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Achieving Low Carbon Thinking Everywhere in Infrastructure Delivery

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Who Should Read This White Paper?

Low Carbon Thinking (LCT) is applicable in all aspects of policy, regulation, planning, codes, design, and the operation of energy systems. Hence, it should be of primary interest to governments, regulators, industry, as well as academics when considering current and future infrastructure. To achieve the challenging climate targets, LCT needs to be instilled early on in the decision making processes, starting from project inception to the final analyses of the infrastructure focussing on low carbon options. Typically large scale by nature, energy infrastructure projects tend to have a long useful life, complicated arrangements for inception and deployment as well as societal implications. As a result, infrastructure facilities—such as those in electricity or transportation sectors, once commenced are deemed certain to make significant greenhouse gas (GHG) emissions throughout their lifetime. With Low Carbon Thinking everywhere, great potential to reduce carbon emissions from all sectors of infrastructure can only be realised when such a concept is embedded in all efforts dealing with infrastructure and the services it provides so that such a concept should become the norm.

Key Messages from the White Paper

1. In addition to resilience and sustainability, Low Carbon Thinking must be also included in in the planning, design, procurement, construction, and operation of all infrastructure.

   Elaboration: CO_2 reduction targets make mitigating the carbon footprint of infrastructure a high priority. In essence, this must be considered throughout the lifecycle of projects identifying the interdependencies between the infrastructure and its service provisions so that meaningful progress to reduce emissions sits at the core of all considerations.

2. The fulfilment of infrastructure needs should be linked to outcomes that can be evaluated through the betterment of managing carbon emissions.

   Elaboration: As the building block for economic growth, existing and future infrastructure will continue to be a major source of carbon emissions. While existing infrastructure may be able to adapt to changes (albeit small), future infrastructure should be low carbon and planned well ahead. Having CO_2 reduction an explicit outcome makes measurement, understanding, and management of carbon everywhere in infrastructure of central importance. Hence, links between infrastructure needs and outcomes that are measurable by carbon footprints and their impacts should be identified in the infrastructure fulfilment processes (i.e. plan, design, construct, operate). As part of our Low Carbon Thinking, the links are necessary to help facilitate the evaluation of infrastructure needs in relations to other performance measures providing the needed evidence to support risk understanding and climate change mitigation.

Abstract

Low Carbon Thinking (LCT) refers to achieving an overall carbon emission reduction through embedding such thinking in the lifecycle of infrastructure. It spans the effective use of technology and policy drivers geared to support the utilisation of low carbon resources, energy efficiency measures, efficient process and appliances, and the empowerment of consumers. Such an approach will ensure meeting our climate goals in more timely and efficient manner, while bringing greater opportunities and economic growth for society. Due to the ever-present competing factors affecting energy and its infrastructure and their link to emissions and climate change, this work aims to highlight approaches that convey the interplay between these issues and provide a synthesis of the current status of thinking in the field. In addition, this work also aims to identify areas where additional evidence and further research are needed to support decisions that can propel the UK into a low carbon pathway in its energy mix.

Key Words

Low carbon thinking, emission reductions, energy, infrastructure, interdependency of infrastructure

Connections to Other ICIF White Papers

1. Evidence for the Value of a Systems Approach to Infrastructure Planning, Delivery and Operation
2. Infrastructure Resilience: a multi-disciplinary perspective
3. The Potential Benefits of Outcome based Assessments of Infrastructure Performance
4. Smart Infrastructure – Benefits and Pitfalls
5. Rethinking 'Sustainable Infrastructure': Natural Processes, Context, Value and Balance

Where Can I Find Out More?

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Achieving Low Carbon Thinking Everywhere in Infrastructure Delivery

1 Introduction

Energy provision underpins every aspect of our lives. In most of the developed world, energy as a commodity is taken for granted, not only in terms of instant availability of the services it provides but also in meeting increasing demands. This notion, is however, unsettled when the availability in the supply is interrupted or when the cost of such a commodity has increased. This then triggers a debate on the issues of supply security and affordability, which becomes more prominent in the political sphere. In addition, global legislation especially in relation to emission reductions and domestic energy policies also plays a major role in driving policy at both national and international agendas. These issues are a manifestation of the complexity and value of energy, which needs to be appreciated within both global and national contexts. These issues can be considered under the 'energy trilemma' — energy security, affordability, and sustainability, which offers real opportunities for the UK in terms of low carbon options in both supply and demand. New approaches to large-scale low carbon technology deployments (generation and demand reduction) will be needed that can create a renaissance in industry, businesses, and the knowledge base galvanised to develop natural resources, innovative new products, and services geared to enhance security of supply and growth. Fig.1 illustrates how energy and sustainability, low carbon technology, and growth can be linked in both global and national contexts. All the highlighted areas will have many branches to the various options and interdependencies. Global carbon reduction agreements are set forth to filter through to affect national energy policy legislation. Sustainability will join with domestic security and affordability requirements to form a tri-objective mission to shape domestic energy demand and policy, which, once effectively implemented, are expected to support growth through the development and deployment of low carbon technologies at scale.

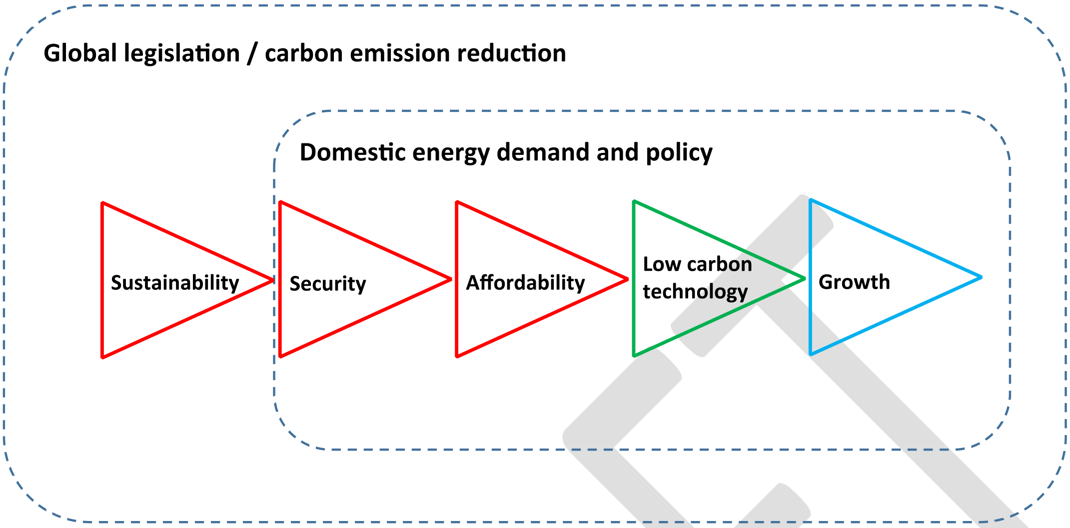

Fig.1 Energy trilemma and low carbon technology as drivers for growth

The UK is blessed with vast natural sustainable resources of energy — wind, marine energy (wave and tidal), and solar to (some extent) which, when coupled with the national innovation prowess, could propel the country to be a major leader in low carbon. However, this will necessitate a clear and long lasting strategy and planning as well as investment portfolios developed specifically for exploiting these resources. An overarching long-lasting strategy can make a real difference to the energy trilemma and could generate national wealth. Embedding *low carbon thinking everywhere* would require long-lasting and appropriate support mechanisms in an overarching strategy encompassing the following:

(a). Energy efficiency in industrial, business, and domestic sectors including procurement

(b). Development of affordable indigenous sources of energy, addressing security of supply, and reduction of greenhouse gas emissions (c). Integration of energy demand and supply into flexible platforms, such as management and control of smart grids

This work aims to highlight approaches that convey and gather the interplay between these issues, review and synthesise the current status of thinking in the field, and identify areas where additional evidence and further research are needed to support decisions that can propel the UK into a low carbon pathway in its energy mix.

2 UK Energy sector

It is instructive to get a clear picture of the energy sectors in the UK. Fig.2 gives a Sankey diagram of the energy pathways including consumption by sector and export.

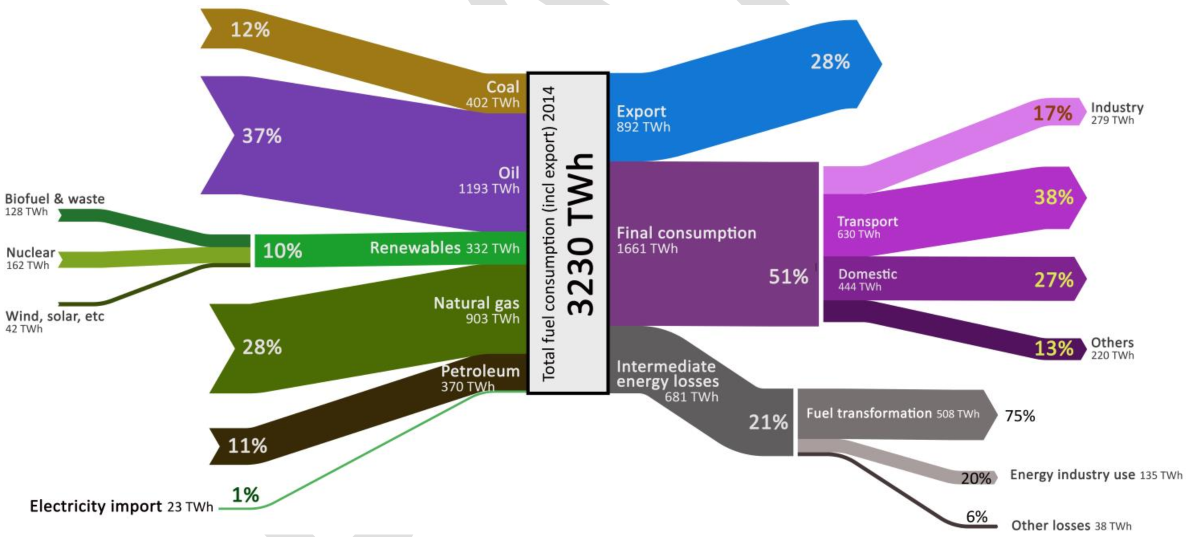

Fig.2 The UK’s energy pathways including consumption by sector and export, (data to construct the diagram is from DUKES 2014)

It is clear from Fig.2 that major opportunities can be gained not only through the final consumption pathway, but also in reducing intermediate energy losses. Hence, *Low Carbon*

Thinking Everywhere concept as described below can play a major role in identifying interconnected frameworks to address efficiencies in consumption as well as reducing overall losses.

3 Low Carbon Thinking

Low Carbon Thinking (LCT) in this work refers to achieving an overall carbon emission reduction through effective use of technology and policy drivers to support: the utilisation of low carbon resources, energy efficiency, efficient process and appliances, and empowering consumers through policy, and/or legislation. In this regard, LCT comprises all tasks involved in managing energy supply and demand, its inherent infrastructure, and how these can be optimised for reducing emissions by use of technologies and human interactions. Due to the ever-present undercurrents of several factors affecting energy and its infrastructure and the link to emissions and climate change, LCT is not static or fixed but is dynamic and on-going. It can evolve and adapt with time to changes in cost factors/markets, technology, business practice, policy, human behaviour, and the environment.

LCT should be of primary interest to the governments, regulators, industry, as well as academics through all aspects of policy, regulation, planning, codes, design, and the operation of energy systems and their current and future infrastructure. To achieve the challenging climate goals, LCT needs to be instilled early on in the decision making processes, starting from project inception to the final analyses of the infrastructure and low carbon deployment options. Typically large scale by nature, energy infrastructure projects tend to have a long useful life, complicated arrangements for inception and deployment as well as societal implications. As a result, infrastructure facilities—such as those in electricity or transportation sectors, once commenced are deemed certain to make significant greenhouse gas (GHG) emissions throughout their lifetime. With Low Carbon Thinking everywhere, great potential to reduce carbon emissions from all infrastructure sectors can be realised when such a concept is embedded in all efforts among all sectors so that it becomes the norm. Low Carbon Thinking should be encouraged everywhere at all scales including large-scale power infrastructure projects down to the appliances scale taking into account interdependencies and implications to society, environment, and economics. Such an approach will ensure meeting our climate goals in more timely and efficient manner, while bringing greater opportunities and economic growth for society.

4 Infrastructure and GHG Contributions

The provision of effective and resilient future infrastructure systems faces many challenges: increase in demand for infrastructure services, significant investment requirements, increase in complexity and interdependence of infrastructure networks, as well as the goal to maintain and improve environmental standards (Hickford et al. 2015). Under the EU mandatory energy targets, the UK is committed to produce 15% of its energy from renewable resources by 2020. In addition, to address the risks of climate change, the UK, through its 2008 Climate Change Act is committed to drastically reduce greenhouse gas emissions from 1990 levels by 80% by the year 2050. To progress towards this target, the Act stipulated interim carbon budgets laid out to 2027, (see Section 5). Fig.3 shows UK emissions for 2013 by sector in relation to the 2050 carbon target. The latter is estimated to be around 160 $MtCO_2e$ in 2050 as compared to 1990 level of 811 $MtCO_2e$. From 2016 and over the next five years, the UK will be investing £48 billion annually in energy infrastructure sector whereas the value of the infrastructure pipeline is £411 billion (Infrastructure UK 2015). Coupled with the unprecedented large-scale public and private spending, the timelines of projected GHG reductions (i.e. 2nd and 4th carbon budgets until 2027) and infrastructure investments (i.e.

pipeline at least until 2021 and beyond) will coincide for at least the next six years although the expected life of built infrastructures generally is much longer. During this time, effective low carbon initiatives, e.g. energy market reform, demand reduction, electric vehicles, new codes and appliances, significant investments in renewable energy and supply chains, and sustainable infrastructure improvements, are essential to drastically transition to a low carbon economy. In the meantime, existing infrastructure networks will continue to function to support social wellbeing and productivity while major critical infrastructures such as power and transport sectors will undergo a significant transformation to upgrade and decarbonise their facilities. Such confluence presents a rare opportunity for the UK to bring long-term policy drivers and optimised processes coupled with new technologies and system approaches to address the needed multi-sectorial infrastructure improvements and renewals through a unified *low carbon thinking* framework.

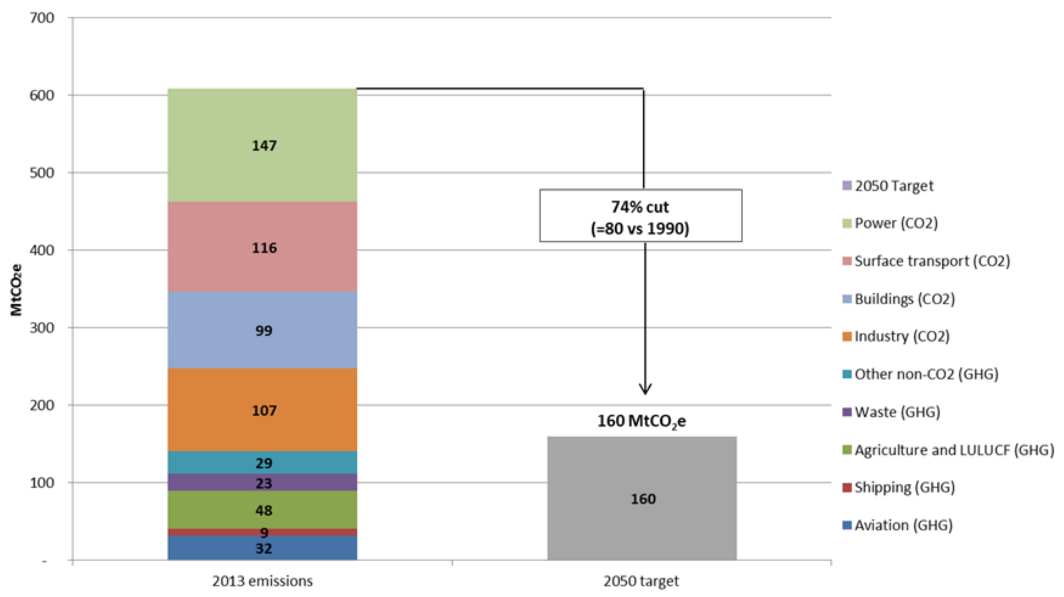

Fig.3 UK emissions by sector, numbers rounded to the nearest whole number, Committee on Climate Change calculations, (CCC 2016)

The major efforts drawn to reducing CO_2 emission are mostly related to power generation. However, in order for us to succeed, such efforts will also need to be applied across all sectors including appliances, buildings, communication networks, industry, and transportation undertaken in concert rather than in isolation. To lower carbon, all work will need to encompass strategies for all the relevant sectors as well as behaviour change. This includes increase the share of renewable energy in the power sector, lower carbon fuels for transport, reduce energy demand through improving efficiency of industrial plants and buildings, and sequester and dispose of produced CO_2, perhaps through carbon capture and storage (CCS).

It is well accepted that our infrastructure, e.g. energy, transport, and water, are interconnected and interdependent in many ways, either by physical, cyber, geographical, or logical means, through, for example, technology and information systems, which are also an infrastructure themselves (Rinaldi et al. 2001). With interdependency, the functioning and operating conditions of one system can under some conditions severely affect the performance of another. In some cases, disruptions or failures of one infrastructure system can cause consequences that can completely disrupt another system resulting in a total loss of productivity or service.

Take water and energy systems for example; energy production such as in hydro or thermal power plants does require water in extraction, conversion, and production of power (or energy) while water system uses energy in the production, as well as the construction and maintenance of infrastructure facilities and their peripherals. Another example: road and rail networks need electricity for propulsion, space conditioning, lighting, and signals to operate while power plants rely on roads and rails to transport fuels and materials for electricity generation and other operations. In addition, designs to link existing rail networks in relation to an airport expansion would have implications to the deployment and operation of power and telecom networks, while fit-for-purpose design and effective use of information and communication technologies (ICT) to share logistics information would help save fuel and carbon emissions, e.g. emissions due to combustion, fuel transport, construction, and operation. Effective data sharing and timely access to infrastructure interdependency information will also support improved efficiency and quality of decisions, especially in case of emergency management (Pederson et al. 2006, Kim et al. 2007).

By direct or indirect contributions, an infrastructure system can cause GHG emissions not only by the very existence of built infrastructure and services but also through its interdependency with other systems. Rather than working on each infrastructure system in isolation, an integrated approach to planning, operation, and sharing of information between sectors (e.g. water and energy) would lead to more sustainable and beneficial outcomes such as improved quality of service and system efficiency for both sectors (Nair et al. 2014, Goldstein et al. 2008). Hence, an LCT approach to decision making in infrastructure improvements will not only enable the necessary functions and satisfactory outcomes but also improve the resilience and sustainability of infrastructure networks.

5 UK’s emission reduction targets and carbon budgets

Since the Climate Change Act 2008, the UK through the statutory Committee on Climate Change (CCC) has established the national `carbon budgets’ as guidance to ensure progress towards its long-term 80% GHG reduction target by 2050. As a result, UK emissions are largely dominated by carbon dioxide, accounting for about 82% of the UK’s GHG emissions in 2013. Set for interim targets, a carbon budget is the total amount of carbon emissions in million tonnes of carbon dioxide-equivalent ($MtCO_2e$) allocated in blocks of five years. It is common to average emissions to $MtCO_2e$ per year for reporting on progress in meeting each budget. Fig.4 shows UK annual GHG emissions since 1990, the CCC's cost-effective path, and projections towards the 2050 target. The green bar represents the 2050 target and the grey bars the UK's first four carbon budgets. The blue bar represents the recently proposed fifth budget, to be set by the end of June 2016. The red lines show emission projections from DECC, which are expected to overshoot the budget by roughly 10% for the 4th carbon budget, provided that each budget includes an allowance for international aviation and shipping emissions (IAS).

In the past decade, significant progress towards the needed reduction to targets has been made through effective implementation of initiatives, policies, and investments at multi levels of targeted instruments by the government. Outcomes largely supported the expansion and improvement of important infrastructures and policy instruments, such as road vehicle fuel efficiency in transport, low/lower carbon technologies in power production, energy efficiency in the buildings sector as well as energy consuming appliances. As a result, the UK met its first Carbon Budget (2008-2012) and is now in its second Carbon Budget period of 2013-2017. In relation to the latter, emissions from the power sector, transport, industry, and buildings made up about 80% of the 520 $MtCO_2e$ total GHGs emitted in 2014. The rest arose from agriculture, waste, and other non-CO_2 emissions. However, UK emissions in 2013 were 30% lower than in 1990 and there was an improvement of 8% from 2013 to 2014. This period also corresponded to an economic growth of 3%, providing evidence that low carbon options support growth (HM Government 2015).

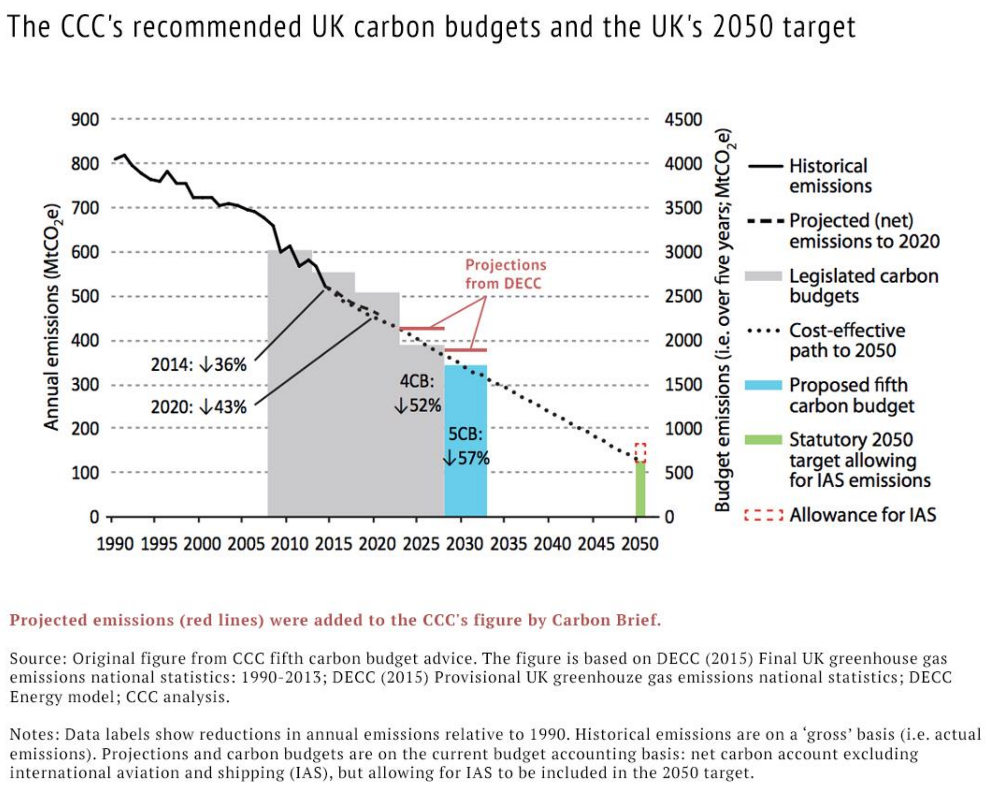

Fig.4 Overall UK greenhouse gas emissions since 1990 including the CCC's carbon budgets and cost-effective path to the 2050 emission reduction target (Carbon Brief 2015)

Furthermore, the emission data indicates that around one half of the domestic carbon dioxide and GHG emissions came from the transport and power sectors. The fact that few sectors being the major contributors is expected to continue, which emphasises that efforts should be focused first on sectors where the potential for emission reductions is the greatest, a reminiscence of the 80/20 rule—that 80% of the effects come from 20% of the causes.

However, an immediate prominent issue now for such budgets is how reduction shortfalls will be addressed in the medium term? In general, the CCC recommends increasing the level of financial support and commercialisation for low carbon power generation and heating, energy efficiency improvements, and transport decarbonisation through adoption of electric vehicles (CCC 2015). Centred around the LCT framework, infrastructure decisions to be made will have significant impacts to help reduce emissions, especially those required for infrastructure support for CCS, heat networks, and electric vehicles.

6 Decarbonising the Electricity and Transport Sectors

Decarbonisation of the power sector has a critical role in decarbonising and improving the resilience of UK infrastructure networks. A case in point is the potential for electricity to provide other sectors with decarbonised electrical power (CCC 2016). For instance, a widespread adoption of ultra-low emission vehicles such as electric and plug-in hybrid powered cars will help cut down GHG emissions and pollutions on the roads. Bearing in mind that additional capacities will need to be in place to take the resultant (shifted) loads, the decarbonisation of transport exemplifies how other sectors can follow suit by substituting their high-carbon-intensity energy sources with low carbon electricity. However, the decarbonisation of the electricity supply sector predominantly relates to the introduction of cleaner or low-carbon alternative energy sources, such as wind, solar, marine, hydro, and nuclear into the power generation mix to replace high-carbon-intensity fuel sources such as coal or natural gas. In this sense, the UK is blessed with huge renewable resources around its shores. Exploiting these will provide security of supply and needed economic growth if long-term support mechanisms are in place to provide market confidence and stability for developers. Nevertheless, proper balance of fuel sources and/or generating technologies will typically make a better diversified generating portfolio, which in turn would enhance the overall systems' security and resilience against any undesirable supply shortages or disruptions.

By 2050, demand for power will likely double from today. In addition, an estimated £100 billion of investment will be needed by 2020 in the electricity generation infrastructure, transmission, and distribution networks (DECC 2014). Historically, the power sector contributes around one fifth of total GHG emissions. Year on year emission reductions in the power sector vary and are not on a trajectory to show steady progress due to factors affecting trends or changes in emissions. These factors are uncertain and have a material impact on emissions and their projection. They include macroeconomic drivers/markets, number of household and population, government policies, and climate dependence. Additionally, extreme weathers, pricing/fuel switching, mothballing/retiring of power plants, and investments can have a significant impact on energy consumption and emissions. For example in 2014 being a warm year, there was an 8% fall in overall emissions directly resulting from lower energy demand due to high winter temperatures though part of the fall was helped by reduction in coal burned for electricity and progress in renewable deployment.

Recent issues about uncertain factors affecting mitigation efforts in the energy sector can be highlighted as follows. EU regulation for new vehicles, UK regulation for boilers, taxation for waste, and subsidy for renewables were designed to help with progress and to secure financial return for low carbon generators (CCC 2015). However, given the current climate of austerity, some of these support mechanisms are under threat and are likely to be shelved. For the electricity infrastructure, further significant investments will be needed including: support for renewables, removal of grid bottlenecks, commercialisation of CCS, expansion of heat networks, and an increase utilisation of electric vehicles. This provides an opportunity for an integrated approach with LCT at its core.

7 Discussion

The UK's legislated carbon reduction targets have made mitigating the carbon footprint of the country a high priority which will have an impact on all infrastructure delivery plans. Building infrastructure and services that not only enable critical functions but also increase societal productivity coupled with optimised energy consumption will need to be an integral part of the UK's strategy for its climate objectives. This will need to encompass sustainability, resilience, and competitiveness (Infrastructure UK 2014, Rhodes 2015). A key to successful delivery of a low carbon infrastructure may be found in the link between carbon budgets and how different sectors contribute to carbon emissions. In essence, infrastructure and its operation if not derived from zero carbon technologies, can be viewed as an energy consumer and thus a GHG contributor. Although end users, services, businesses, and industrial activities are part of an overarching infrastructure that delivers and consumes energy (hence contributes to emissions), this can be perceived to be an overall interconnected infrastructure comprising a "system of systems," where energy and resources are taken in as inputs whereas products and services are produced as outputs. It can also be considered that interconnected infrastructures with pairwise mutually dependent functionality and/or interoperability, i.e. being interdependent, *is* a system whose components are built facilities linked up by services and operations to make a purposeful infrastructure network. Such understanding points to a framework that has at its core: *Low Carbon Thinking* whether in the planning, design, and operation that needs to be employed as an overall integration framework for infrastructure systems (or a system of systems). Once built and operational, infrastructures and systems based on this framework, such as an oft-visualised future with decentralised low carbon electricity networks interconnected and enabled by SMART grid and control devices, can be used not only to manage generation and demand reductions (hence emission reductions), but also overall performance of the system.

Policy mechanisms to lower carbon emissions such as improvement in fuel efficiency for conventional vehicles in transport and switching to alternative energy sources in electricity generation have been proven to be effective as mitigation measures in their respective sectors. However, with interdependency of infrastructures, such as seen in power and transport, ICT and rail networks, etc., there is a need for overarching and novel ways to collectively manage GHG mitigation that would mutually benefit all sectors. An immediate example is the use of ICT in automotive, electrical power system, as well as demand reduction through the combined use of electric vehicles, charging stations, battery storage, renewable power, and smart control devices, based on the internet of things (IOT). In such concepts, designs of charging schemes to exploit variable energy sources (e.g. wind and solar) and demand peaks would feed back to changes in grid connection layouts, user behaviour, and business implications to operators of both existing and new electrical infrastructure.

Furthermore, as technological and social innovations continue to enable new sustainable business models, a big step forward in delivering future infrastructures lies in the ability for the UK to see interdependent infrastructure systems as a whole, and focus its investments and necessary support schemes on where it can have large impact on emissions most effectively at scale. To this end, *Low Carbon Thinking Everywhere* seems appropriate as a sensible strategic framework for all as the concept of energy and carbon reduction are readily built-in in all infrastructure sectors. As an overarching concept, it can be applied at different levels to multiple infrastructure sectors and their functions. If designed well, it can provide the needed assessments that are linked to the national targets as well as the capability of measuring the system performance such as overall energy consumption, efficiency, and carbon emission. The concept can also be used in conjunction with common financial performance indicators such as, return on investment, cost-benefit, net present value, etc. In addition, while the concept of *Low Carbon Thinking* may be seen as a proxy to sustainability in the sense that, "low carbon" simply means "reducing our carbon footprint," it also has the capacity of enhancing climate change mitigation and hence, overall sustainability.

8 Concluding Remarks

Early and rapid reductions of GHG emissions and low carbon infrastructures are needed to avoid the significant impacts on our resources and climate change. The key is to have a coherent strategic framework that provides tools for measurement and target settings. To achieve the UK's challenging carbon reduction goals, we must deal with several uncertainty factors and regularly evaluate our progress using the measure or performance metrics. As proposed here, *Low Carbon Thinking Everywhere* is a conceptual framework that can have an overarching impact on emission goals. It can be thought of as a practical system thinking in action that takes infrastructure-centric point of view, and employs energy use and carbon emissions as its performance measure. With the ever increasing pressure to utilise electricity for heating, transport, and possibly other sectors in future, thus, making our infrastructure even more dependent to electricity and vice versa, LCT can play a major role in identifying the low carbon pathways for society. While it is strategically important to look at infrastructure networks as a living interdependent system of systems, it is equally important that we have a strategic framework like LCT to help with our future infrastructure delivery.

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