOS); introducing a new energy and carbon reporting framework for business to replace existing schemes; and dedicating £18m to industrial heat recovery (BEIS, 2017b). In addition, the CGS proposes a funding framework for R&D in industrial decarbonisation, with £162m to be invested by 2021 (BEIS, 2017b) on a range of projects covering energy, resource and process efficiency, better low carbon fuels and CCUS. The Industrial Strategy Challenge Fund additionally has the 'Transforming Foundation Industries Challenge', covering glass, metals, cement, ceramics and chemicals.

However, the CGS provides little detail on the design and implementation of these strategies and it remains unclear how they would collectively deliver significant reduction in GHG emissions in line with UK and global ambitions.

Ultimately the success of these schemes will come down to the detail of their design and implementation, including the ability to target the most cost effective measures and to reduce the associated transaction costs. Learning from other countries is essential here. For example: Canada has introduced an industrial energy efficiency programme in four provinces; Denmark has established a 'Secretariat for Energy Savings', targeting industry with information-based measures providing assessment and analysis of energy use (IEA, 2017a; IEA, 2017b); the Netherlands has a system of 'Long-term Agreements' with industry; Germany has an energy efficiency framework, which has been highly effective at reducing energy intensity; and Japan has had their 'Top Runner Programme' since 1999, orientated towards the manufacturing sector (Geller *et al*, 2006; IEA, 2016; IEA, 2013; IEA, 2014).

We now consider what a successful programme could potentially deliver in relation to energy efficiency and whether there should be an increased level of ambition.

Energy efficiency options in industry

Energy efficiency is often seen as 'the first fuel', delivering cost saving as well as delivering environmental benefits. It is seen as highly attractive because it does not necessarily rely on changes to behaviour and lifestyles and allows the continuation of existing business models. Therefore, is the CGS right to identify such a small role for energy efficiency in industry to deliver GHG emission reductions?

The CGS analysis draws from a road-mapping exercise for eight sectors of UK industry (WSP, Parsons Brinckerhoff and DNV GL (2015)) and concludes that, under a scenario of incremental improvements, energy efficiency could annually contribute 5.3 Mt CO_2 savings by 2050 (4% reduction as noted above). Under a scenario of 'maximum technology', which ignores economic and commercial considerations, and includes technologies currently at low technology readiness levels, this figure increases to 7.6 Mt CO_2 (6% reduction).

Energy efficiency saving potentials were found to be lowest in percentage terms in energy intensive sectors, such as iron and steel, and cement manufacture, which aligns with the findings of other work (Griffin *et al*, 2014). This is consistent with the observation that energy efficiency improvements within energy intensive sectors have been plateauing in recent years (Hammond and Norman, 2016). The high share of energy in overall production costs of these sectors has driven energy efficiency improvements for decades, and so the remaining potential may be relatively small and difficult to realise. For example, it is widely acknowledged that several energy intensive industrial processes (such as steel production) are close to what is technically feasible in relation to energy efficiency (Norman *et al*, 2016). This broadly leaves two options for these sectors: radically different industrial processes as envisaged by the CGS and/or changes in demand for their products.

Options such as CCUS have yet to become economically viable and are unlikely to be implemented at scale in the short term. Rapid reductions in cumulative emissions to meet internationally agreed climate targets require changes in the next decade.

Conversely, the non-energy intensive sectors, having historically not had such strong drivers to improve efficiency, may have relatively greater opportunities remaining (often referred to as 'low-hanging fruit'). There is limited evidence of where such potential might lie as these non-energy intensive sectors represent a challenging area for analysis, with poor data availability and highly heterogeneous uses of energy (Griffin *et al*, 2016). The potential for opportunities related to 'cross-cutting technologies' used in multiple sectors of industry (such as boilers and motors) are often relied on to assess the emissions reduction opportunities in non-energy intensive sectors. This leads to an incomplete analysis of the improvement opportunities by not representing the diversity of energy-using processes and efficiency options. Examples of particularly complex sectors include food and drink, textiles, chemicals and engineering. More evidence is needed to ensure a thorough appreciation of the opportunity in the non-energy intensive sectors.

In conclusion, the level of ambition for industrial energy efficiency identified in the CGS should be increased. However, it is highly unlikely that dramatic gains are going to be possible in the short term. The most promising area for further rapid action may be the non-energy intensive sectors, but they also represent a smaller proportion (~35%) of total energy demand. Realising major additional improvements in the energy intensive sectors will require significant process change and therefore capital investment, which is unlikely to materialise in globally competitive markets without significant Government support. Therefore, identifying opportunities for sustained reductions in industrial energy use to 2050 also requires an understanding of how to reduce demand for the most energy intensive materials and products, which we explore in the following section.

Going beyond energy efficiency to reduce industrial energy demand

All energy demand in industry ultimately relates to goods and services provided for households and government. With limited options available to reduce energy demand through efficiency improvements, changing demand for the goods and services produced by industry offers further mitigation options. Energy is embodied in products as raw materials (e.g. minerals) are processed into useful materials (e.g. glass and metals) and manufactured into products (e.g. buildings, cars and electronics) which in turn are used as inputs to all intermediate sectors (e.g. agriculture, construction, transport and financial services) or sold to final consumers (e.g. households and government) (Scott *et al*, 2018). As 'carriers' of industrial energy, the trade of materials and products results in the transfer of embodied energy between sectors, countries and consumers (Scott *et al*, 2018). Figure 7 shows how UK and international energy supply flows (through materials) from the energy system, to industry and to final consumers of products in the UK, commonly defined as the UK's consumption-based GHG accounts[7].

7 Latest data for the UK is available from: www.gov.uk/government/statistics/uks-carbon-footprint

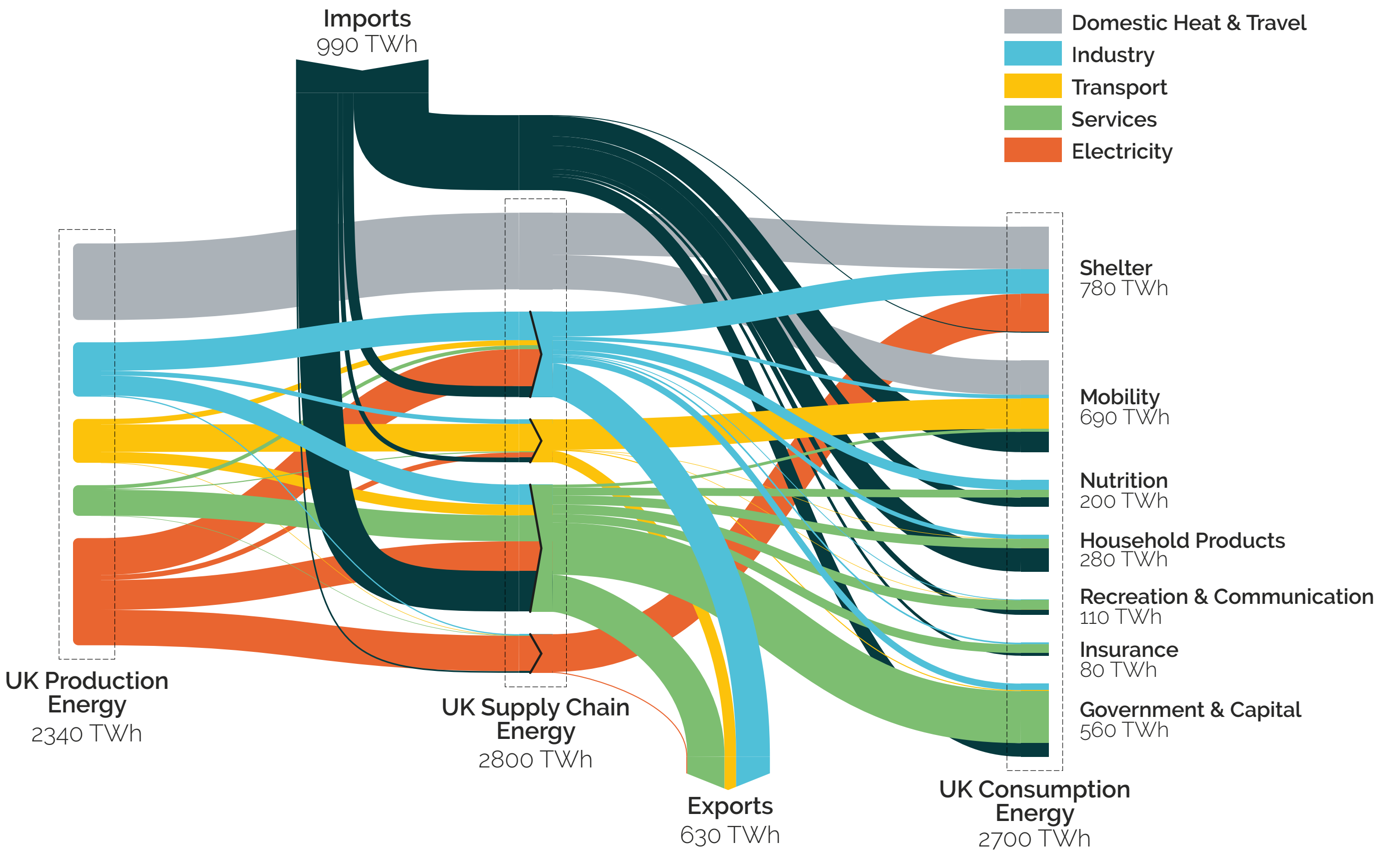

Figure 7: Embodied energy analysis of the UK, extracted from data in Scott *et al*, 2018. Source: All data from University of Leeds.

The left of the figure shows the energy demand of the UK (2340 TWh) for five sectors. The UK imports a further 990 TWh of embodied energy in materials that are imported either into industry (intermediate demand) or as final product to consumers (household demand). It also exports 630 TWh, making the UK a net importer of embodied energy. On the far right of figure 7 is the energy embodied in household services such as shelter, mobility and nutrition.

The value of this analysis is the ability to identify additional mitigation options beyond energy efficiency. These could be broadly described as 'Putting Less In' (production changes) and 'Getting More Out' (consumption changes) to change our use of materials and products that ultimately reduces the need for industrial energy. Production changes could include reducing waste in industry, lightweighting products and packaging, fabrication yield improvements, modular design or remanufacturing. Consumption changes could include household reductions in waste, shifts from recycling to refurbishing, using products longer, accessing services as opposed to ownership (car clubs for example) and sharing (higher occupancy rates in vehicles and buildings). Indirectly, all these changes have the potential to reduce industrial energy demand.

Scott *et al*, (2019) calculated the potential for material efficiency across seven sectors (see table 1), considering measures that include waste reduction, lightweighting of products, material substitution and product longevity.

Table 1: Summary of material productivity strategies. Source: Scott *et al*, 2019.

Sector	Putting less in (production)	Getting more out (consumption)
Clothing & textiles	Reduce supply chain waste through efficiency improvements in fibre and yarn production, dyeing and finishing	Dispose of less and reuse more Dispose of less and recycle more Use for longer
Food & drink	Reduce avoidable food waste in food services and hospitality sectors	Reduce avoidable household food waste
Packaging	Reduce weight of packaging (metal, plastic, paper, glass) Waste prevention	n/a
Vehicles	Reduce steel, aluminium and additional weight without material or alloy changes Yield improvement (metals) in car structures through cutting techniques Steel fabrication yield improvement Reuse discarded steel products	Shift from recycling to refurbishing Car clubs Use cars longer
Electronics, appliances & machinery	Reduce steel without material or alloy changes Steel fabrication yield improvement Reuse discarded steel products in industrial equipment	Sharing less frequent electrical appliances (e.g. vacuum cleaners), power tools and leisure equipment Use for longer Remanufacturing instead of throwing away
Construction	Design optimization to reduce material inputs Material substitution Material reuse	n/a
Furniture	Reduce steel without material or alloy changes	Dispose of less and reuse more Dispose of less and recycle more

Collectively, these options offer a greater potential for emission reduction by reducing energy demand than all the current planned reductions in industry documented in the Clean Growth Strategy related to energy efficiency in industry (5 Mt CO_2 in 2030). These material efficiency options offer potential savings of 21 Mt CO_2 in 2030. The material efficiency measures documented in Scott *et al* (2019) represent a conservative assessment of the potential for emission reduction and are by no means the maximum potential. They rely on evidence from existing case studies and therefore once the UK started on a path towards material productivity further options are highly likely to emerge.

One of the key advantages of material efficiency strategies relates to timing. The reality of climate change is that it is the total cumulative GHG emissions that relate to temperature rises, meaning that reductions in the short term offer significantly more investigation potential, especially if the changes create a long-term change. Many of the material efficiency strategies listed above require no major breakthrough in technology and limited capital investment but do need Government intervention to ensure that they materialise.

The other advantage of these measures is that GHG emissions are not just reduced within the UK but would reduce emissions in other countries. The UK is a large importer of energy intensive materials and many of the strategies would reduce the UK's reliance on imports. While the analysis above only lists the emissions savings that would occur in the UK, other studies suggest that a similar, if not greater reduction, would occur in other countries as a result of UK action (Barrett *et al*, 2013). This reinforces the notion that the UK could become a global leader in tackling climate change while also reducing its reliance on imports.

Conclusions and recommendations

Industry is often considered a hard to mitigate sector and most emissions scenarios allocate a larger proportion of the carbon budget by 2050 to industry because of this. Under such scenarios further and faster emission reductions are required in other sectors to allow for the additional 'carbon space' allocated to industry. At the same time, demand for industrial energy has not declined as rapidly as may appear from national energy data, because some of it has simply been offshored, with no benefit for global efforts to reduce emissions.

The current UK Government strategy is framed around achieving an 80% reduction in GHG emissions by 2050 (based on 1990 levels). It is clear that this target is inconsistent with international efforts to reduce GHG emissions to net-zero in the 2050s, and therefore the UK Government is currently considering a net-zero target by 2050, in which case industry emissions would need to be much closer to zero than is currently assumed. Under this framing, choices between energy efficiency **or** fuel switching **or** CCUS disappear. The required framing is energy efficiency **and** fuel switching **and** CCUS **and** a comprehensive assessment of changing consumption patterns to reduce the needs for materials and products. With material efficiency measures potentially being three to four times more significant in reducing emissions than energy efficiency options, there is an urgent need to ensure that the Waste and Resource Strategy aligns with the CGS.

The good news is, collectively, these options could deliver substantial reductions ensuring that industry does not require a favourable allocation of future carbon budgets over other sectors. However, the efforts to achieve these reductions should not be under estimated, requiring additional policy and strong partnerships between the UK Government and industry. Without Government intervention they will simply not be realised. This requires alignment not just in climate and resource efficiency strategies but more broadly with economic objectives and future industrial strategy. With responsibilities cutting across Government departments (in particular Treasury, Business, Energy & Industrial Strategy, Ministry of Housing, Communities & Local Government, and the Department for Environment, Food & Rural Affairs), a joined-up, coherent and comprehensive plan is required. This plan is urgently needed to accompany the CGS, along with clarification of the rather vague measures currently proposed.

What all these schemes have in common is the need for high quality data, benchmarking and metrics to enable successful targeting, monitoring and measurement. At present, the UK lacks the data and institutional framework to deliver such a programme. Data on energy consumption linked to industrial processes is very poor, with economic data often being used to derive proxies for energy use. This makes assessments of progress and potentials very difficult, with non-energy intensive sectors being particularly poorly understood. The first step to implement an energy and material efficiency scheme for industry is to establish the necessary structures around data and management. This ensures that a transparent platform is in place for Government to engage in a transformative plan with UK industry to deliver a net-zero target by 2050.

In summary, our key recommendations are as follows.

- **We recommend that Government increases the ambition for energy demand and emission reductions goals in industry (BEIS)**. These needs to align with internationally agreed targets and goals for net-zero emissions.
- **We recommend that Government adopts industrial energy-use goals that include energy efficiency, fuel switching, process decarbonisation, CCUS and reducing the demand for materials and products (BEIS, Defra, Devolved Governments)**. The savings potentials to deliver stronger goals exist, but delivering them requires a more holistic approach, including energy efficiency and fuel switching, but also going further to include demand for materials and products for short-term reductions and transformative technologies for longer-term gains.
- **We recommend that Government develops a comprehensive industrial energy demand policy, providing support and incentives for innovation and deployment of new technology and business models, including for energy efficiency and material efficiency by final consumers (HMT, BEIS, Defra, Devolved Governments)**. The scale and pace of change required is not going to happen by itself and therefore needs more policy intervention. This needs to involve Government playing an active role in supporting innovation and creating markets, including by ensuring that their own procurement patterns reflect the changes needed.
- **We recommend that Government accepts the need to address questions of lifestyle and behaviour change to deliver energy and material efficiency (HMT, BEIS, Defra, Devolved Governments)**. The options for energy efficiency improvement in the energy intensive sectors are very limited in terms of emission reductions, in the short term. Therefore, the UK Government needs to openly recognise that technology alone will not be enough and initiate a public debate on our lifestyles and their lack of consistency with a net-zero future.
- **We recommend that Government develops a cross-Government approach to energy, climate, waste and industrial strategy (Defra, BEIS, Devolved Governments, HMT)**. This is needed to ensure that investment support, tax regimes and strategies are aligned. Energy, climate and waste policies need to be seen as integral parts of an economic policy that provides the right incentives to guide and support industry.

- **We recommend that Government aims to take a leadership position internationally on energy intensive material supply chains (BEIS, Defra, DIT, FCO, DfID)**. With the UK being heavily reliant on imported energy intensive materials and products, the UK Government must work internationally to reduce the energy and associated emissions of international supply chains.
- **We recommend that Government works with industry and the research community to develop and share better industrial energy and materials data (BEIS, Defra)**. Given the far-reaching nature of the changes, policies need to be evidence-based. Data availability and quality are currently not good enough for the level of analysis that is needed. Uncertainty is too high and not enough is known. An investment in more robust and transparent industrial energy data linking energy demand with key processes and infrastructure to allow more accurate benchmarking of sectors, materials and products is urgently required.

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4. Transport & Mobility

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Introduction

Road transport accounted for just under three-quarters of transport energy consumption in the UK in 2017, with the remainder almost entirely from air travel (23%). Of the road component, energy use from cars accounts for more than half (60%), with most of the remainder coming from light duty vehicles (vans) (16%), heavy goods vehicles (HGVs) (17%) and buses (3%) (BEIS, 2018a – figures derived from Tables 2.01 and 2.02). Energy use from transport has increased by 16% since 1990 (6% since 2013) against a UK economy-wide decrease of 4% (CCC, 2018a) and remains 98% dependent on fossil fuels. It has grown as a share of overall carbon emissions with no net reduction between 1990-2017 (vis-à-vis –43% for all sectors combined) (CCC, 2018a).

The treatment of transport in the Clean Growth Strategy (CGS), as well as subsequent pronouncements in the Road to Zero (R2Z) (DfT, 2018a) and the Future of Aviation (DfT, 2018e) strategies, assumes that the demand for travel will continue to grow, and seeks to reduce the use of fossil fuels by:

- accelerated deployment of more efficient end-use technologies (road vehicles, trains, aircraft and ships); and
- changes in the dominant fuel source, predominantly from electrification and biofuels.

The primary focus is changing the vehicle fleet from petrol and diesel, first to ultra low emission vehicles (ULEVs), and then to zero-emission vehicles (ZEVs)[8], primarily through electrification. This focus is reflected in 44 actions out of the 46 listed in the R2Z Strategy (DfT, 2018a).

8 ULEVs produce < 75 gCO_2/km under the existing test cycle and includes pure Battery electric vehicles (BEVs), Plug-in hybrid electric vehicles (PHEVs). Zero emission vehicles emit no carbon or pollution from the tailpipe and include BEVs and Fuel cell vehicles. Strictly these are only zero emission when powered by renewable or zero emission electricity (DfT, 2018a).

This chapter reinforces the growing consensus that the ambition in relation to fuel switching and vehicle efficiency could and should be strengthened. We nevertheless question the almost exclusive reliance upon technical improvements for two main reasons.

- The Department for Transport's (DfT) own scenario forecasts (DfT, 2018b) show that the uptake of ULEVs is likely to put upward pressure on traffic growth by lowering the costs of motoring. 'Clean' growth involves more than attending to the carbon implications; it means considering the combined effects of continued car dependency leading to more urban sprawl, inactive lifestyles and congestion together with the lifecycle impacts of vehicles and batteries, charging infrastructure, and road and car parking capacity.
- The almost exclusive reliance on technical solutions will only be able to produce the necessary reductions if the DfT's lower traffic growth futures are assumed. Evidence suggests a lower rate of demand for passenger mobility is credible, but this would require a different policy package to achieve and 'lock in' the new demand patterns. Thus, whether we assume underlying high growth trends whereby technological developments cannot hope to mitigate the externalities from traffic demand, or we assume that lower or even negative rates of growth could instead be enabled, a different suite of policies focused on shaping the demand for travel is required.

In its rather critical response to the DfT's R2Z strategy, the Committee on Climate Change (CCC) also pointed to the dangers of relying on technical solutions, suggesting that policies influencing the demand for travel should have a more significant role. They recommended that the DfT should "set out a vision for future travel demand" (CCC, 2018b) and this chapter contributes to that vision[9]. The remainder of this Chapter focuses largely on road passenger transport. Issues related to low carbon fuels for heavy vehicles are addressed in Chapter 6.

Uncertainties in forecasts of the volume of traffic

The context of forecasting traffic has changed fundamentally in recent years, and this is reflected in future scenarios which span from continual high growth (as happened up to the late 1980s), to low growth or even decline, as has happened since the 1990s). In either case, the demand for the mobility itself (i.e. the distances travelled and the travel modes used) will be at least as crucial to future energy demands as the fuel types and efficiencies of the vehicles.

For many years, DfT forecasts of traffic volume, used as the basis for calculating projected energy use, comprised a long-term uninterrupted continuation of high rates of growth, with rather narrow sensitivity tests intended to allow for uncertainty in economic performance, population, and fuel costs.

9 The early work in CREDS will focus on passenger demand, including some limited focus on aviation. Additional funding may be directed to heavy goods vehicles and freight. Whilst the core arguments expressed here will apply also to freight, aviation and shipping, the balance of the issues will differ.

However, it became apparent that the forecasts systematically overestimated traffic growth (for reasons which are not entirely agreed) and since 2015 the official traffic forecasts have used a scenario approach with a much wider range of possible futures, none of which are given precedence as a 'most likely' official view of the future. The 2018 scenarios, and the DfT's estimates of their CO_2 implications, are shown in Figures 8 and 9.

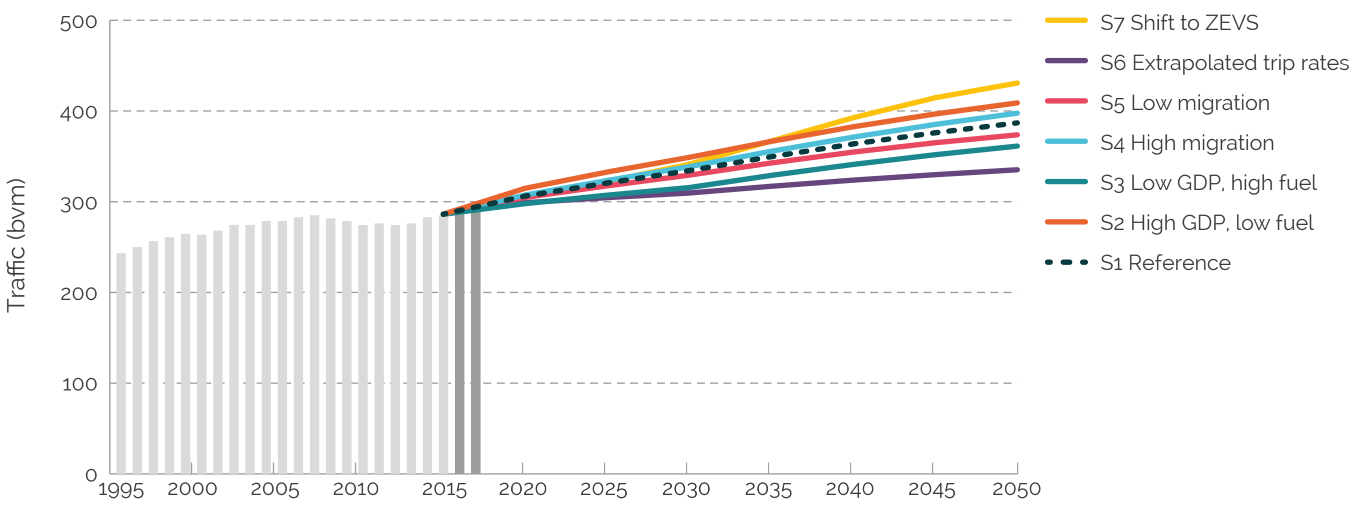

Figure 8: Vehicle miles forecasts for England and Wales. Source: DfT (2018), Road Traffic Forecasts 2018. Moving Britain Ahead. September 2018. Figure 25, pp 51.

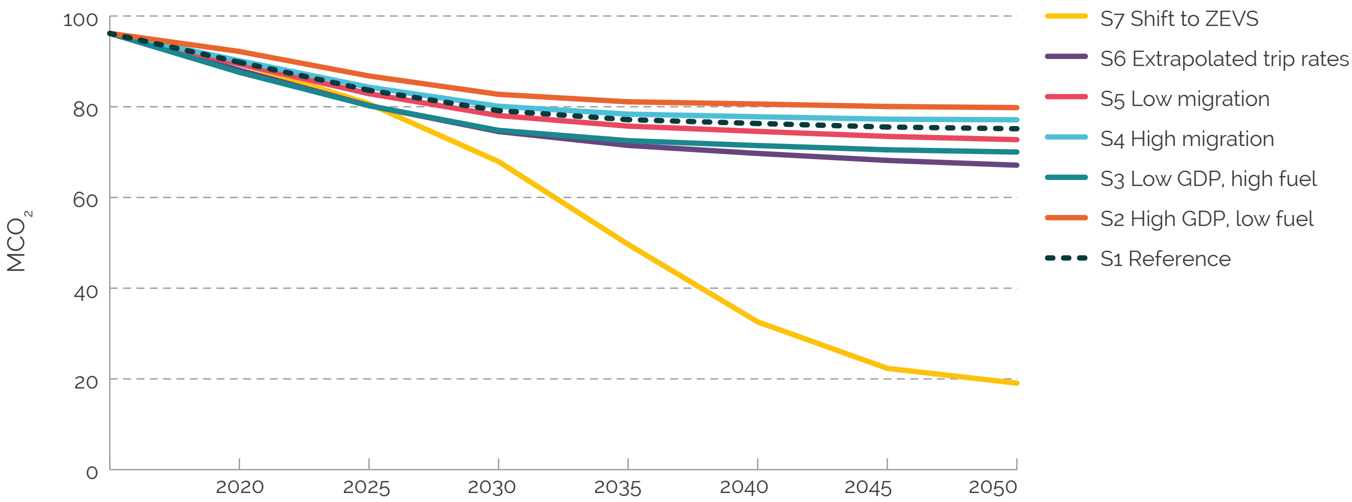

Figure 9: CO_2 emissions associated with the vehicle miles forecasts in England and Wales. Source: DfT (2018), Road Traffic Forecasts 2018. Moving Britain Ahead. July 2018. Figure 40, pp69.

Scenarios 1 to 5 are forecasts with different assumptions about economic growth, population and fuel price, with Scenario 1 as a 'reference case' using long-standing assumed demand relationships. It predicts an increase in traffic volume of 35% and a calculated reduction in CO_2 of 22%, with the share of electric cars and light goods vehicles (vans) growing to 25% of miles travelled by 2050.

Clearly a penetration of 25% electric vehicles by 2050 is not compatible with meeting carbon reduction commitments. Scenario 6 is an alternative reference case forecast based on the trend for decline in trip rates recently observed, which gives substantially lower demand growth, and proportionately less CO_2 emissions. This is discussed further below. Scenario 7 is not a forecast as such, but a trajectory of what would happen if electric vehicles are assumed to meet nearly 100% penetration of cars and vans by 2050. In this case, CO_2 would fall by about 80%, with most of the deficit accounted for by non-car and van road traffic. Upstream and embodied emissions are not accounted for.

This base then allows us to consider the feasibility of relying only on technical change, and a starting point for considering the scope for changes in the volume and structure of traffic.

Feasibility of relying on energy efficiency improvements and electrification

The CGS and R2Z's aims for a reduction in CO_2 emission from transport emissions by technology, without changing demand, do not appear to be based on a realistic assessment of what is practically possible. We outline two further points of potential failure: an inadequate treatment of targets for ULEVs, and the gap between declared vehicle performance and real-world results.

Weak targets for uptake of ultra-low emission vehicles (ULEVs)

Only targets defined in terms of the penetration of ULEVs, rather than the energy service they provide, are used to frame UK transport policy and its carbon and energy implications. Moreover, these targets are themselves weak and muddled, with relevant Government departmental and CCC publications recommending, or working with, different targets (Table 1). The differences relate to the target years (mostly either 2030 or 2050), the inclusion of cars and vans or just cars, the expression of the target in relation to new vehicle sales or the proportion of vehicles on the road. Only the DfT traffic forecasts supply a figure in terms of the proportion of vehicle miles travelled. Targets are further weakened by the continued confusion about which technologies are expected to be included in the definition of a ULEV. These differences make it challenging to compare ambition across reports, Government departments and over time.

Table 1 demonstrates how policy has evolved very slowly, even on road vehicle technology: by allowing hybrid vehicles to be included, the 2040 target in the R2Z strategy is possibly even less stringent than was proposed six years earlier in the 2011 Carbon Plan. Moreover, the official 2040 target is weak by international standards: Norway aims for all new car sales to be ULEVs by 2025; Scotland by 2032, and the Netherlands, Denmark, Ireland, Austria, Slovenia, Israel, India and China aim for this by 2030 (Committee on Climate Change, 2018a for a review of these targets).

Table 1: Targets and recommendations for uptake of ULEVs in England and Wales

	2030 (/35)	2040	2050
HM Government, December 2011		All new cars and vans to be "near zero emission at the tailpipe"	
Committee on Climate Change, November 2015	60% of new cars/vans ULEV by 2030		
Defra & DfT, July 2017		End the sale of all new conventional petrol and diesel cars and vans by 2040	
HM Government/ CGS, October 2017	30% of new car sales will be ULEVs and possibly as much as 70%	End the sale of new conventional petrol and diesel cars and vans by 2040	Every car and van on the road should be zero emission in 2050
DfT RTF, July 2018	Approx. 35% of the car and van on road fleet (deduced from figure 19, page 42 of DfT, 2018)	Approx 80% of on road fleet and 100% of sales of cars and vans are zero emission by 2040	25% (S1) – 100% (S7) of miles travelled by cars and vans in the fleet.
DfT / R2Z (July 2018)[a]	At least 50% (and up to 70%) of new cars (and up to 40% of new vans) will be ULEVs	All new cars and vans will have "significant zero emission capability" and the majority will be 100% "zero emission"	"By 2050 we want almost every car and van to be zero emission" (not specified if this is sales or on road)
Committee on Climate Change, October 2018[b]	100% of new cars/vans ULEV by 2035		
BEIS Committee, Oct 2018	100% of new cars/vans ULEV by 2032		

a The proportion of zero emission mileage is modelled as if these were electric vehicles (p30).

b The CCC net-zero advice published in May 2019 kept this target but added "If possible, an earlier switchover (e.g. 2030) would be desirable"

In any case, a stated target is not seen to be a strong enough signal for all actors concerned [10]. Instead it needs to be a ban to be supported by (potentially UK-independent) legislation. In addition to 'fuzzy' targets, the R2Z contains only unspecified delivery mechanisms. This is especially surprising given the slower than expected uptake of electric vehicles thus far, especially pure battery variants which only comprised around 0.5% of car sales at end 2018, compared to 1.5-2% for plug-in hybrids (PHEVs).

10 Including by the CCC, the National Infrastructure Commission, the UK Energy Research Centre and others.

Preliminary analysis by researchers involved in CREDS shows the inclusion of hybrid technologies could lock significant amounts of fossil fuel into the sector well beyond any target date[11]. Figure 10 shows the Internal Combustion Engine 'ICE ban 2040' scenario representing the loosest definition of ULEVs which allows both conventional hybrids (HEVs) and PHEV cars and vans. When compared to 1990 levels, this scenario shows reductions in tailpipe CO_2 emissions of only 61% by 2050. When also banning new HEVs from 2040, the results show a 88% drop, or 93% if from 2030. This suggests that the trajectory for urgent CO_2 savings requires phasing out all forms of conventionally fuelled ICE and HEV cars and vans by 2030 and that net-zero (for tailpipe emissions) may only be achieved by also phasing out PHEVs by this date.

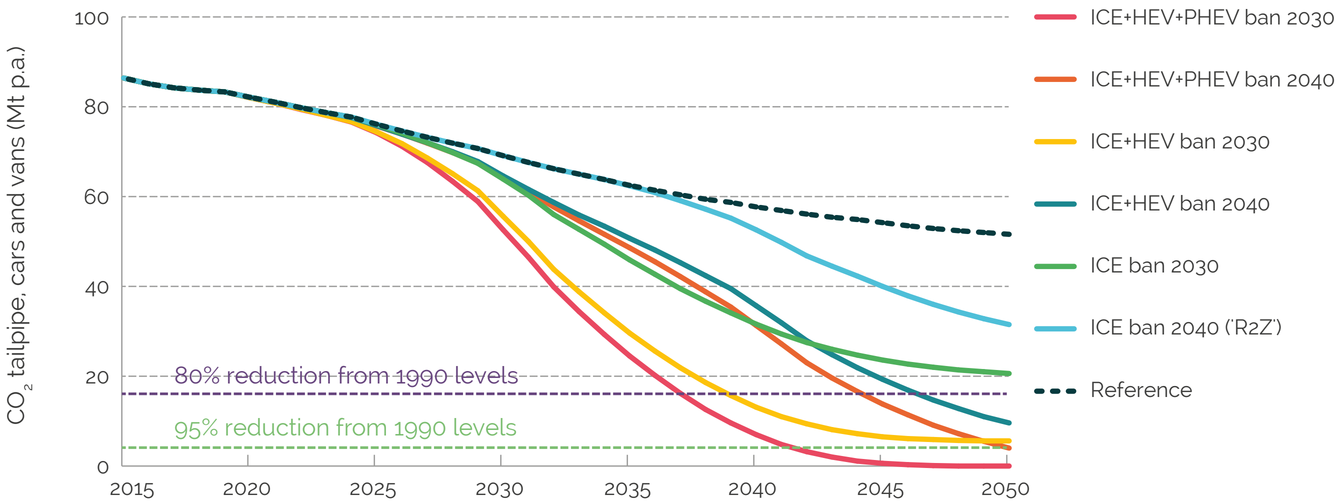

Figure 10: Tailpipe CO_2 reductions by 2050 from UK cars and vans based on different combinations of Internal Combustion Engine (ICE) and (Plug-in) Hybrid Electric Vehicle ((P)HEV) phase-out. Source: Anable, J. & Brand, C. (2018). Consumer behaviour: priorities for progress. Presentation at the Low Carbon Vehicle Partnership annual conference, June 2018.

This analysis is heavily dependent on the assumption that new car and van CO_2 emissions for all propulsion systems will undergo continuous improvement (Brand *et al*, 2017) and that a generous proportion of miles undertaken in PHEVs will use the electric battery (largely for urban driving, i.e. approx. 40% of the total mileage with motorway and rural driving assumed to mostly use the ICE). This compares to 73% of PHEV driving done in electric mode assumed in the R2Z analysis (DfT, 2018c pp. 130)[12]. This is important because, so far, 3 out of every 4 plug-in vehicles sold in the UK has been a PHEV. In the summer of 2018, analysis of real-world fuel consumption data on 1,500 company owned PHEVs (comprising seven models) (Middleton, 2017; Hollick, 2018) found the vehicles only achieved an average of 45mpg or 168 gCO_2/km compared to their advertised average consumption of 130mpg or 55 gCO_2/km.

11 Based on new approach in Brand *et al*, 2017.

12 Note that in the linked report on the modelling methodology, this figure is reduced to 62%.

The report concludes: "On the evidence of our sample, one has to question whether some PHEVs ever see a charging cable" and suggests PHEVs would attract the highest rate of company car tax if they were to be assessed on their real instead of on laboratory test results.

Real-world performance

Until recently, the EU mandatory regulations for new cars would appear to be a resounding success for CO_2 standards. The rate of reduction in official average tailpipe CO_2 values of new passenger cars in the EU increased from roughly 1% per year to more than 3% per year after their introduction in 2009. However, two factors mean this success is not all that it appears.

Firstly, there has been no improvement in tailpipe emissions in the UK since 2015 and average level of CO_2 emissions of new cars sold in September 2018 was 128.3 gCO_2/km, the highest recorded since July 2013. A switch away from diesel only accounts for a small proportion of this increase, the main culprit being the swing over the past decade towards larger passenger cars, particularly SUVs (dual purpose vehicles) while the rest of the market declines (SMMT, 2018). SUVs now account for around a quarter of car sales in the UK with no sign of slowing down. Somewhat shockingly, this proportion holds true for electric vehicles (BEVs + PHEVs) – 25% of all the 32,048 plug-in cars registered by the end of 2017 comprised one make and model only (Mitsubishi Outlander) – an SUV in the form of a PHEV and one of the most polluting cars on the road when not driven on the electric battery.

Secondly, although the above figures suggest a 30% reduction in tailpipe CO_2 emissions since 2000, these are based on test cycle measurements. In practice, there has only been an estimated 9% reduction in tailpipe emissions in real-world conditions, and only 4% since 2010. The performance gap between official and real-world values has grown over time, standing at 42% in 2016 (Teitge *et al*, 2017), although this gap has now stabilised. This gap has effectively negated any reported savings from efficiency improvements over the past decade.

The regulatory failure of the test cycle versus real-world emissions was not mentioned in the CGS but was addressed in the narrative of the subsequent R2Z which frequently noted it would be considering "real-world" emissions. A new test procedure, the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), is being currently being phased in. Whilst a step in the right direction, the WLTP is not a silver bullet and will not close the performance gap on its own. The discrepancy matters to how meaningful the regulatory or stretched targets are and thus how quickly forward projections will be met. Whilst it could be argued that if electricity is zero carbon this should not matter, the energy efficiency of the transport system is an important issue in its own right and will become more important as vehicles play a key part of the electricity storage solution to balance electricity demands on the grid.

Prospects for travel demand change

Collapse of 'business as usual' trajectories of travel demand

The CGS generally adopts an approach of identifying a firmly established baseline forecast of demand, given by reasonably clear economic trends, and treating this as either inevitable or as a target for policy intervention only after other largely technical solutions have been exhausted. Yet, in the context of travel, there is now a strong evidence base that the trends have changed, and continue to do so. Since the early 1990s (but only now being retrospectively understood), actual road traffic growth has been systematically less than forecast so that the hitherto uninterrupted growth in car use is no longer the dominant trend. Periodic discussion of 'peak car' has led into investigations of the evidence (Marsden *et al*, 2018; Chatterjee *et al*, 2018), which reveal that structural changes in travel demand due to shifts in the pattern and location of activities, social changes including delayed family formation, economic changes in the nature of retail and employment (especially youth employment), and possible impacts of mobile internet access, all correlate with a downward trend in overall trip rates. These trends are manifesting differently among different groups and in different types of built-up area (BUA) (Figure 11).

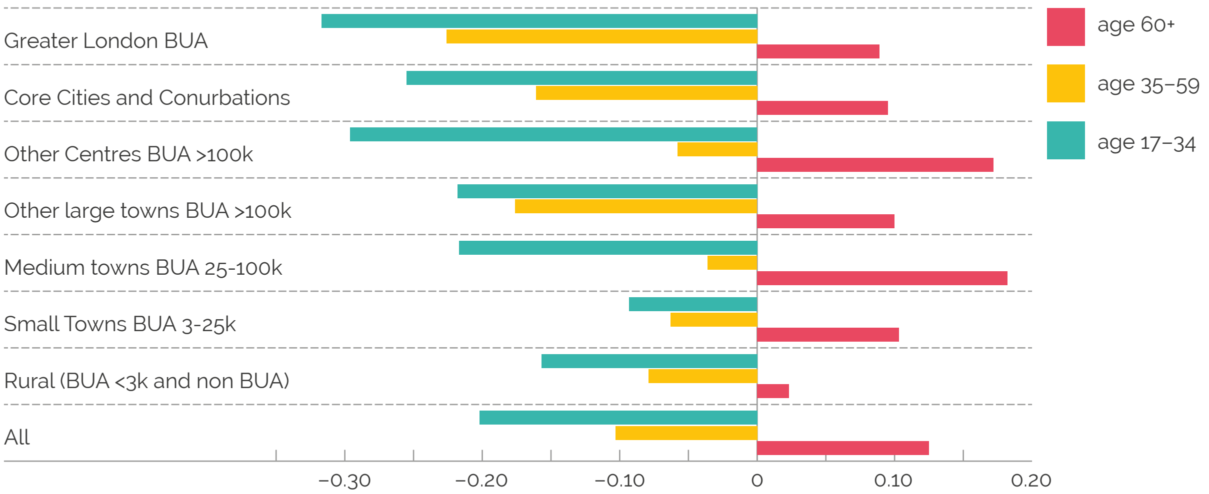

Figure 11: Percentage change in car driver miles per head per year by age group and area type (England 2002–05 to 2011–14). Source: Analysis by P. Headicar as Chart 17, pp18 in DfT (2018). Analyses from the National Travel Survey Statistical Release.

This shows a reduction of 20% and 10% respectively among the two younger groups, an increase of 12% among 60+ year olds with differences in the magnitude (but not direction) of these changes in different places. The outcome is that since the early 1990s, aside from general population growth, it is only an aging cohort of people, now over 60, that has contributed to traffic growth, whereas successive cohorts of younger people have shown a reduction in driving licence-holding, car ownership, and car use.

Such findings sit alongside a very substantial body of experience and evidence about the effects of policy interventions intended to address a much wider range of policy objectives than energy use alone, including health, quality of life, commercial vitality, safety, and equity. These various objectives have all tended to converge on policy packages aimed at reducing the need to travel by better land-use planning, restrictions on car use in central, residential, and environmentally sensitive locations, and facilitating transfer of car trips to public transport, walking and cycling by reallocation of expenditures, street design, pricing and regulation. This allows for a policy perspective where reduced energy use does not run counter to quality of life but arises from measures designed to enhance it. Conversely, relying mainly on electrification of vehicles to reach carbon targets can have the consequence of increasing traffic congestion because of the lower cost and lower taxation of electric fuel. This is seen in the DfT Scenario7 above, where 100% electrification has the highest level of traffic growth.

Thus, it is no longer adequate to adopt what used to be the central or most likely traffic forecasts produced by the DfT as the official view of future trends in demand and, from these, calculate the scale of technological deployment needed to mitigate the carbon consequences of this growth. There is a need for new approaches to demand analysis on how to treat the scope for such policies. Underpinning the observed changes, there are new theoretical understandings of the dynamic processes of travel demand, where changes can happen through demographics, migration, churn, habit formation and breaking, and interactions with land use outcomes, disruptions and social norms. In other words, **"societal needs and demands are not given: they are negotiable, dynamic, and in part constituted by technologies and policies, including those of efficiency"** (Shove, 2017).

Thus, the pattern of co-benefits, empirical evidence on trend shifts and policy implementation, and better understanding of influences on demand, give scope for considerably more ambitious reductions in passenger transport energy and carbon use than has been assumed in the CGS, DfT and CCC publications. Moreover, evidence suggests a lower rate of demand for passenger mobility is a necessary and a credible future, but that this would require a different policy package to achieve and lock-in the new demand patterns, alongside new vehicle technology.

Recommendations for policy

Travel behaviour is already changing in ways that provide opportunities to enable a lower growth trajectory to be deliberately locked-in. National and international examples of sustained lower car-dependent lifestyles indicate that this can be achieved at least in some localities. Such a prospect puts much greater emphasis on policies which influence and provide for more energy-conserving lifestyles, including: emerging models of car 'usership', changing social norms around mobility, new spatial patterns of population growth, the changing nature and location of work, education, housing, healthcare and leisure, reconfiguration of travel by digital technology, and new ways of paying for road use or energy (electricity).

The Avoid-Shift-Improve (Schipper & Liliu, 1999) hierarchy has been used to emphasise the priority ordering and layering of our recommendations that stand apart from the dominant supply and vehicle technology-oriented approach to energy reduction and decarbonisation in the sector. The recommendations focus on surface passenger travel and are targeted at national and local policy makers.

Avoid travel demand and car ownership

Lock-in recently evidenced demand changes

Where specific groups have already shown flexibility in demand, there should be targeting to lock-in those changes, and to extend the behaviour to wider numbers. This can be done through policies such as car clubs, smart ticketing, investment in rail and in digital technology. Access to subsidised or free public transport is at present largely determined by age, and it is clear that behaviour patterns also show strong age effects, but making best use of this may justify an overall review of age boundaries both for the young and old. Improving the experience for these sub-groups of living without a car should not only improve the chances of them opting to live without one (or with fewer per household than they might have done) for longer, but will simultaneously improve non-car travel for a wider set of people and places.

Design regulatory frameworks to steer emergent innovations (e.g. On-Demand mobility, autonomous vehicles) to deliver societal benefit and avoid high travel lock-in in the future

Ignoring the dynamic interactions between society and technology led to the performance gap in real-world energy consumption of vehicles. We are in danger of repeating this mistake with respect to new forms of 'on-demand' mobility services, relinquishing of ownership in favour of shared assets, autonomous vehicles and the two-way integration of vehicles and the electricity grid (see for example Wadud *et al*, 2016). To ensure these developments reduce vehicle miles travelled, a 'preventative' regulatory framework designed to enable these innovations to result in a net increase in co-benefits such as social inclusion and transport and energy system flexibility is needed. Specific interventions such as mandating the use of autonomous vehicles in shared contexts, public investment in car-clubs or on-demand services in rural areas and designing car scrappage schemes to accelerate the uptake of mobility packages as opposed to new vehicles, will be necessary[13].

Develop a cascading framework of national and local support for car clubs

Having access to a shared vehicle has been shown to lead to reductions in personal car ownership and miles driven, as well as increased use of other modes of transport (Marsden *et al*, 2018). This reduction includes households giving up a car completely, but equally important is reducing from, say, two cars to one car. More creative support options can be explored at the national and local levels to ensure that more people can opt out of owning a car in favour of accessing shared car club services.

13 Transport for West Midlands is trialling a Mobility Credits Scrappage Scheme from March 2019.

These support options can take the form of both carrots (e.g. supporting interoperable underpinning ICT infrastructure, 'smart' design of car scrappage, integrating shared travel into multi-modal journey-planning apps, providing dedicated car parking, charging and signage to car club vehicles) and sticks (e.g. parking charges and restrictions in residential areas and workplaces for privately owned vehicles). The benefit of a nested approach to national and local support for car clubs is evident from Scotland, where there was membership growth of 29% between 2016 and 2017 (Steers Davies Gleave, 2018). The overall aim would be to reduce the size of the passenger car fleet as well as accelerate its decarbonisation as vehicles are utilised more intensively and renewed more frequently.

Incentivise the coordination of transport and planning objectives to reduce the need to travel

Enabling travel avoidance is chiefly a matter of coordination of planning and transport objectives in the housing type and location, density of development and location as well as timing of services (including workplaces, schools and healthcare). Local authorities receive bonuses for achieving housing targets with none of this bonus tied to the travel and energy efficiency of the developments. Businesses also need to be engaged through incentivisation of the reduction of their travel footprint, including commuting, perhaps linked to an expanded system of Display Energy Certificates. Similarly, there should be greater integration between the planning and prioritisation of investment in digital infrastructure and transport to support many of the above initiatives but also to deliberately substitute some travel by virtual access in ways that avoids further spatial fragmentation and net increases in demand.

Develop a zero-growth indicator

By adopting a scenario approach for car travel, the DfT analysis suggests de facto acceptance of a varied range of potential growth scenarios for alternative modes. Under this multiple scenario approach, policies need to be appraised themselves not under a single scenario, but under the assumptions of at least the high growth and low growth possibilities. This itself means that flexibility and adaptability – if (when) forecasts turn out to be wrong – becomes an advantage. This flexi-appraisal would be extended to non-transport transport policies – i.e. traffic-generating land use developments, service reductions in rural areas and policies leading to the centralisation of core services such as health and education.

From this, it is possible to imagine the development of a zero traffic or transport energy growth objective, or indicators based on capacity constraints on the electricity grid. For instance, Norway has adopted a zero-growth objective for car traffic in urban areas embedded in a national transport plan which introduced 'urban environmental agreements' (Norwegian National Rail Administration, 2016). This will involve environmental and time differentiated road tolls linked to "stronger investment in urban areas".

Incentivise local authorities to achieve a zero-growth indicator

The CGS does not address the issue of scale and location. Nevertheless, place-based industrial strategy is gaining traction as a key principal of innovation programmes at the European and UK levels. Just as we have highlighted that recent changes in travel demand have been unevenly distributed, the uptake of technology, including energy generation, will also differ. Methods of analysis, policy design and appraisal need to work with this geographical diversity. In particular, local authorities need to be incentivised to reach the zero-growth target indicator outlined above.

Shifting travel to the most sustainable modes

Systematic support for the very lowest energy modes of transport

Enabling and encouraging a shift from private motorised travel to more energy efficient modes requires systematic support for the very lowest energy methods of transport – walking, cycling (including e-bikes and e-scooters) and public transport, through investment programmes on both capital and revenue spending, priority use of road space, and an expansion of 'soft' or 'smarter' methods of encouraging behavioural change. The goal would be to design **"a mobility system where it is more normal to take part in activities using the most sustainable modes more of the time"** (Marsden *et al* 2016).

Institute a new approach to prices and taxes to reflect a fuller range of costs and benefits

A new approach to transport pricing would ensure that the relative prices of different transport options reflect the full range of costs and benefits to the consumer, including health, energy, embedded emissions, congestion and other environmental impacts. Restructuring prices could include direct subsidy to lock-in sustainable travel choices by charging for use of scarce resources at a rising unit rate where more is used. Such pricing mechanisms would therefore expand the traditional notion of road user charging to reflect wider transport and energy system usage and will incorporate thinking on how to avoid increases in demand that may be stimulated by lower motoring costs of ULEVs.

Improving efficiency of individual modes

Improve the efficiency of vehicles in use, particularly through increased occupancy

A focus on efficiency of vehicles in use is much more than eco-driving. It considers maximising assets in ways that substantially reduce single car occupancy and individual ownership. There is no detectable policy weight placed on the efficiency of vehicles in use, even though increasing vehicle occupancy, potentially through mobility sharing platforms, would ratchet down energy intensity of travel considerably. There are a number of potential types of initiative targeting both businesses and individuals, again falling into carrot (mileage fee reimbursement rates and salary sacrifice incentives) and stick (regulation of the 'grey fleet' (use of own cars on business travel), parking restrictions and fees) as well as a review of company carbon accounting to incorporate commuting travel.

Restructure ULEV targets to include phasing out hybrid cars

As our own empirical work has highlighted, the trajectory for urgent CO_2 savings requires phasing out all forms of conventionally fuelled ICE and HEV cars and vans by 2030 and that net-zero (for tailpipe emissions) may only be achieved by also phasing out PHEVs by this date. The current wording of targets is at best muddled, but at worst leaves the door open for hybrid vehicles, and subsequent locking-in of a substantial amount of fossil-fuelled mileage during and beyond the target dates.

Regulate to reduce the availability and sales of large cars

The stagnation in average CO_2 emission values of new passenger cars in the UK in recent years has much to do with an upsurge in purchase of larger cars. Some of this trend is likely to be due to people choosing to apply the savings from greater energy efficiency to buy more comfortable, more reliable, or more prestigious vehicles which, being larger and heavier, use more energy than necessary for like-for-like journeys. The implication is that measures of energy efficiency which reduce costs can only be fully effective if they are combined with other measures to prevent or offset such countervailing processes. In this case, regulation of sales-weighted average new car carbon emissions is failing and needs to be redesigned to, once again, lock-in the net benefits of this policy. This could potentially involve regulating to phase out the largest vehicles or restrict their use to genuinely appropriate circumstances.

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5. Electricity: making demand more flexible

Jacopo Torriti and Martin Green (University of Reading)

Background

The UK Government's Clean Growth Strategy (CGS) places significant importance on flexibility in electricity demand. Flexibility is important because the integration of intermittent renewables in the supply mix, as well as high penetration of electric vehicles and electric heat pumps, will challenge the balance of demand and supply. The CGS considers demand flexibility will need to play a vital role for a stable electricity system as existing approaches to balancing are inadequate. In this context, there are opportunities to reduce the costs of electricity if smart systems and battery storage are used to flex demand at times when it is high. In a nutshell, demand-side flexibility is portrayed in the CGS as a win-win solution, as consumers will help balance the grid in return for lower bills if they take advantage of smart appliances and smart tariffs.

The key part of the CGS on demand-side flexibility is in 'Delivering Clean, Smart, Flexible Power'. This points to investments from the UK Government of £265 million between 2015 and 2021 in research, development and deployment of smart systems to reduce the cost of electricity storage, advance innovative demand-side response (DSR) technologies and develop new ways of balancing the grid. The move to low carbon generation will increase the variability of electricity supply, as key technologies depend on both weather (e.g. wind speed) and daily and annual cycles (e.g. solar radiation). The general view is that a more flexible system is required. Most of the principles underpinning the vision for demand flexibility are set out in the 2017 smart systems and flexibility plan (BEIS and Ofgem, 2017). The plan is based on a report that shows a system using DSR and distributed storage to provide flexibility would be between £17bn and £40bn cheaper over the period to 2050 compared to a system that relies on enhancing flexibility through interconnectors and pumped hydro storage (Carbon Trust & Imperial College, 2016).

This chapter focuses on drawing together existing research evidence to inform an independent analysis of the flexible energy demand aspects of the CGS. Given the importance and relative novelty of flexibility at the scale envisaged in the CGS, the policy implications need to be thought through carefully and based on evidence. Research needs to ask fundamental questions around whether flexibility benefits systems as well as consumers. The two key aims of this chapter are: (i) to assess whether different/additional policies and measures will be required, and (ii) to identify important research gaps to be filled by CREDS through co-created research. In order to deliver these two aims, this chapter compares the overall level of flexibility forecast in the CGS with other studies; presents alternative approaches to achieve flexibility; and suggests areas of research in this emerging field. It is concluded that moving to higher levels of demand flexibility will require radical shifts. This calls for more clarity at the planning stage on the following questions: will flexibility be achieved through technology interventions alone? What role do smart tariffs play at different levels of penetration? Critically, research is needed to assess the win-win proposition stated in the CGS, i.e. that consumers and the electricity grid will both benefit from the introduction of greater flexibility.

This chapter questions how ambitious the flexibility target in the CGS is compared with existing studies; describes what is planned in the CGS; proposes a radically different Government approach on flexibility; and concludes by identifying three significant research gaps.

How much flexibility? An unambitious target

The CGS presents figures on levels of flexibility for the future based on BEIS' 2032 pathway calculations for an 80% renewables future. Electricity demand is projected to increase by 3% (10 TWh), with an increase in peak demand of 4% (2.8 GW), by 2032 from 2016 levels. The extra capacity and flexibility is proposed in the CGS to originate from DSR (4.9 GW), storage (0.3 GW), clean generators (0.5 GW) and fossil fuels (1.2 GW). The increase in peak demand is argued to arise from the uptake of electric vehicles and heat pumps. This allows for some implicit DSR (i.e. the effect of consumer response to time-dependent pricing), which would consist of shifting to overnight charging for most electric vehicles and smart controls of heat pumps.

This proposed increase in DSR is a relatively unambitious target. National Grid estimates that 2.7 GW of DSR capacity, equivalent to two large power stations, participated across their portfolio of balancing products and services in 2017 (National Grid, 2017). A report by the Association for Decentralised Energy suggests that by 2020 DSR could provide 4.5 GW thanks to 2.8 GW from industrial demand flexibility and 1.7 GW from commercial and public sector demand flexibility (ADE, 2016). A report by Element Energy estimated that the non-domestic potential of DSR in 2011 was in the range of 1.2–4.4 GW (Element Energy, 2012). The scenarios prepared by the Carbon Trust and Imperial College suggest DSR deployment of between 4.1–11.4 GW by 2030. This variation highlights the opportunities, yet clear uncertainty, in the DSR potential offered by the electrical assets in UK businesses.

Figure 12 shows future levels of DSR in the UK according to different studies and reports. The size of the bubble represents how large forecast DSR levels are and the position of the bubble indicates the year to which the forecast applies. The red line represents the trend and, notably, the purple bubble (i.e. CGS) has the lowest ambition in terms of DSR penetration.

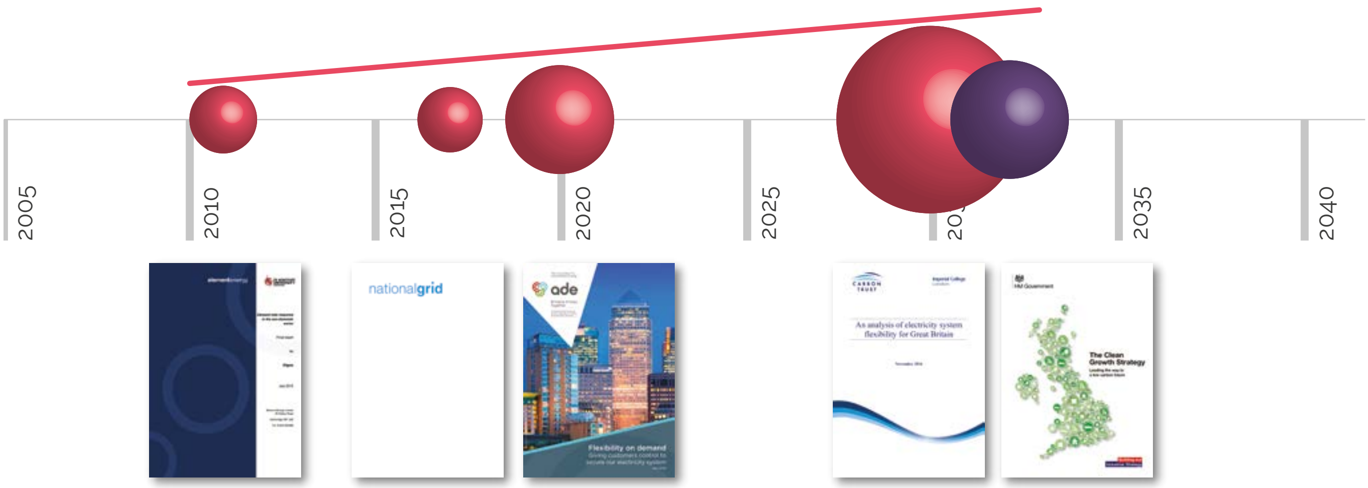

Figure 12: Forecast future levels of UK Demand Side Response (in GW) in different years.

The flexibility target in the CGS is not sufficiently ambitious. This is because the analysis underpinning the target relies heavily on the "five-day stress test", which was designed only to address the challenge of balancing the electricity system during adverse winter weather conditions of high demand and low renewable electricity output. This approach to the need for flexibility and DSR is anchored in the old 'plan and provide' approach to system operation, in which flexibility is only needed to ensure adequate total capacity. However, in any highly renewable future, flexibility will be needed to meet a variety of requirements, including capacity adequacy under stress conditions, but also the ability to increase, decrease, or shift electricity demand frequently.

Actions planned in the CGS

The 2017 Smart System and Flexibility plan outlines 29 actions under three areas (removing barriers to smart technologies; smart homes and businesses; and markets which work for flexibility).

With regards to market arrangements, the actions are aimed at amending issues preventing DSR participation, including ensuring that storage and demand flexibility participate on a level playing field in the Capacity Market; delivering efficient access for independent aggregators to the Short Term Operating Reserve (STOR); simplifying ancillary services and making them more transparent; changing network charges; and improving stakeholder engagement in flexibility.

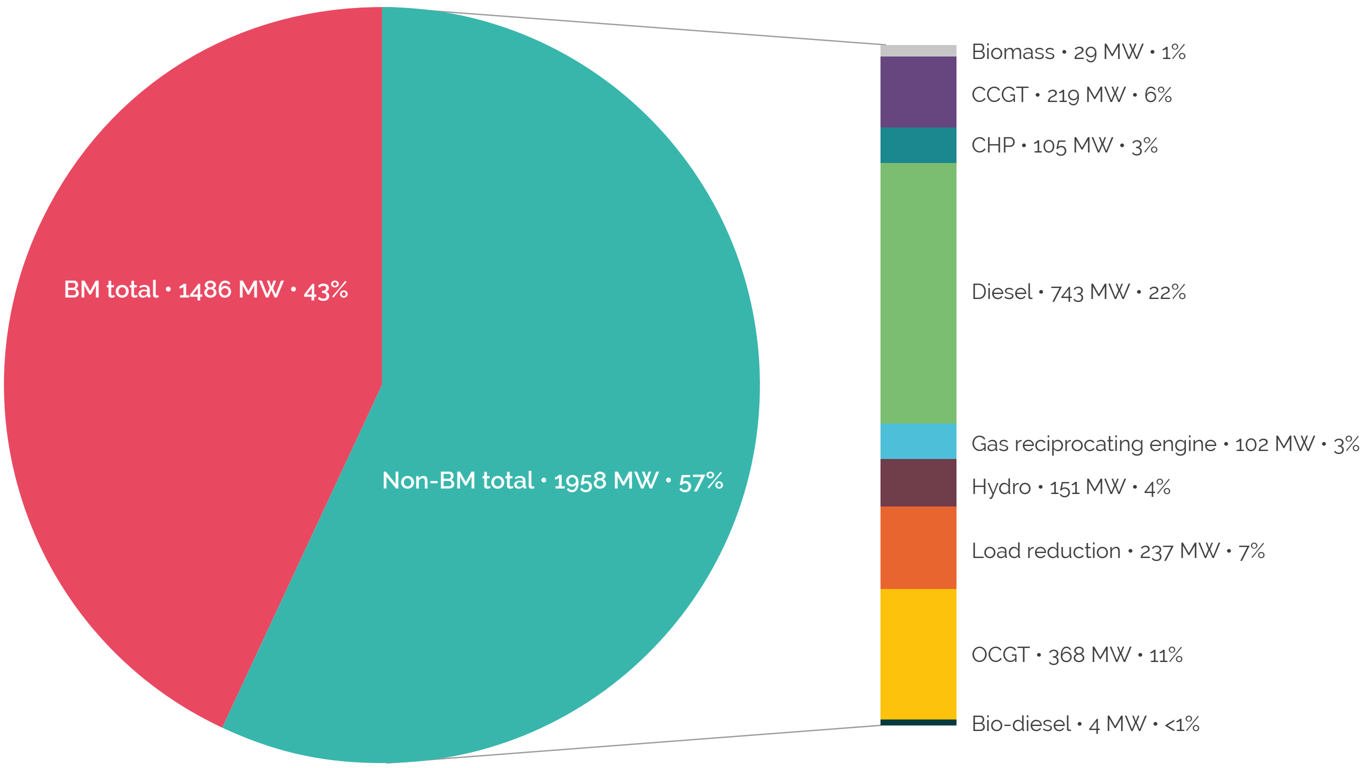

Figure 13: Detailed breakdown of non-balancing mechanism. Source: National Grid, 2015.

Figure 13 provides a breakdown of the resources used by the System Operator (National Grid) to balance supply and demand at different times. The Balancing Mechanism (BM) uses price signals to incentivise generators to come on or off the network. Outside the BM are several other options that can be deployed quickly, for example through STOR. The figure shows that 237 MW (7% of overall STOR capacity) is from load reduction (which in this case is likely to also include load shifting DSR, as the National Grid uses the term 'load response' to cover both load shifting and 'turn-down') (National Grid, 2017). In addition, DSR contributes to the provision of adequate capacity. The turn-down DSR only Capacity Market auction in March 2017 resulted in Ofgem awarding 300 MW of contracts to DSR (Ofgem, 2017). These two MW figures cannot simply be added as each could be provided from the same assets. Therefore, based on the figures obtained from published reports and assuming additional amounts have been provided via other sources, a rough estimate of turn-down DSR is between 300-500 MW. This represents only 6-10% of what is required to meet the CGS target of 4.9 GW of DSR. A much more radical approach is required for flexible demand as explained in the section below.

Changing approach completely on flexibility

The CGS and the 'Smart systems and flexibility plan' can be seen as the first positive steps towards the inclusion of demand-side flexibility in a low carbon energy system. However, in order to accommodate high levels of flexibility the actions they put forward will be insufficient. This section puts forward more radical suggestions for the integration of flexible demand in a low carbon future.

If flexibility is to play a major role, the rules have to be changed entirely

There is no specific market programme for flexibility in the UK and DSR is instead contained within the current electricity balancing services of the Electricity System Operator (a company in the National Grid Group). While STOR is a means of providing DSR, its current structure provides a number of barriers to uptake and discourages investments in DSR. These market rules favour generator-based services and restrict turn-down solutions. Battery storage is currently charged fees for using the energy network as both a demand customer and a generator, i.e. both when drawing power from and discharging power back to the system.

Table 1 – Review of DSR barriers

Barrier Category	Barrier	Research Source							
		1	2	3	4	5	6	7	8
End user	Lack of DSR awareness / understanding	●							●
	Impact Concerns	●	●			●	●		●
	Risk aversion / trust issues		●				●		●
Regulatory	Regulations unfavourable for DSR	●		●	●	●	●	●	●
	Current regulations preventing DSR							●	
Technical	Lack of ICT infrastructure	●				●			
	Cost of enablement			●			●		●
	Equipment not suitable for DSR			●			●		●
Market	Lack of DSR market options	●		●		●		●	
	Insufficient financial incentives		●	●		●	●		●
	Traditional large generation bias			●	●	●			

Source Key:

1 (Strbac, 2008) Demand Side Management: Benefits and Challenges

2 (Owen, Ward, & Pooley, 2012) What Demand Side Services Could Customers Offer?

3 (Cappers, MacDonald, Goldman, & Ma, 2013) An Assessment of Market and Policy Barriers for Demand Response Providing Ancillary Services in U.S. Electricity Markets

4 (Warren, 2014) A Review of Demand-Side Management Policy in the UK

5 (Nolan & O'Malley, 2015) Challenges and Barriers to Demand Response Deployment and Evaluation

6 (Olsthoorn, Schleich, & Klobasa, 2015) Barriers to Electricity Load Shift in Companies: A Survey-based Exploration of the End User Perspective

7 (SEDC, 2017) Explicit Demand Response in Europe: Mapping the Markets 2017

8 (The Energyst, 2017) Demand-side Response: Shifting the Balance of Power: 2017 Report

Box 1 – key barriers for DSR uptake:

The research literature on DSR identifies many different types of barriers, which fit into the four main categories of: end user, regulatory, technical, and market (Table 1). The end use barrier focuses on issues that end users have direct influence over, such as lack of interest in DSR. Examples of regulatory barriers include the fact that several Governments do not yet acknowledge the role of independent DSR aggregators in enabling uptake. One of the major technical barriers is end user equipment being deemed as unsuitable for DSR. Market barriers consist primarily of the absence a specific market programme for DSR.

National Grid's estimate of the DSR contribution to overall balancing (2.7 GW in 2017) is probably an overestimate as it includes smaller scale diesel generation, which is not truly DSR as diesel generators are not associated with an energy user; rather, they are dedicated supply-side assets as illustrated in Figure 13. Considering only user-led demand management and on-site generation participating in the Balancing Services, the amount of DSR used for balancing the system in 2017 was approximately 700 MW. Changing the rules entirely might involve, for instance, the development of a flexibility market which can place a higher value on more flexible resources (DECC, 2013).

The capacity market is an ineffective instrument to provide flexibility

The UK's Electricity Market Reform policy aims to deliver low carbon energy and reliable supplies. A key mechanism this uses is the creation of a Capacity Market that "provides a regular retainer payment to reliable forms of capacity (both demand and supply side), in return for such capacity being available when the system is tight" (DECC, 2013). While this policy specifically includes DSR and storage as a measure for meeting the mechanism's aims, it has been criticised for restricting participation, arbitrarily limiting contract lengths and offering only uncertainty about storage capacity during transitional arrangements (Yeo, 2014). The Capacity Market only offers one-year storage contracts compared with the up to 15-year terms available for fossil fuel generator contracts. The problem with supporting flexibility through the Capacity Market is that the latter was originally intended for security of supply and, where auctions award long-term contracts, to help de-risk power station construction. Balancing the electricity system depends on two conditions: capacity adequacy, i.e. enough power generating capacity to meet demand; and flexibility, i.e. the system's responsiveness to changing conditions. In the past, capacity adequacy has been the dominant concern of policymakers and the Transmission System Operator. However, the structural shift to renewables is making flexibility a priority.

Following the ruling by the European Court of Justice, the Capacity Market is currently in a 'standstill period'. The last auction for delivery in winter 2019 cleared at £6 per kW. This very low price reflects the high level of capacity, 10.7 GW, bidding for a target of 4.9 GW, although around 5.8 GW was awarded. The Capacity Market standstill provides an opportunity to think collectively about its rules. Is a Capacity Market really needed? If a Capacity Market needs to be in place, we suggest that different rules in terms of size, duration and notice periods should be considered in order to ensure participation of flexibility assets (Grunewald & Torriti, 2013).

Demand turn-up should not be isolated – it will become a vital part of the system affecting wholesale prices

The CGS defines the need for flexible capacity (6.9 GW) as the need to meet peak demand (4.9 GW in addition to current peak demand). This mainly relates to peaks in winter evenings, which traditionally are associated with the lowest margins between supply and demand. However, in a low carbon future, flexibility will need to be integral to the system, not only a small resource to be drawn upon in an emergency as an aid to capacity adequacy. For instance, electricity wholesale markets in Germany and GB have, on several recent occasions, moved into negative prices, which is to say that buyers are paid to use power by sellers. Examples of sunny and windy Sundays in which demand is low and renewable generation is high abound and will increase the need for increasing demand ('turn-up') (Torriti, 2016). Some examples of questions currently unaddressed in the CGS include the following: are there monetary benefits for consumers in relation to demand turn-up; will these be seized be specific categories of consumers? In research, as well as in policy, there needs to be greater clarity over the role of demand turn-up.

The CGS does not address how much flexibility will come from implicit DSR

Over the past couple of decades, flexible electricity demand, in the form of turn-down and load-shedding has predominantly taken place through the participation of industrial and large commercial users[14]. Whilst there are studies which suggest that much more flexibility is technically and economically available from industry, ambitious targets will need to consider various forms of flexibility from different types of consumers. Moreover, 'implicit' demand response, in the form of time of use (ToU) and other time-dependent tariffs is generally seen as a way to increase flexibility in residential use. The CGS is not explicit about the levels of flexibility to be derived from the residential sector. This may be due to uncertainties about the social and political acceptability of a system in which tariffs are no longer flat. The timing of electricity use by individual households is currently estimated using average 'profiles'. The introduction of smart meters provides an opportunity to collect more detailed data and use this to allocate electricity to suppliers based on a customer's actual demand in each half-hour. Whilst moving away from profiling to half hourly metering does not imply that there will have to be variable tariffs, some of the main benefits of smart meters (e.g. reducing the need for new generation and network capacity) are supposed to be associated with the introduction of variable tariffs. The impact of more cost-reflective pricing will vary between consumers and this will need to be better understood.

Areas in which different and/or additional policies and measures will be required

We recommend that BEIS should create a common policy for DSR in order to maximise the flexibility potential of electricity demand. DSR to date has been mainly an operational decision in the hands of National Grid, relying mostly on the flexibility of industrial and commercial end-users. National Grid is currently revisiting the services in which DSR operates. However, the next step, possibly in the next two years is for BEIS to introduce a common GB policy, which would encourage uptake from residential end-users with significant implications for grid balancing and cost reduction.

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14 This has been explained as a reflection of interruptible programmes and aggregators having higher incentives for higher capacity in Torriti *et al*, 2010.

The policy should improve the current rules of the game of DSR (as highlighted in Box 1) as they significantly prevent participation from smaller energy users and leads to limited participation of load turn-down which requires more than 10 minutes' notice (see Figure 14).

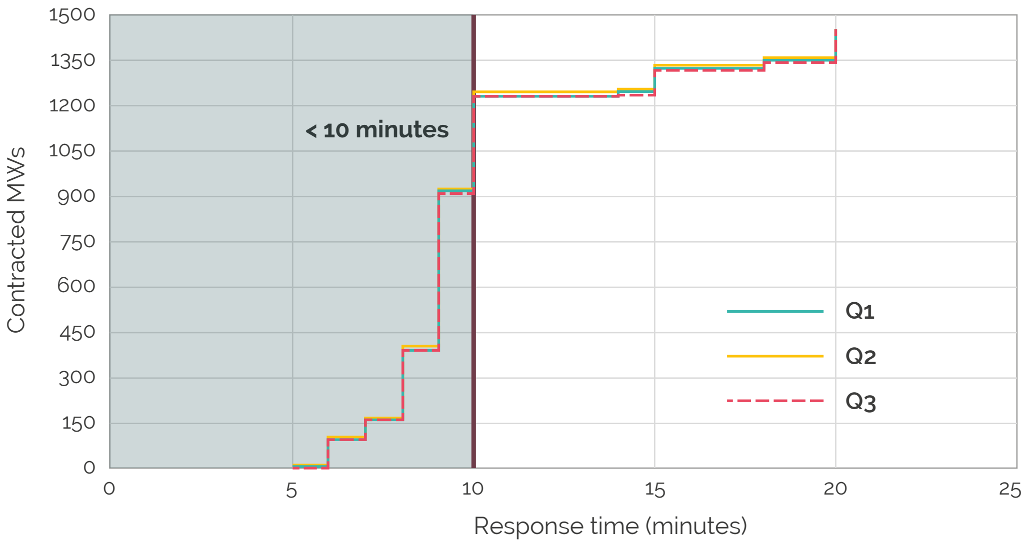

Figure 14: Distribution of STOR contracted loads by response time. Source: National Grid (2017). STOR Market Information Report.

1. **We recommend that consumers should be enabled to benefit from the reform of the pricing settlement**. Ofgem's recent decision to move to **half-hourly settlement** enables suppliers to know how much their customers consume every half hour. Hence, suppliers could offer tariffs based on **dynamic pricing**, such as ToU tariffs, which have the potential to shift demand away from times when demand is higher. A reduction in the amount of consumption at peak times should reduce the need for investment in new generation and network capacity and hence bill payer cost.

2. **We recommend that the National Grid Capacity Market should aim to increase storage and DSR participation, extending the one-year contracts under transitional arrangements for a longer time period**. This will decrease investors' uncertainty and boost the uptake of storage technologies. BEIS should consider contract duration as part of their review of Capacity Market rules. BEIS should review Capacity Market rules also in terms of the balance between capital expenditure (Capex) and operational expenditure (Opex). The current low Capex and high Opex system means that capacity payments are more certain than market revenue, investors are incentivised to build diesel and gas engines, at the expense of low carbon and more efficient gas solutions.

3. **We recommend reform of the current system of double charging for storage**. To avoid this, the Ofgem Access Framework should be modified to develop clearer definitions of capacity rights as distinct from connection capacity. In practice, changes to the Electricity Act 1989 will need to include the definition of storage as a subset of generation asset class and not as end consumers of energy.

Research gaps

This brief review of the CGS points to three main areas in which further research is needed.

First, any transition brings about change that could potentially disrupt the more vulnerable and strengthen those who have capital means. If the transition to a low or zero carbon economy is to be equitable, there will be a need for research on how vulnerable consumers will be impacted. An example comes from ToU tariffs, which in principle offer significant potential benefits to the system by enabling responsive electricity demand and reducing peaks. However, the impact of more cost-reflective pricing will vary between consumers. In particular, those who consume electricity at more expensive peak periods, and who are unable to change their consumption patterns, could end up paying significantly more. Understanding the distributional effects of ToU tariffs becomes vital to ensuring affordability of energy bills, while making demand more flexible. Research will shed light not only on average responses to changes in prices, but also on how people's flexibility varies based on the time of the day, location, work and social commitments.

Second, the CGS views technologies as (the only) enablers of higher flexibility. Attempting to engineer solutions may not lead to the desired effects of higher flexibility unless there is a deep understanding of how everyday life changes along with the new technologies. If such solutions and interventions are only developed to meet current 'need' and their business case assumes this 'need' is fixed, then the risk of developing rapidly obsolete and uneconomic interventions is high. Research can help understand the trajectories of change that must be considered and thus inform adaptive intervention design. Research is needed to understand, for instance, how electric vehicles and home battery storage might shape, and be shaped by, patterns of demand in people's everyday lives.

Third, the CGS views flexibility as originating from DSR, storage, clean generation and fossil fuel generation. However, flexibility could be derived from a variety of actions and changes, some of which may originate from the non-energy sphere. The impact of electric vehicles is an obvious example of new possibilities for flexibility which has only gained currency in recent years. The decarbonisation of heat could provide fuel switching and other opportunities for flexibility. Similarly, flexibility could be the result of non-energy changes in society and technology. Research which breaks the boundaries of sectors could shed light on opportunities for flexibility beyond existing options. For instance, in the future flexible work arrangements and an increase in work from home might have implications for when and where energy is consumed and the types of flexibilities available at different scales.

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6. Using zero carbon energy

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Introduction

Earlier chapters of this report set out the scope for reducing energy demand through deployment of improved efficiency and changes to energy-using practices. These are very significant and, in many cases, likely to be cost effective in a zero carbon economy. However, even with significant improvements in efficiency and reductions in demand, the fuels used throughout the economy will need to be decarbonised. This has obvious implications for the energy supply system, but it will also require major changes in the way that energy is used.

This chapter sets out the issues involved in moving towards the use of decarbonised fuels. Using a demand-side perspective allows the incorporation of important questions such as 'How much energy do we need?', 'What are the alternatives for providing a similar service?' and 'How socially acceptable are they?' into the analysis.

To date, the main focus of the transition to zero carbon fuels has been on electrification. Decarbonisation of energy services that are difficult to electrify remains less well-addressed. This is now widely accepted as the major challenge for decarbonisation of energy. It is clearly a challenge for new forms of energy supply to scale up to replace petroleum and natural gas. However, there are also huge implications for energy users. In most cases, switching from high carbon to zero carbon fuels cannot be achieved without changes in technology and practices at the point of energy use.

Current UK policy set out in the Clean Growth Strategy (CGS) reflects some of these issues and the potential role of fuels other than electricity, particularly in its hydrogen pathway in the sections on "transforming manufacturing and heavy industry" (page 68), "the future of heat decarbonisation" (page 82) and "lower carbon (transport) fuels" (page 91). In each case, some relevant innovation challenges are identified. However, the demand-side challenges associated with use of zero carbon fuels are not fully addressed.

Electrification of demand and its limits

Electricity has proven to be the easiest energy vector to decarbonise. There are multiple low and zero carbon options. There has been huge progress in reducing the cost of solar and wind technologies; these are now broadly competitive with conventional generation under UK climate conditions, and further price reductions are likely.

The potential role of increased electrification in decarbonisation has been known for many years in buildings (Johnston *et al*, 2005), transport (Romm, 2006), and more broadly (Edmonds *et al*, 2006). However, only more recently have mainstream studies projected electricity to become the dominant energy vector, both in the UK (CCC, 2008; BEIS, 2017) and internationally (IEA, 2015; IPCC, 2014; Sugiyama, 2012).

The extent to which electrification will increase total demand for electricity will depend on the balance between demand reduction and electrification (Eyre, 2011). Assumptions about demand reduction opportunities, in particular, have led to very different official projections for electricity demand growth, for example much lower in Germany (BMWi, 2015) than in the UK (DECC, 2011). Many models designed to address global climate issues are insufficiently detailed to address energy demand questions reliably (Lucon *et al*, 2014). Only recently have global analyses emerged that allow for known demand reduction opportunities (e.g. Grübler *et al*, 2018), showing the important potential of demand-side change for climate mitigation.

Greater levels of electricity demand flexibility will be needed in a system with increasing levels of variable and inflexible generation (see Chapter 5). However, this is far from the only constraint on electrification. There are several energy services for which use of electricity as a replacement for other fuels is problematic. These are discussed below.

- Industrial processes. These are highly diverse, but many rely on fossil fuels for reasons other than their energy content. These include the roles of high temperature flames in heat transfer, and the chemical properties of fuels, for example as a chemical reducing agent or a feedstock.
- Freight transport, shipping and aviation. Whilst electric vehicles (EVs) are now widely expected to become the low carbon choice for light vehicles, electricity storage for electrification of road freight, shipping and air transport is more problematic, because of the weight and volume of batteries required.
- Space heating in buildings. The scale and seasonality of space heating demand imply that complete electrification would require very large investments in either or both of peaking generation and inter-seasonal energy storage. Both are likely to remain expensive, making complete electrification an unpromising strategy.

Low carbon vectors other than electricity are required to address user issues in these sectors, but also to replace the long-term energy storage provided by fossil fuels.

Alternatives to electrification

The most commonly considered non-fossil alternative in these applications is biomass. There is a very active debate about its role in global decarbonisation driven by concerns about its availability, its potential to compete with food crops, biodiversity impacts and the sustainability of the natural carbon cycle. In the UK, constraints are amplified because of the high population density: the practical resource is only ~10% of current UK energy use (Slade *et al*, 2010; CCC, 2018a). Whilst importing biomass is possible, it seems unlikely to be a secure option for the UK in the context of global demand for low carbon fuels. Moreover, in terms of climate mitigation, these limited supplies of biomass are better used for sequestering carbon than for combustion without carbon capture (CCC, 2018a).

More recently, attention has focused on hydrogen (BEIS, 2017; CCC, 2018b). Whilst the investment costs of a transition to hydrogen would be very large, there seems little doubt that it is technically possible to convert gas distribution grids to hydrogen (Sadler *et al*. 2016). This would offer significant benefits in avoiding stranded assets in the gas sector. The Clean Growth Strategy assumes that the preferred route to hydrogen production will be steam methane reforming of natural gas with carbon capture and storage (CCS). Analysis indicates it is likely to be the cheapest option (CCC, 2018b). However, CCS is not well-established at a commercial scale, so costs are uncertain. Other options exist (RS, 2018). The most promising is electrolysis, as lower costs and rising output from variable renewables will increasingly make cheaper electricity available for large parts of the year (Philibert, 2017).

There are other hydrogenous gases and liquids which are potentially easier to store and transport. There is increasing attention to ammonia produced from renewables, as an industrial feedstock, a fuel for shipping and an energy storage medium. Carbonaceous liquid fuels, synthesised from hydrogen and carbon dioxide, can be carbon neutral and have obvious attractions in transport. However, feedstocks and/or conversion processes would have to change for costs to be competitive with other low carbon options.

A demand-side approach

Perspectives that focus solely on decarbonising energy supply imply that there will be wholesale change to the energy supply system, but no significant change to the structure of demand. This is contrary to the experience of previous energy transitions. The development of coal supply and steam power is synonymous with the industrial revolution, in which human economic and social activities were transformed. Similar effects can be expected in the low carbon transition. Supply technologies will coevolve with the activities and technologies that use energy. Buildings, transport and industry, and their energy uses, are all likely to be very different after a zero carbon energy transition. **We therefore recommend that analysis of fuel decarbonisation includes assessment of the implications for energy use and the potential for alternative approaches to providing energy services**.

Demand-side approach – industrial processes

Chapter 3 of this report sets out the opportunities for reducing energy demand in industry by improving process efficiency and reducing the demand for new materials. Decarbonisation of fuels will also be required. It is difficult to make generic statements about energy use in industry, given the wide range of processes used. Electricity is already dominant in some sectors, notably aluminium and chlorine manufacturing, as well as important sub-sectors such as secondary steel-making. Some additional electrification is possible, for example in relatively low temperature processes such as drying, where heat pumps can provide a more efficient option than fossil fuel technologies.

Similar easy wins are not available in many high temperature process sectors, such as primary steel and cement, and therefore more radical decarbonisation options need to be explored. There is a growing literature (Philibert, 2017; BZE, 2017; ETC, 2018a; ETC 2018b; CCC, 2019), which explore options that go beyond the UK Government's road maps (BEIS, 2015) and the related actions plans that were published alongside the Clean Growth Strategy (BEIS, 2017b). These have some common elements, including a short-term focus on energy efficiency, with future decarbonisation based on some combination of CCS, hydrogen and biomass.

The longer-term options will require policy intervention to support innovation and to displace the incumbent, fossil fuel intensive processes. There are welcome signs of innovation support under the Industrial Strategy Challenge Fund. However, the road maps and action plans developed in collaboration with industrial stakeholders are too restricted. Their focus is on decarbonising existing processes, with insufficient attention to fundamental changes in demand. This is most obvious in the documents addressing the oil refining sector. These assume a significant continuing role for petroleum products in transport in 2050, which we judge incompatible with global and UK Government energy system decarbonisation goals.

Decarbonisation of production will raise the costs of key materials. These and other changes will change the demand for those materials. Decarbonisation analyses need to include potential new processes and materials with lower energy and carbon intensities. The Government roadmaps include on-site material efficiency options, but exclude demand-side resource efficiency. We believe this is a significant omission. Industrial process energy use is a prime example of where we need to think about 'what energy is for', and whether the services provided by the materials and products can be delivered in different, and more sustainable ways. For example, the process and manufacturing emissions involved in making cement can be reduced upstream – by more efficient processes, different fuels and CCS – but also downstream by recycling, new materials and new construction techniques. **We recommend that the analyses underpinning the UK industrial roadmaps is extended to include material efficiency options**. Existing analysis (see Chapter 3) and future research by CREDS can feed into this.

Demand-side approach – freight transport, shipping and aviation

Chapter 4 of this report sets out the opportunities for changing energy demand through changed patterns of mobility and new passenger road transport technology. Light goods vehicles in urban areas offer some early opportunities for electrification due to the potential for dedicated recharging facilities. Heavy road freight, shipping and aviation are not so amenable to electrification and will require different approaches to decarbonisation.

Electrification of long-distance road freight using batteries has weight and volume penalties. The most widely-considered alternative is hydrogen-powered vehicles, using either internal combustion engines or fuel cells. This raises the issues about large-scale production of hydrogen that are discussed above. However, the filling stations used for liquid transport fuels may be an easier early market for electrolytic hydrogen than gas grid decarbonisation.

Battery operated ships and planes appear technically feasible over short ranges, but these transport modes are principally used for long-range transport. There is interest within the shipping and aviation sectors in use of biofuels. However, the underpinning assumption that long-range transport is the best use of limited bioenergy resources is not supported by current evidence (CCC, 2018a). Moreover, at the altitudes used for most long-distance aviation, any combustion releases emissions that contribute to climate change.

We welcome the commitments in the Clean Growth Strategy to supporting technological innovation for advanced fuels and improved efficiency in road freight, aviation and shipping. These will undoubtedly be necessary to achieve energy policy goals. However, the analysis assumes the continuation of existing trends of growth in long-distance freight transport, driven by increased consumption and trade. As Chapter 4 of this report indicates, demand growth is not inevitable and projections need to be subject to critical review.

Demand-side approach – space and water heating

Chapter 2 of this report sets out the importance of, and scope for, improving the energy performance of UK buildings, in particular by using better insulation and ventilation. It is theoretically possible to reduce the energy demand for space heating to zero. However, this is not practically possible, even with Passivhaus new-build construction, and is inconceivable for the whole UK building stock over the few decades within which the transition to a zero carbon economy has to be achieved. Energy demand reduction for water heating is more difficult to deal with. Decarbonisation of the fuels used for providing heat in buildings is therefore unavoidable if carbon targets are to be met.

The Clean Growth Strategy recognizes that decarbonisation of heating is a major and long-term challenge. More recently, Government has published the evidence base on heat decarbonisation (BEIS, 2018). Both reports cover energy sources (e.g. renewable electricity, bioenergy), energy vectors (e.g. electricity, mains gas) and conversion devices (e.g. boilers, heat pumps), but do not always distinguish their roles clearly.

It seems likely that the dominant energy vectors for heating will be electricity, mains gas and district heating (DH). None of these is a priori low carbon, but all can support low carbon sources and their use. Conversion devices at the point of end use will be important. They have to be affordable and socially acceptable if they are to be adopted. Their efficiency has a major impact on overall system efficiency, and therefore the scale and cost of the whole energy system. A critical constraint is the ability to deal with periods of system stress, which are likely to remain associated with high winter demand. There will be a requirement for the energy system to store energy, including over periods much longer than a day. In developing plans for decarbonisation of heat, a whole system analysis is needed of heat options, including the performance of energy conversion devices and energy storage. **We recommend that greater attention is given to energy conversion devices and energy storage in the analysis of heat decarbonisation**.

There is broad agreement that significant electrification of building heating is very likely to be required for complete decarbonisation. Heat pumps, rather than electric resistance heating, are the efficient means with which this could be delivered. However, heat pumps are not simple replacements for fossil fuel boilers; their effectiveness in retrofit depends on being able to operate heating systems at lower than conventional temperatures. This in turn requires some combination of reduced heat loss, larger radiators, or a shift to continuous heating. Deployment of heat pumps, particularly in retrofit, requires careful design and sizing, and skilled installation (RAPID-HPC, 2017). Expanding the supply chain will take time and is unlikely to happen without Government intervention. **We recommend that financial support for heat pump heating systems be continued and that more policy attention be given to the building heating supply chain**.

Some early scenarios with high heat pump adoption (e.g. DECC, 2013) overlooked the multiple challenges delivering a systemic change in building heating. In particular, the impact on peak electricity demand of very high levels of electrification is unlikely to be acceptable, and therefore a more diverse mix of energy carriers will be needed (Eyre and Baruah, 2015).

Exemplars of high DH use that are often cited (notably Denmark and Sweden) have been based on an evolving mix of energy sources (Danish Energy Agency, 2017; Werner, 2017). The advantages of DH are its flexibility with respect to sources of heat, its ability to support significant economies of scale in heat conversion and thermal storage, and the fact that it removes technical complexity from dwellings. The UK Government is supporting the expansion of heat networks through the Heat Network Development Unit. These networks require regulation, which has been slow to materialise in the UK, but which is now under consideration (BEIS, 2018b).

However, for DH to play a significant part in the decarbonisation of heat a number of additional measures are needed, including development of the supply chain, reduction of perceived risk and thus financing costs, linking to the availability of low carbon heat sources, and development of models for the effective integration of heat, electricity and gas networks. **We recommend BEIS develops a comprehensive strategy for heat, including heat networks, but also other options**.

More recently, there has been attention to decarbonising gas, through some combination of biogas and hydrogen. As set out above, there is an ongoing debate about the relative merits of steam methane reforming with CCS and electrolysis for hydrogen production. However, end-use perspectives are equally important. A major proposed benefit of hydrogen is enabling households to retain existing end-use technologies. However, whilst the ability to use existing household appliances has obvious short-term merit, transition to higher levels of hydrogen will almost certainly require new end-user equipment. Much UK analysis (e.g. BEIS 2018; CCC, 2018b; CCC, 2019) has focused on the option of using hydrogen (or biogas) in hybrid heat pumps, in order to avoid meeting peak heat demand solely with electricity. This implies a long-term commitment to burning zero-carbon gas in a boiler, which is a sub-optimal use of a high cost vector. It will be important to explore more efficient options, including combined heat and power and gas-fired heat pumps. Analysis of hydrogen as a heating fuel cannot be separated from its potential value in providing inter-seasonal energy storage. **We recommend that ongoing analysis of hydrogen as a heating fuel by both BEIS and the CCC covers questions of end use and storage, as well as production and networks**.

Most current analysis (e.g. CCC, 2016) points to early growth in electricity use in areas off the gas grid. It accepts that more research and trials are needed to explore the merits of different options in other locations. Our key message is that decarbonising heat is very different from decarbonising electricity, as it has major implications for energy users. Demand for thermal comfort, building fabric performance, heating technology efficiency and choice of vector are all likely to be important. And they will be the key determinants of the low carbon fuels used.

Implications for policy

In our chapters relating to demand reduction and flexibility, we set out specific short-term actions for Government, along with some longer-term challenges requiring further research. For decarbonisation of end-use fuels, the agenda is less well-developed, there are more unknowns, and therefore we place greater emphasis on research. Some decisions, notably strategic investment in gas, electricity and heat networks, imply very substantial infrastructure costs, and therefore the value of information is potentially high in helping to avoid stranded investment and to improve our knowledge of the different options for decarbonisation.

However, this is not an excuse for inaction. Early action is required, not just to deliver quick wins, but also to develop learning, skills and supply chains. Basic research is still needed, but there are already options in transport, buildings and industry where demonstration, trials and deployment are appropriate. These will be some of the key technologies of the low carbon transition. Developing a UK industrial strength in low carbon technology requires investment in these areas. The UK Government announcement in December 2018 of a 'net-zero carbon cluster' is a welcome development. **We recommend that Government develops and maintains a comprehensive programme of innovation support for decarbonisation of difficult sectors**.

In the short to medium term, many of the options set out above are unlikely to be cost effective against current technologies. To make this the test of financial support would be a strategic mistake. Whether a new option can out-perform the gas boiler, the diesel engine or the blast furnace in the high carbon economy is irrelevant in the face of the Paris Agreement. The right question is whether a technology or practice has a significant chance of forming part of an approach to long-term decarbonisation that is likely to be socially acceptable, and, if it does, how to support it on its pathway to widespread use.

Changes to technologies for buildings, vehicles and industrial processes will be important. However, as we have emphasised, there is every reason to expect very significant changes in user practices and commercial business models, as well as supply infrastructure as these sectors decarbonise. **We recommend that changing practices among end users and throughout supply chains should be more central to the decarbonisation innovation agenda**.

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7. Policy: delivering further and faster change in energy demand

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Introduction

Policy to reduce energy demand will be critical in delivering the Clean Growth Strategy (CGS), helping to achieve the low carbon energy transition. The UK has been a pioneer in low carbon policy, with some influential energy demand policies in addition. The Climate Change Act is internationally leading, the GB energy efficiency obligation scheme has strongly influenced EU policy, and the London Congestion Charge has inspired similar schemes elsewhere. However, more significant change is needed if the UK is going to meet the 2050, and intermediate, targets for 80% GHG emissions reduction (CCC, 2018). Further, the 80% target will need to be strengthened if the UK is to contribute fairly to the Paris Agreement ambition of restricting global temperature rise to 1.5C (Pye *et al*, 2017). This challenge has been addressed by the Committee on Climate Change (CCC), whose 2019 report advises that the UK should adopt a net-zero carbon target by 2050 (CCC 2019).

The unprecedented challenge of decarbonising energy means that, while we can and should learn from past UK, EU and international policy experience, we are likely to need new approaches to the design, types and mixes of policy, institutions and delivery mechanisms. We will need to rethink governance and expand the ambition and reach of policy. The energy transition will require changes in technologies, practices and choices for every household and business, many of which we do not currently know how to organise technically, cost-effectively or in a socially acceptable way. To aid this transition, CREDS' 'policy and governance' research theme will contribute new ideas, analysis and evidence to help characterise and meet the multiple challenges involved.

This brief review of policy and policy processes within the CGS is based on existing research and knowledge. It makes recommendations for change by Government, and highlights where CREDS can contribute new knowledge. First, there are detailed comments on the policy approach and policy mix within the CGS. Then governance and institutional aspects are discussed. Finally, policy innovations to deliver further, faster and more flexible change are presented.

Policy approach

First the contents of the CGS are briefly analysed and compared with the policy making approach of the Scottish Government Climate Change Plan. Then the policy mix and policy types employed within the CGS are discussed. Finally, a case is made for the importance of including equity in policy design and delivery.

From a strategy to a plan

The CGS is a report required under the UK Climate Change Act in which the Government has to set out the policies and proposals it considers necessary to keep emissions within the legislated carbon budgets. The carbon budgets, therefore, provide an overarching constraint on the future envisaged by the CGS. The CGS contains many policies and proposals – over 200 by our count. However, many do not have timescales, funding or targets attached (for detailed analysis see Appendix 1 or Reiss 2018). There are very few policies that impose specific obligations on anyone.

A generous interpretation would be that this lack of detail is a function of the stage of policymaking (although the publication had been repeatedly delayed, and came six years after the first 'Carbon Plan'). The CGS points forward to a range of consultations and sector-specific plans, which will create openings for more detailed policies, but these are yet to emerge. By contrast, the Scottish Government has produced a Climate Change Plan (Scottish Government, 2018) which sets out sectoral emissions' envelopes and specific indicators against which progress in policy development and outcomes can be judged. The UK Government however has more powers than the Scottish Government, including some which affect Scottish emissions; powers over energy taxation and regulation, for example, are reserved to the UK Government.

A significant difference between the CGS and the Scottish Climate Change Plan is that the UK government does not expect to produce a single Clean Growth Plan against which progress is measured. Hence the CGS does not break the overarching carbon budget down into budgets for specific sectors. Sector-specific emission levels are mentioned, but only to illustrate emissions along "one of several plausible pathways" (Appendix 2 or Hawkey 2018). Instead regular reporting is promised, in combination with the response to the CCC's Annual Progress Report. Using a sector-specific approach would, however, have the advantage of allowing the UK Government to set differential targets for sectors of the economy where climate policy is perceived to threaten international competitiveness (energy intensive industries) and sectors where this is not a significant issue (particularly buildings and transport).

Recommendation: Government should work swiftly to turn CGS proposals into policies with specific targets, dates and budgets. This should include setting sectoral targets, or envelopes.

Policy types and policy mixes

The CGS does not specify an approach to policymaking, neither does it explain how it will determine the mix of policies needed to meet particular goals, beyond saying it will use "all the tools available" (p49). The majority of proposals are related to innovation investment, i.e. delivering clean growth through technological breakthroughs; only about a quarter of proposals aim to address clean growth through regulatory or fiscal measures (Appendix 1 or Reiss, 2018). While innovation is important, adoption of innovative products does not generally happen without the support of policy instruments.

The importance of policy mixes in delivering effective energy efficiency improvement has long been recognised, given the variety of instruments needed to overcome different barriers or to support different technologies at various stages of development (Rosenow *et al*, 2016). For many traded goods – including lighting, electrical appliances, motors, vehicles and boilers – an EU-wide market transformation approach has been taken, which incorporates standards for testing, minimum efficiency and labelling, and product bans, complemented by national information, advice, training and subsidy programmes. Policies to encourage fuel switching, or policies to change behaviours, practices or management of energy also require a mix of instruments.

Recommendation: In developing its more detailed plans, the Government should detail the mix of policies, regulatory and market-based, needed to deliver innovations.

Equity in the energy transition

Equity and justice need to be integral to the energy transition, for principled and pragmatic reasons (Parkhill *et al*, 2013). Fairness and perceptions of fairness are critical to successful policy in the UK; perceived unfairness has undermined many past policies, e.g. VAT on fuel, fuel duty escalator, feed-in tariffs. UK policymakers have long-acknowledged that householder access to energy/energy services and transport/mobility are unevenly distributed. For household energy use, this has led to considerable policy attention on fuel poverty. Policy has not, however, succeeded in ending fuel poverty (BEIS, 2018). Energy prices have increased at a higher rate than incomes for poorer households, and energy efficiency policies have not reduced energy demand in homes sufficiently such that adequate energy services are affordable for all.

More attention is needed on how the costs and benefits of the energy transition are going to be distributed between different groups in society and different sorts of organisations. This topic is not addressed in detail in the CGS (Appendix 1 or Reiss 2018).

Recommendation: More detailed equity and fairness analysis/questions should be included in consultations and other documents following up the CGS.

Governance

This section considers the governance of policy and the role of actors at different scales from individuals to national administrations. It proposes new institutional arrangements for delivering policies in the CGS, and finishes with comments on the role of politics in policymaking.

Individuals, intermediaries and organisations

Despite its focus on technological innovation, the CGS has limited focus on the users or adopters of new technology, and the supply chains and installers which will deliver it. Research shows that these groups are critical to the adoption of innovations (Owen *et al*, 2017). Future research funding for helping people to 'stop wasting energy' is announced (CGS, p81); this frames people as the problem, rather than as integral to the low carbon transition. A wealth of research – some of it commissioned by Government – shows that more sophisticated conceptualisation and engagement with people and organisations as decisionmakers, investors and users of energy pays dividends.

The CGS has little to say about micro-businesses and SMEs, although they are responsible for 55% business energy use (as noted in the CGS, p61). SMEs have less capacity and resources to adapt to change than larger firms, and require distinctive forms of policy and financial support (Hampton and Fawcett, 2017). To enable and encourage them to contribute to the energy transition, SMEs collectively will require additional research and tailored policy attention.

Recommendation: Government to assess the effectiveness and impacts of policy design and delivery in relation to specific groups, including householders, intermediaries, SMEs and other organisations.

CREDS contribution: To undertake research focused on people and organisations and their centrality to, and many roles in, the energy transition.

Governance within the UK

There is as yet no strategy for coordinated governance of policy on energy efficiency and demand in the different nations and regions of the UK. Regional action is mentioned in only one CGS policy proposal, despite the focus on driving regional growth through local industrial strategies, highlighted in CGS Chapter 1. Earlier work has however argued that more systematic, comprehensive and faster improvements in energy saving could be achieved through explicit UK, devolved national and local/regional government frameworks for action on low energy buildings and clean energy (Webb *et al* 2017).

Scotland, Wales and Northern Ireland currently have different devolved powers relevant to energy policy, with Northern Ireland having most autonomy; in Britain energy taxation, regulation and licencing is reserved to Westminster. Within this framework, Scotland has developed the Energy Efficient Scotland programme, and Wales the Energy Efficiency Strategy for Wales, each emphasising coordinated national and regional action.

The Scottish Government is also now consulting on a new statutory power for local government to develop comprehensive Local Heat and Energy Efficiency Strategies (LHEES) and implementation plans. In England, governance arrangements are more piecemeal and experimental, including for example recent BEIS funding for six pilots to test locally-customised supply structures for private housing retrofit.

Local government needs guidance if it is to make high quality, locally sensitive decisions around energy. Scottish LHEES pilots are testing proposals for development and adoption of standard socio-economic assessment metrics for evaluating cost effectiveness of different energy saving strategies suited to each locality. In the Smart Systems and Heat programme, local energy planning tools have been developed to model cost-optimal routes to a low energy, low carbon building stock at locality scale, but underlying cost calculations are contingent on multiple future uncertainties, and resulting scenarios can be difficult to evaluate for local governments with limited technical capacity. More work is needed on development of standards for assessing the cost effectiveness of different approaches responsive to local problems and priorities.

Recommendation: UK Government to work with devolved national and regional governments to develop clearer frameworks, mandates and metrics to support further, faster local authority action to reduce energy demand through local and regional energy planning and implementation.

CREDS contribution: Our research programme will develop knowledge and capacity on emerging comparative governance strategies within Britain, with a particular focus on energy use in buildings.

Institutions and approaches for policy delivery

Delivering energy efficiency through policy requires a complex mix of policy instruments (Rosenow *et al*, 2017). Most OECD countries use some form of energy agency to manage this complexity. An external agency also adds specialist market and project management expertise, which is difficult to provide via a generalist civil service with restrictive procurement rules (Mallaburn & Eyre 2014). However, this approach comes with risks, particularly around loss of Government control and accountability, which was the main reason why public funding was removed from the Carbon Trust and Energy Saving Trust in 2012.

A new generation of hybrid energy efficiency programmes is emerging that fuse industry-led, voluntary programmes with selective Government intervention (van der Heijden, 2017). For example, the National Australian Built Environment Rating System (NABERS) is a voluntary initiative, supported by the Government, to measure and compare the environmental performance of commercial buildings and tenancies. It has been widely adopted, and is considered to have been successful in increasing environmental and energy performance (Mallaburn, 2018). The German energy efficiency networks apply the same approach to industry (Durand *et al*, 2018).

Recommendation: The overnment should evaluate the case for hybrid energy efficiency programmes run by a new national Energy Agency or similar facility to help deliver the CGS.

CREDS contribution: to review the impact of hybrid energy efficiency programmes and the agencies that run them and to consider how the approach could work in the UK.

The politics of policymaking

Policymaking is not an apolitical process: policies are made by governments with particular political priorities and values, and within a wider socio-economic context (Appendix 2 or Hawkey, 2018). At certain times there may be 'policy windows' for ambitious climate change policies, but such windows may also close unpredictably (Carter and Jacobs, 2014). Nevertheless, some policies have achieved lasting cross-party support, and the UK has shown leadership in establishing carbon reduction as a priority shared across the mainstream political landscape. Analysis of 40 years of UK energy efficiency policy has shown that energy efficiency can meet different goals and fit with different political philosophies (Mallaburn and Eyre, 2014). However, other emerging approaches to demand reduction, such as sustainable prosperity in a circular economy (Jackson, 2017) or sufficiency (Darby and Fawcett, 2018), are more politically contentious. These, too, are legitimate and important subjects of research.

CREDS contribution: to explore the full range of policy solutions, including radical options, and to consider their robustness against different political priorities.

Further, faster and more flexibly

To reduce energy demand further and faster, and to make it more flexible, innovation in energy and relevant non-energy policy will be required. A number of changes to current policymaking are suggested: joined-up policy, going beyond short-term win-win and energy efficiency, and taking the reduction of demand more seriously.

Joined-up policy: Heat decarbonisation as an example

The call for more joined-up policy is not new. However, given the scale of change envisaged in the energy transition and the interconnected nature of the changes required, a joined-up, systematic approach will be essential. The changing nature of the energy system itself is widely acknowledged with, for example, distributed generation, increasing renewables and smart meters all opening up new opportunities for policy intervention, and requiring new policy frameworks. The relationship between supply and demand of energy is different and more joined-up now. It is important that analysis by researchers and Government identifies the social/technical/economic systems surrounding new flexibility, low energy or low carbon innovations, and that policy builds on this.

Heat decarbonisation, a CGS priority, demonstrates the complexity of change envisaged and the need for joined-up policy. Low carbon heating systems, such as low temperature heat delivered by heat pumps or low carbon gas (hydrogen/biogas + Carbon Capture Use and Storage – CCUS), are currently more expensive, complex and problematic than the incumbent technologies. To enable adoption of these technologies, it will be vital to reduce the energy used for heating and hot water in buildings (Webb, 2016). Reducing energy demand in buildings is the best-understood and lowest risk element of a heat decarbonisation strategy. However, this is not acknowledged in the CGS, where the focus is on supporting low carbon heating technology through a) supporting measures to become more attractive so that homeowners will adopt them; b) investing in long term knowledge generation for fuel switching; c) investing £320 million in heat network infrastructure to develop a self-sustaining market post-2021 (Heat Networks Investment Project, 2018). There is a notable lack of policies to deliver more efficient existing buildings, particularly in the non-residential and able-to-pay residential sectors (as discussed in Chapter 2). Policy for new buildings is also less strong than it could be. Thus, by focusing primarily on the supply of heating systems, and not addressing demand for the energy services they supply, the CGS is left without an overarching strategy to govern the decarbonisation of space and water heating.

Recommendation: Government needs to join up policy on all aspects of decarbonisation of heating, and prioritise policies to ensure high standards of efficiency of the new and existing building stock. More generally, a joined-up systematic approach to policy is required.

Beyond short-term win-win

The CGS expects mitigation actions to be win-win: in the short-term, actions should deliver both carbon reductions and economic benefits to their adopters. This is constraining. For example, a decarbonised heat system is forecast to lead to cost increases (Energy Research Partnership, 2017) which are difficult to reconcile with short-term win-win framings. The costs of low carbon options can fall more quickly than expected, reducing the economy-wide cost of the energy transition – with solar PV and batteries being good examples (CCC, 2109). Policy support prior to these technologies being win-win options, both in the UK and abroad, has helped deliver cost reductions. Nuclear and off-shore wind generation are not subject to a win-win expectation. Public subsidy is considered justified, despite cost increases in the case of nuclear power. Government is also prepared to support controversial supply-side options, e.g. fracking (not mentioned in the CGS); such support has been lacking when demand-side policies become controversial, e.g. in the debate about the impact of 'green charges' on energy bills in 2013 (Carter and Clements, 2015).

There are alternatives to a short-term win-win approach. In Scotland, the Government announced in 2015 that it would treat energy efficiency as a national infrastructure priority. This approach to demand-side policy is leading to a requirement for specific policy instruments (Scottish Government, 2017). Another option is the 'energy efficiency first' approach taken by the European Union, which builds on the principles of integrated resource planning.

Policy could be framed around energy services, rather than energy itself, as proposed under the ETI/Energy Systems Catapult 'Smart Systems and Heat' programme (Energy Systems Catapult, 2018). This is intended to create incentives for suppliers to invest in building fabric retrofit, where this is the more cost effective route to provision of contracted service levels. Finally, a multiple benefits approach to developing policy would ensure that the full social, environmental and economic effects are taken into account. This approach can provide a powerful case for action which appeals to a variety of values and priorities (IEA, 2014). Each of these proposals would have different implications for policymaking.

Recommendation: Government should reconsider the requirement for short-term win-win from technologies and energy saving, low carbon options at the earlier stages of innovation and adoption.

CREDS contribution: to build capacity on energy demand policy which is not necessarily win-win in the short-term and learn from the emerging approaches elsewhere.

Beyond energy efficiency

For the UK as a whole, energy efficiency has been, and will continue to be, an important route to demand reduction – but this is truer for some sectors than others. For buildings, energy efficiency has been key to reducing demand over recent years and offers significant scope for further reductions (Chapter 2). For industrial energy use, energy efficiency has delivered one-third of the savings due to reducing energy intensity, but the remaining efficiency opportunity is limited (Chapter 3). However, for transport, internal combustion engine vehicle energy efficiency improvement has been insufficient to deliver decreases in energy use, with considerable concern about the mismatch between lab test and real world energy efficiency (Brand, 2016; Chapter 4). In addition to energy efficiency, demand-side policy must also encompass fuel switching and flexibility. Government must also acknowledge its own role in shaping demand.

The current policy approach to fuel switching varies by sector. The CGS has set a date for the phase out of fossil-fuelled cars and vans (albeit not as ambitious as called for in Chapter 4). Until recently, the same drive to require fuel switching has not been seen in the buildings sector. . However, in March 2019, a 'future homes standard' was announced which will ensure that new UK homes will be built without fossil fuel heating from 2025 (Hammond, 2019). This is a good start, but covers just a small part of the building sector (i.e. not the existing building stock). The electrification of heating and transport are both likely to require planned withdrawal of existing fossil fuel supplies and their infrastructures – a complex social/technical/economic process which now urgently requires policy development.

Government policy contributes to shaping demand for energy, energy services, travel and mobility. This is arguably most strongly the case in the transport sector, where nearly all infrastructure is publicly funded (Marsden *et al*, 2018). Decisions to expand airport capacity inevitably increase energy use and carbon emissions.

However, more indirectly, economic, tax and monetary policies also contribute to stimulating and shaping demand. Acknowledging tensions between climate goals and economic goals, where these exist, is important. Not all growth can be clean growth.

The CGS does not challenge existing energy-intensive practices, such as long-distance air travel, or the growth of new energy uses, e.g. the internet of things, big data storage and exchange, or cooling of buildings. It does not consider any substantial policy to reduce demand for mobility or the services that energy provides. While such policy may be thought contrary to the usual aims of Government, it is important to recognise that the Government has already expanded policy into new areas in order to deliver energy savings and the multiple benefits these bring. For example, it has introduced minimum standards for energy efficiency of (some) existing privately owned homes – an intervention previously considered politically impossible. The Government will need to find new intervention points if carbon reduction targets are to be met.

Recommendation: Government to develop stronger policy on switching away from carbon-intensive fuels. Also to recognise the role of its own policies in stimulating and shaping demand, and to consider how these could contribute instead to the net-zero transition.

CREDS contribution: By analysing policy across sectors, and taking a whole systems view, to develop new evidence and arguments for more rapid change.

Taking demand more seriously

Demand reduction and flexibility will be hugely important in delivering the energy transition – but policy still focuses disproportionately on energy supply. For example, the CGS dedicates almost three times more investment to the electricity system (responsible for 21% of emissions), via power and smart systems investments, than to businesses and homes (responsible for 38% of carbon emissions, including the 32% of national emissions for heating). This is despite recognising the necessity to decarbonise heat and its status as "our most difficult policy and technology challenge to meet our carbon targets" (CGS:p75). Given the expected future role of electricity across all sectors, this may be the right balance of investment. However, the apparent mismatch does require closer attention.

Recommendation: Government to reassess the relative priority given to supply and demand policy.

CREDS contribution: Research on reasons for policy asymmetry between energy supply and demand

Conclusions: raising the ambition level

As the CCC concluded, the CGS will not deliver sufficient carbon savings to meet Government-legislated targets. This chapter has suggested a number of ways of raising ambition within the current framing of policy – by setting more detailed policy targets and stronger standards, designing appropriate policy mixes, involving and coordinating with multiple actors at different levels of governance, and considering new institutional arrangements. There is also the more challenging call to reconsider the limits and purpose of policy. Successful policymaking also requires paying attention to equity, and to the individuals and organisations who make up (and meet) the demand for energy services and mobility.

CREDS aims to conduct research on reductions in demand which go further, faster and more flexibly – options beyond 'business as usual'. This will include investigating demand for energy services and mobility, and proposals for reducing these, consistent with equity, climate protection and energy policy goals. CREDS will provide recommendations and evidence for radical or non-marginal changes in delivering emissions reduction, as well as incremental improvements.

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8. Conclusions

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Why energy demand?

Our analysis shows that changing energy demand is critical to the development of future energy systems that are secure, affordable and sustainable. In particular, meeting the ambitious climate goals of the Paris Agreement and the UK's Climate Change Act involves a systemic change in the energy sector – for energy demand as well as energy supply.

Supporting energy efficiency is consistent with the central goal of the Government's Industrial Strategy of improving UK productivity. Energy efficiency is not just a 'nice to have' green add-on to energy policy. It is, by definition, energy productivity. It is productive investment, creating employment, supporting competitiveness and contributing to an innovative economy.

The analysis in the previous chapters shows the diversity of measures to change energy demand across the sectors in which energy is used. We deliberately use the term 'changing energy demand' to emphasise that the demand-side agenda is now broader than its traditional agenda of implementing modest efficiency improvements. It includes action on the fundamental drivers of energy demand – the human activities that require energy services. It also increasingly involves flexibility; changing when energy is used, and decarbonisation; the fuels used. So the energy demand agenda is complex.

Learning from experience

Improving energy efficiency at the point of use remains critically important. Efficiency improvement generally supports all three pillars of the energy trilemma (security, affordability and emisson reductions). It has the potential to deliver policy goals at a lower cost than by relying on supply-side options alone. The International Energy Agency (IEA, 2016) now refers to energy efficiency as 'the first fuel', that is, the first option to consider in developing energy policy.

Our evidence supports this approach. Of course, not all conceivable energy efficiency investments are sensible or cost effective, but the scale of historical under-investment means that there remain major opportunities that have bigger benefits than investments in new supply. Reducing demand should be a priority. **We therefore recommend that the Government adopts the position that policymaking should, as a principle, consider energy efficiency improvement and other measures that reduce demand as 'the first fuel'**.

Drawing on the analysis set out in the previous chapters, we believe that the evidence shows that there have been three important factors in driving demand reduction.

The first important factor is innovation. As recognised in the Clean Growth Strategy, this involves more than research and development. It also includes demonstration, deployment and adoption processes through to mass deployment. Innovation needs to be considered as a systemic process as we set out in Chapter 1.

Innovation expenditure is currently strongly weighted towards energy supply. Whilst Research Council commitments to energy efficiency have increased in recent years, support for deployment has fallen. Major subsidies for deployment of some energy supply technologies dwarf the sums now allocated to supporting energy demand innovation. **We recommend that the imbalance is corrected by ensuring that energy innovation support gives equal priority to energy supply and energy demand**.

The second important factor is the role of energy users. The energy transition cannot be delivered without greater engagement of energy users – both in households and businesses. Some individuals already play a key role as early adopters of clean technology and advocates of lower carbon living. Similarly in the business sector, companies for which energy is a strategic priority perform better (Cooremans, 2012). But many energy users are disengaged. So the ambition of the Clean Growth Strategy for "a shared endeavour between Government, business, civil society and the British people" is important. There are decades of programme experience with a variety of users (Mallaburn and Eyre, 2014), but the lessons do not feature strongly in the Clean Growth Strategy. There is increasing evidence motivation may be driven by benefits other than cost and carbon savings. **We recommend the Government develops a systematic approach to engagement on energy demand across all sectors of the economy as part of the next Energy White Paper**.

The third factor is the role of public policy, which affects both technological innovation and engagement. Incentives, information and regulation all have a role, with a policy mix generally providing the most effective approach (Rosenow *et al*, 2016). Government has a central role in helping business and householders capture the value of energy efficiency by providing support and advice and where necessary intervening to overcome barriers and remove poor performers.

Within such a policy portfolio, clear and well-enforced standards, announced well in advance, have an important role, as shown by the effectiveness of efficiency standards for key products such as domestic heating boilers.

There is uncertainty about future product standards if the UK leaves the EU Single Market. **We recommend that Government commits to ensuring a continued framework of increasingly ambitious product standards, as part of a portfolio of policy instruments**.

Unfortunately, much UK Government policy has become less ambitious and effective in recent years. The scale of policy-driven investment in home energy efficiency has been reduced substantially. The Green Deal policy is widely recognised to have failed and has not been replaced. There is, in effect, no support policy at all on commercial buildings. Energy efficiency advice programmes have been cut and business energy efficiency incentives and support weakened. Transport energy use has begun to rise again as fiscal measures have weakened and investment has fallen in alternatives to private road travel.

Developing a vision and framework

A vision for energy demand is missing and is now urgently required. There has been a drift in public policy towards assuming that energy demand is solely a consumer responsibility. Of course, improvements in energy efficiency result in financial benefits for households and businesses, which should be encouraged to invest without financial support where possible. However, energy demand change also has important public benefits: in improved energy security, better public health and urban environments, and major employment opportunities, as well as lower carbon emissions. Research is increasingly able to quantify these impacts. **We recommend that Government assess the scale of public benefits from potential energy demand change**.

Many of the assets requiring energy efficiency investment, notably buildings and mass transit infrastructure, have the characteristics of infrastructure. They should receive the same focus and support as energy supply infrastructure. **We recommend that Government departments and the National Infrastructure Commission should develop plans to ensure low cost capital is available for infrastructure investments in energy demand reduction**.

These benefits should be reflected in policy support. The Government accepts the case for a stable framework for low carbon energy sources in order to reduce investment risk. The case for similar support for energy efficiency is even stronger, as the public benefits are at least as big and the non-financial barriers to investment are often larger. The higher cost effectiveness of energy efficiency means the public benefits derived from public investment tend to be higher. We welcome the fact that the Clean Growth Strategy sets ambitious targets. If these are to be achieved, the weakening of policy needs to be reversed, through comprehensive policy intervention. **We recommend that Government develops a long-term framework for incentivising demand-side investment in all sectors that at least matches the priority assigned to supply-side policy. This should cover demand reduction, demand response and fuel decarbonisation**.

This would be consistent with the broad approach of the Clean Growth Strategy of setting clear long-term visions, within which business and civil society can plan. We welcome the commitments to ending the sale of petrol and diesel vehicles. Other areas where Government could take a similar lead with the potential for popular support include: a shorter timescale for requiring net-zero carbon new-build than 2025; ambitious goals for high-performance building renovation; targets for reduced road vehicle use in urban centres; and goals for reducing the use of carbon intensive materials.

Winning the broad argument for change will need to accompany the legal and policy framework required to implement it. People are therefore central to any coherent programme on energy demand. Long term, systemic change inevitably involves the energy practices and services that drive the need for energy. We recognise the reluctance of policymakers to be seen to interfere in consumer decision-making, and therefore to prefer policies relating to 'things' rather than people. But it is a false dichotomy. Many policies frame, shape or constrain individual decisions and there is ample evidence that consumers want and expect Government to make decisions that are in the public interest. They do not want the 'right' to have a cold home, a polluted environment or throwaway products. The key issue is to ensure that decisions are understood in terms of public good and working with the community, rather than as arbitrary constraints on individual freedom. It will be important for Government to be explicit about this and to build support within civil society. **We recommend that Government consults on and develops a long-term 'national conversation' of citizen engagement, addressing both the personal impact of policy measures and wider issues**.

Developing a transition plan

The Clean Growth Strategy provides a starting point. What is now needed is a Clean Growth Implementation Plan. The detail will be important as any plan for energy demand has implications for consumer behaviour, business decisions, innovation and governance.

In the buildings sector, energy demand has fallen, but the trend is now weakening, as there has been a reduction in ambition for both the energy performance of new buildings and the rate of renovation of the existing stock. The latter is the tougher challenge, but both need to be addressed. Both housing and non-domestic buildings need to be addressed. This will need a range of interventions, including tighter standards, better enforcement and incentives. One critical aspect of delivery will be to re-skill the workforce to meet the task of delivering buildings that are high performing in practice, not just on paper. The longer-term challenge is complete decarbonisation of heating in buildings, where options need to be opened and a route map developed.

In the transport sector, there are many similar challenges in ensuring the continued improvement of vehicle efficiency. Again, the progress in practice recently has not matched what is claimed by the industry due to poor enforcement. There are clear signs of the early stages of light vehicle electrification; this is welcome although it raises new challenges for generation and distribution.

Freight transport, aviation and shipping remain more difficult. In transport, there is also very large potential for reducing demand by changing the patterns of land use and by modal shift. This is frequently neglected in discussions about transport and energy demand, and this deficiency needs to be addressed.

In industry there remains significant scope for technical efficiency improvement, although less so than in other sectors. The potential is least in energy intensive manufacturing processes. This points to the need for consideration of two more fundamental issues. The first is the role of energy intensive materials and products in modern society – how they are used, reused and recycled, and the extent to which they can be substituted. The second is the development of different process technologies, using electricity and/or other decarbonised vectors to replace fossil fuels.

In all sectors, there needs to be a focus on performance rather than merely technology. There is a long history of both energy management in business and energy advice to the general public that shows the scope for performance improvement with any given set of technology. New technology will be critical to the transition, but is not a panacea. There is a chronic performance gap, between design and use in both vehicle and buildings technologies. Better real-time data provides a huge opportunity to help address these, both by improving the quality of policy instruments such as labels and standards, and by enabling smart technologies to provide real-time support for energy decision-makers.

Ultimately, to meet the UK's obligations under the Paris Agreement, it is likely that the fuels used in every sector will need to be completely decarbonised. To date, priority has largely been given to decarbonising electricity. Decarbonisation has therefore been seen as primarily a supply-side issue. However, attention will increasingly need to be paid to decarbonising heat and other difficult sectors, whether by electrification or otherwise. The practices, preferences and choices of energy users are then critical. Hence the importance of a national conversation about what is needed.

In all sectors, what is needed is more than marginal efficiency improvement. To facilitate the transition to a society powered largely by renewables, demand needs to be reduced and made more flexible. Flexibility is a newer challenge and is particularly important for electricity use. It can be delivered both by enabling energy using practices to be more flexible and by using various forms of energy storage. Our judgement is that both approaches are likely to be required, and that both need policy support.

It will be tempting for policymakers to focus on the technical innovation required to deliver such fundamental change. However, for the reasons set out above, 'end users' cannot be neglected in considerations of 'end use'. Policies will need to address people as well as technologies. In a sustainable energy system, deep demand reduction, flexibility and decarbonisation are likely all to be critically important. This is a newer research agenda than modest demand reduction. However, for both demand response and fuel switching, there is a substantial amount to be learnt from energy demand reduction experience in consumer behaviour, supply chain development and policy design.

CREDS plans to develop the evidence base and an approach to policy integration. **We recommend the Government coordinates the development of policies for demand reduction, flexibility and decarbonisation in an Energy White Paper**.

The energy sector also needs reform. Energy demand and supply can no longer be governed separately. The UK led the way in the mid-1990s in ensuring that energy regulation required energy suppliers in liberalised markets to deliver energy saving programmes. This catalysed similar activity across Europe, but this leadership has now been thrown away. The very strong focus of existing policy on wholesale markets in energy policy, e.g. in the process of Electricity Market Reform (EMR), is very unhelpful. With the growth of distributed generation and the increasing availability of storage, the assumption that energy will be sold as an undifferentiated commodity is under threat. Self-supply and peer-to-peer trading are increasing and may undermine existing markets. A new vision is needed in which energy retail policy does more than control unit prices. We welcome the renewed interest in retail market design issues in Ofgem, but a more fundamental review is required. **We recommend that Government initiate a review of the fundamentals of electricity and gas retail markets, and whether their focus on commodity sales is fit for purpose in the context of the energy transition electricity**.

Throughout this report, the implications of digitalisation for energy demand are apparent. These are likely to be mixed, but are also unpredictable and rapidly moving. The obvious early impact for energy demand in the UK is from the roll-out of smart meters. The initial cost-benefit analysis relied heavily on reducing demand through improved user engagement. This relies on meters being installed with this as an objective (Darby, 2010), which is an example of the need for better engagement in general. From our analysis, smart meters are important, not primarily to achieve modest demand reductions, but to enable innovation and make demand flexibility a realistic option.

Understanding the benefits of action on demand

We welcome the emphasis in the Clean Growth Strategy on the need to consider the energy transition in the context of its wider implications for the economy and society. This is particularly important when considering the role of the demand side.

Local studies (BEIS, 2017 page 26) show the extent to which low carbon sectors are increasingly important within local economies. There is a range of contributions, but it is changes in energy demand that are frequently the source of most benefits. We know enough about these multiple benefits of addressing demand to better inform policy. So our research will focus on how decision-making might better use this type of analysis, including at the local level and through the Commission on Travel Demand.

We can also improve our knowledge. Our research on industrial energy efficiency and on digitisation aim to quantify the macroeconomic effects of improved energy productivity. Our research on buildings will address the importance of the comfort and health benefits that are often neglected. Our work on transport will also consider the health benefits of transport technology change, but importantly also the multiple benefits of lower-impact travel modes.

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9. Detailed recommendations

The complexity of energy demand means there is no 'silver bullet' solution or policy: a range of policy instruments is required to meet energy policy goals. These involve many sectors, institutions and stakeholders, with a range of different timescales for action. We list a large number of recommendations in this report, and bring them together in this chapter. They can be considered under six broad headings.

1. Prioritise energy demand solutions

Energy demand change can support all the key goals of energy policy – security, affordability and sustainability – with more synergies and fewer trade-offs than supply-side solutions. For this reason, treating demand reduction as 'the first fuel' is already the policy of the International Energy Agency (IEA) and the European Union. Demand-side solutions also form a key part of implementing sustainable supply, through using zero carbon fuels and enabling greater use of variable renewables. In UK energy policy, there has been a tendency to focus on energy supply options. We recommend that this is reversed and demand-side solutions are given at least equal weight, and that Government should:

- work swiftly to turn proposals in the Clean Growth Strategy into policies with specific targets, dates and budgets, including setting sectoral targets or envelopes (BEIS)
- reassess the relative priority given to supply and demand policy and adopt the principle that energy efficiency improvement and other measures that reduce demand are considered as 'the first fuel' (BEIS)
- develop a long-term framework for incentivising demand-side investment in all sectors that at least matches the priority assigned to supply-side policy. This should cover demand reduction, demand response and fuel decarbonisation (BEIS, DfT)
- review the fundamentals of electricity and gas retail markets, and whether their focus on commodity sales is fit for purpose in the context of the energy transition (BEIS)
- develop a policy for demand-side response to maximise the flexibility potential of electricity demand (BEIS, Ofgem)

- reform settlement in electricity markets to enable consumers to benefit from half-hourly pricing (BEIS, Ofgem)
- increase storage and demand participation in the Capacity Market by extending the duration of contracts (BEIS)
- reform the current system of double charging for electricity storage (BEIS).

2. Consider and promote all the benefits of demand-side solutions

UK policy with respect to energy demand tends to focus on the benefits of lower carbon emissions and lower bills for energy users, often using the latter as an argument for minimal intervention. Reduced demand, improved energy efficiency, greater flexibility and decarbonised fuels have a much wider range of benefits, notably for health and employment. Addressing energy demand is generally more likely to promote sustainable development than increasing energy supply. As importantly, recognising all the benefits is more likely to motivate action. We recommend that all the benefits of demand-side solutions are considered in developing and promoting policy, and that Government should:

- assess the scale of public benefits from potential energy demand change (BEIS)
- improve understanding of how to exploit the value of the multiple benefits of energy efficiency in buildings (BEIS)
- institute a new approach to transport prices and taxes to reflect a fuller range of costs and benefits (DfT, HMT)
- analyse and consider equity and fairness issues in delivering the Clean Growth Strategy (BEIS)
- assess the effectiveness and impacts of policy design and delivery in relation to specific groups, including householders, intermediaries and SMEs (BEIS, DfT, MHCLG, devolved governments)
- reconsider the requirement for short-term win-win outcomes from energy saving options (BEIS, HMT).

3. Scale up policies that work

UK energy demand policy has featured numerous policy changes in last decade. In some cases, such as Carbon Emissions Reduction Target, the Carbon Reduction Commitment and the proposed Zero Carbon Homes standard, policy instruments that were well-designed and effective have been modified, or much reduced in scale. This has significantly reduced the effectiveness of UK energy policy. We recommend greater consistency in demand-side policymaking and, in particular, scaling up policies that have been shown to work, and that Government should:

- use a mix of policies, regulatory and market-based, in developing its more detailed plans (BEIS, DfT, Defra, MHCLG, HMT)
- develop plans to ensure low-cost capital is available for infrastructure investments in energy demand reduction (BEIS, National Infrastructure Commission).
- focus policy on the 'as built' energy performance of buildings (BEIS, MHCLG, devolved governments)
- for household heating, focus on actual rather than modelled heat loss from the buildings (BEIS, MHCLG, devolved governments)
- for non-domestic buildings, introduce a performance-based policy framework based on successful overseas experience (BEIS, MHCLG, devolved governments).
- introduce measures to deliver rapid, low-cost emission reductions from existing technologies and systems, for example using product labels to reflect operational boiler efficiency (BEIS)
- continue financial support for heat pump heating systems, giving greater attention to the building heating supply chain (BEIS)
- increase the ambition of energy demand and emission reductions goals in industry (BEIS)
- commit to ensuring a continued framework of increasingly ambitious product standards, as part of a portfolio of policy instruments (BEIS, DfT)
- adopt policies to lock-in recent changes in reduced travel demand (DfT, devolved governments)
- develop a cascading framework of national and local support for car clubs (DfT, devolved governments)
- provide systematic support for the very lowest energy modes of transport (DfT, devolved governments)
- improve the efficiency of vehicles in use, particularly through increased occupancy (DfT)
- regulate to reduce the availability and sales of large cars (DfT).

4. Develop long-term plans for demand-side innovation

There has been a tendency in policymaking to see the demand side as having the potential to provide quick wins, but not to have a major role in the transition. Our analysis indicates that this is unhelpful. Energy demand reduction, flexibility and decarbonisation will need to play a critical role and this should be recognised in energy innovation policy. We recommend that Government should develop long-term plans for demand-side innovation, including:

- energy innovation support that gives equal priority to energy supply and energy demand (BEIS, UKRI)

- stronger policies on switching away from carbon-intensive fuels (BEIS)
- a comprehensive programme of innovation support for decarbonisation of difficult sectors (BEIS)
- restructuring of ultra-low emission vehicle (ULEV) targets to include phasing out hybrid cars (DFT)
- regulatory frameworks to steer emergent travel innovations to deliver societal benefit and avoid high travel lock-in in the future (DfT)
- industrial energy-use goals that include energy efficiency, fuel switching, process decarbonisation, carbon capture use and storage, and reducing the demand for materials and products (BEIS, Defra, devolved Governments)
- a comprehensive industrial energy demand policy, providing support and incentives for innovation and deployment of new technology and business models, including for energy efficiency and material efficiency by final consumers (HMT, BEIS, Defra, devolved Governments)
- extending the analyses underpinning the UK industrial roadmaps to include material efficiency options (BEIS, Defra)
- a long-term policy framework to decarbonise buildings based on successful experience overseas and the latest research (BEIS)
- an overall policy framework for the building sector that provides a clear signal of Government ambition and intent in the medium and long-term that will deliver the buildings element of future carbon budgets (BEIS)
- credible roadmaps for the deployment of emerging technologies such as heat pumps, district heating and solid wall insulation in new and existing buildings (BEIS).
- a comprehensive strategy for heat, including heat networks and other options (BEIS)
- greater attention to energy conversion devices and energy storage in the analysis of heat decarbonisation (BEIS)
- analysis of hydrogen as a heating fuel that covers questions of end use and storage, as well as production and networks (BEIS, CCC)
- assessment of the potential for alternative approaches to providing energy services in overall decarbonisation (BEIS).

5. Build effective institutions for delivery of demand-side solutions

Energy-using activities are diverse, and therefore the policy agenda set out above involves influencing a wide range of stakeholders, including both specialists and the general public. Doing this effectively will require a major increase in activity in demand-side policy delivery in Government at a range of levels. This will require better coordination across departments, more capacity and clearer responsibilities for specialist agencies, devolved Governments and local government departments.

We recommend that Government should reform the existing delivery structures and develop an institutional framework designed for delivering the energy transition. This should include:

- the development of policies for demand reduction, flexibility and decarbonisation in an Energy White Paper (BEIS)
- evaluation of the case for energy efficiency programmes to be delivered by a new Energy Agency
- joined-up policy on all aspects of decarbonisation of heating, prioritising policies to ensure high standards of efficiency of the new and existing building stock (BEIS, MHCLG, devolved Governments)
- development of a national, long-term energy performance dataset for buildings (BEIS, UKRI)
- more effective collaboration to maximise the value of research and demonstration investments (HMT, BEIS, MHCLG and devolved countries)
- a cross-Government approach to energy, climate, waste and industrial strategy (Defra, BEIS, Devolved Governments, HMT)
- commitment to a leadership position internationally on energy-intensive material supply chains (BEIS, Defra, DIT, FCO, DfID)
- development and sharing of better industrial energy and materials data, working with industry and the research community (BEIS, Defra)
- clearer frameworks, mandates and metrics to support further, faster local authority action to reduce energy demand through local and regional energy planning (BEIS, MHCLG, devolved Governments)
- incentivisation of coordinated transport and planning objectives to reduce the need to travel (DfT, devolved Governments)
- a zero-growth objective for traffic or transport energy growth and incentives for local authorities to achieve it (DfT, devolved Governments).

6. Involve wider stakeholders to build capacity across society

A transformation in the way that energy is used needs to be led by Government, but cannot be delivered by Government alone. There is some good practice on which to build, but there needs to be a concerted effort to engage, enthuse and empower stakeholders across business and civil society. We recommend that Government should develop a strategy for Involving wider stakeholders to build capacity across society. This should include:

- a systematic approach to engagement on energy demand across all sectors of the economy as part of the next Energy White Paper (BEIS)

- a long-term national conversation of citizen engagement, addressing both the personal impact of policy measures and wider issues (BEIS, devolved Governments)
- ensuring that the implementation of the Hackitt Review addresses the energy efficiency performance gap on the evolution of and compliance with buildings standards and in the development of skills, standards, procedures and capacity within the building sector (BEIS and MHCLG)
- accepting the need to address questions of lifestyle and behaviour change to deliver energy and material efficiency (HMT, BEIS, Defra, devolved Governments)
- making practices among end users and throughout supply chains more central to the decarbonisation innovation agenda (BEIS).

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This report

'Shifting the focus: energy demand in a net-zero carbon UK' is CREDS' first major publication. It builds on research undertaken by members of the consortium over many years to address the question: "What can changes in energy demand contribute to the transition to a secure and affordable UK energy system that is compatible with net-zero carbon emissions?". It examines the most recent comprehensive statement of UK Government Energy policy – the Clean Growth Strategy. Drawing on expertise in the CREDS consortium across the buildings, transport, industry and electricity sectors, the report sets out a vision for the role of energy demand changes and develops detailed recommendations for action.

About CREDS

The Centre for Research in Energy Demand Solutions (CREDS) was established as part of the UK Research and Innovation's Energy Programme in April 2018, with funding of £19.5M over 5 years. Its mission is to make the UK a leader in understanding the changes in energy demand needed for the transition to a secure and affordable, low carbon energy system. CREDS has a team of over 90 people based at 13 UK universities.

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