

Low Carbon Routemap for the UK Built Environment

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Executive Summary

This report is the culmination of a six month effort to develop a Low Carbon Routemap for the Built Environment. It provides a summary of the approach and methodology used to develop the Routemap, and the key challenges and opportunities. It is intended to accompany the visual Routemap and model found on the website of the GCB (www.greenconstructionboard.org). The development of the Routemap was managed by WRAP, which engaged Arup and the Climate Centre to provide technical support in preparing the Routemap and a model for emissions trajectories to 2050.

The Routemap covers both infrastructure and buildings sectors, and addresses operational as well as capital (embodied) carbon emission components. The scope of the Routemap has been defined to include:

- **Operational carbon in buildings:** GHG emissions from regulated energy use in the domestic and non-domestic sectors.
- **Operational carbon in infrastructure:** GHG emissions from outdoor lighting, waste from construction, demolition and excavation, and water/wastewater. The use of transport infrastructure (by cars for example) is excluded.
- **Capital carbon:** GHG emissions include direct process emissions and indirect emissions from the manufacture and production of UK and imported construction materials and products, emissions from the transport of materials, emissions associated with professional services in support of construction, and all construction and demolition works on site.

Baseline Carbon Emissions

Using this scope to define the emissions within the built environment, a baseline emissions profile was developed for the years 1990 to 2010. This analysis shows the built environment (as defined in the Routemap) was responsible for almost 210 MtCO₂e of

emissions in 1990 and just over 190 MtCO₂e in 2010. The breakdown of these emissions in 2010 is shown in Figure 1. As shown on the figure, the domestic sector has the largest share of carbon emissions (primarily from heating and hot water).

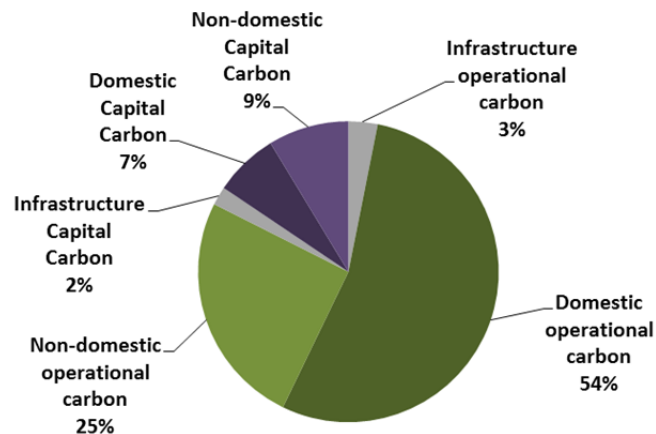


Figure 1: Breakdown of Carbon Emissions in the Built Environment (2010)

Scenarios to 2050

A model of the trajectory of carbon emissions for the built environment was developed for the 2010 to 2050. Three scenarios were assessed, each which used a similar trajectory for grid decarbonisation:

- A Business-as- Usual Scenario which represents the status quo
- A Central Scenario which consists of implementation of measures that have a positive return on investment over their lifetime or are reasonably feasible to implement
- An 80% Carbon Reduction Scenario which reaches the 2050 targets and represents maximum uptake of low carbon technologies from the central scenario, as well as significant uptake of measures that do not have a positive return on investment

The 80% carbon reduction scenario is illustrated in Figure 49.

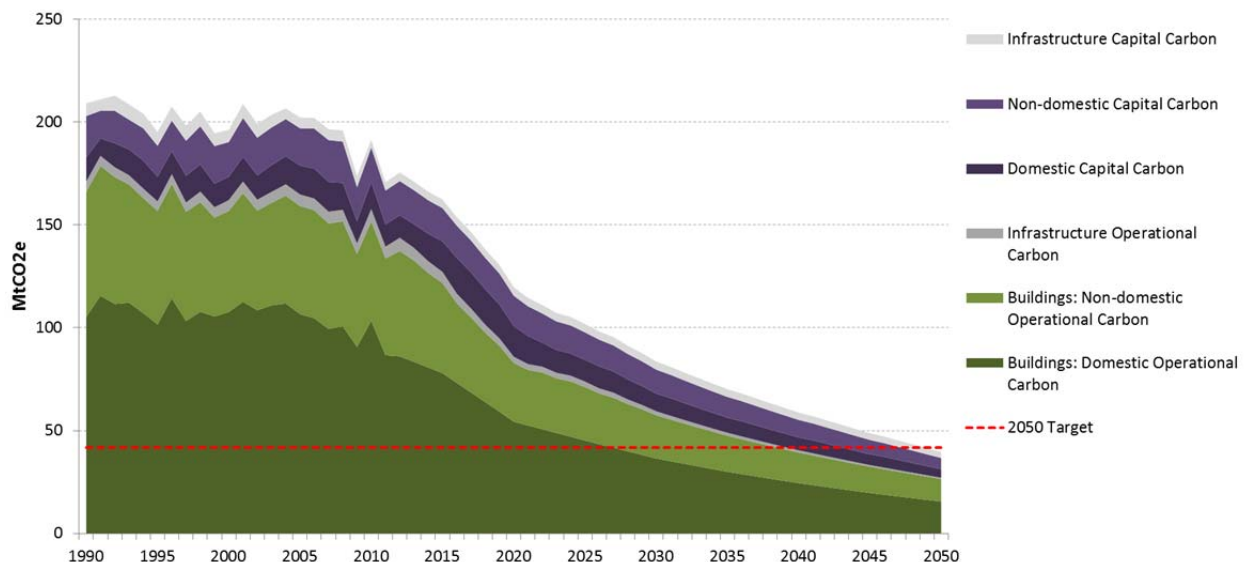


Figure 2: Built environment carbon emissions to 2050 under the 80% Scenario

Key Challenges and Opportunities

In delivering the 80% carbon reduction, the primary challenges and opportunities that have been identified include the following listed below.

Meeting the 80% carbon reduction target is challenging, but technically possible

- It is technically possible to deliver the government's target of an 80% reduction in carbon emissions in the built environment, however, this would require maximum uptake of technically viable solutions in all sectors, including implementation of technologies that at present do not have a financial return on investment over their lifetime.
- Even under the Central scenario, market failures would still need to be addressed as there is not a strong enough business case or incentive for the private sector to implement even those measures which could have a return on investment over their lifetime.

- Taking responsibility for carbon reduction at an industry level is essential to driving uptake and delivering results as quickly as possible. There are many sectors where no industry body “owns” the carbon and no plans have been developed to manage carbon reduction.

There are strong opportunities to drive carbon reduction and promote ownership of carbon in specific buildings sectors

- The most significant source of carbon emissions in the built environment today is domestic direct emissions from space heating (e.g. oil and gas boilers), followed by non-domestic space heating. This is an area where improvements can be made through insulation, draught proofing and building control systems, but ultimately a change in fuel source is required to achieve an 80% emissions reduction. The 80% scenario, indeed, assumes near full implementation of DECC’s heat strategy, enabling substantial improvements to be made in carbon reduction.
- The 80% reduction scenario assumes that about 95% of easy to treat homes and 70% of hard to treat homes will be retrofitted with insulation, draught proofing and superglazing by 2050. This would require a substantial increase in the pace of retrofit, particularly in hard to treat domestic buildings.
- Ordering the 10 non-domestic building types by most to least carbon emitted in 2010 shows that the top five emit 71% (retail, education, warehouses, hotels and catering and commercial offices). There is a need to encourage the industry representing each building sector to take ownership, develop appropriate plans and drive carbon reduction.
- Lighting is a significant source of emissions: it represents about 25% of energy use in 2010 and nearly 40% of carbon emissions within the non-domestic sector. There are significant opportunities to reduce emissions from lighting, particularly as much of the required technology already exists and payback can be quick, but other barriers and misconceptions need to be overcome.
- The government has significant potential to drive carbon reduction in assets it owns, operates, builds and finances, in particular education, civil service and health buildings, which currently account for approximately 28% of operational emissions.

There are key issues that need to be monitored and addressed across the buildings sector to enable carbon reduction to be realised

- Reducing emissions from buildings is highly dependent on the pace of decarbonisation of the grid. Key decisions about what low carbon technologies will be needed in the future and the timing of when they need to be introduced need to be made in consideration of the pathway towards decarbonisation
- The built environment also has a role to play in enabling decarbonisation – if energy load to the grid and power demand can be reduced, the proportion which must be met through renewable sources becomes more manageable.
- The performance gap is a major issue that needs to be addressed, both for new build and retrofit. Addressing this gap can reduce emission “leakage”, reduce the carbon rebound effect, improve the returns from retrofit initiatives, reduce risk and give greater confidence to investors/owners. Faster reduction would also enable cumulative emissions of the built environment to be reduced.

- Included in the performance gap are behavioural dimensions that will need to be addressed as they can have a significant positive – and negative – impact on carbon emissions.
- Overall the analysis undertaken to develop the Routemap shows that despite numerous studies and research, there is still insufficient bottom-up data on building energy use broken down by different building types. Understanding building performance at a detailed level is essential to promoting greater understanding of the scale of the challenge and developing low carbon solutions across the sector

Capital carbon must start to be addressed in tandem with operational carbon

- The model projects that in 2050, capital carbon will represent nearly 40% of the built environment's emissions versus 18% in 2010.
- There is a relationship between capital carbon and achievement of operational carbon reduction. The projected growth in infrastructure spending has a significant impact on capital carbon and offsets many of the gains made in reducing capital carbon intensity; nonetheless, investment in infrastructure (such as rail electrification) is expected to help to reduce the UK's overall carbon footprint.
- Growth in demand for new building stock and investment in refurbishment together with infrastructure development have a significant impact on capital carbon. Significant growth in retrofit at early stages has the potential to cause large increases in capital carbon, unless measures to reduce capital carbon intensity have been implemented in tandem.
- Improvement will be needed in the efficiency of process systems for materials manufacture. Step change manufacture technology will be required to deliver the necessary gains.
- The findings show that to meet 80% reduction targets there will be a reliance on biofuels (for transportation) and carbon capture and storage for energy carbon intensive industries (i.e. steel and cement). The questions of if and when these technologies can be deployed require resolution.
- Technology change need not be the only solution and there is opportunity in fundamental change in supply side business models (materials/steel and systems/façade).
- The material life-cycle loop must be closed with the establishment of end-of-life solutions. This could be through providing buildings and infrastructure with features such as appropriate services life, adaptability and carbon efficient recycling. The opportunities for reuse are many for example with high-rise structural materials and foundations. New systems which generate change, for example end-of-life obligations for asset creators may also be required to effect change.
- Innovation in materials technology can offer solutions in a number of ways including improved efficiency through the delivery of the same utility, with reduced carbon, or in areas such as carbon sequestration.
- Solutions exist with buying local/national, and/or being selective about where materials are sourced from. As the carbon agenda matures the issue of carbon leakage may be relevant. The capital carbon model as it stands is boundary free and therefore includes all carbon regardless of where it arises. However,

formal national carbon accounting does not measure in this way, which might lead to constraints on national industry. The opportunity is that as the world shifts to recognise full Scope III emissions measurement UK industry could be advantaged if it can offer low carbon material solutions.

- There may be a role for meaningful penalty/incentive schemes to limit GHG emissions during manufacture, which is recognised regardless of where products are supplied from.
- Standards for carbon measurement and reporting at all scales (product, asset, organisation, region, etc) are required. These will become the backbone for measurement, benchmarking, target setting and improvement.
- Carbon performance data on materials is required through Environmental Product Declarations, together with carbon databases, building and infrastructure assessment tools, and design guidance to deliver low carbon solutions. A campaign for the development of these together with training to cultivate the necessary skills and knowledge in the industries professional base.

The drive to 80% carbon reduction represents an economic opportunity

- Delivering the 80% carbon reduction will generate significant business opportunities, in particular for SMEs involved in domestic retrofit. By 2030 in the 80% carbon reduction scenario, it is estimated annual spending on domestic retrofit alone could reach £4-4.5 billion. A study by Verco and Cambridge Economics found that treating the UK's 9.1 million fuel poor homes alone could create 129,000 jobs per year¹.
- By directing funding towards research, development and demonstration in the built environment, and undertaking large scale retrofit over the next 20 years, the UK could position itself as a real leader and innovator in the low carbon economy.
- As the pace of grid decarbonisation becomes more clear, R&D and skills development efforts could focus on what low carbon technologies might be needed in the future, in particular relating to the future heat strategy for the UK.

¹ Jobs, growth and warmer homes: Evaluating the Economic Stimulus of Investing in Energy Efficiency Measures in Fuel Poor Homes, Verco and Cambridge Econometrics, 2012

Glossary of Frequently Used Terms and Acronyms

Capital carbon	All GHG emissions associated with construction and demolition activities in the United Kingdom, including those embodied within imported construction materials and products, and those associated with the provision of professional support services (e.g. architecture and engineering).
CCC	Committee on Climate Change
CLG	Department for Communities and Local Government
CO ₂	Carbon Dioxide
CO ₂ e	Carbon Dioxide Equivalent
DECC	Department for Energy and Climate Change
Defra	Department for the Environment, Food, and Rural Affairs
Direct emissions	Emissions resulting from on-site combustion of hydrocarbons for the purposes of space heating and hot water
GCB	Green Construction Board
GHG	Greenhouse Gas
GHGI	Greenhouse Gas Inventory
Indirect emissions	Emissions resulting from the off-site combustion of fossil fuels to provide for energy demands (electricity) in buildings
MtCO ₂ e	Mega (million) Tonnes of Carbon Dioxide Equivalent
ONS	Office for National Statistics
Operational carbon:	All direct and indirect GHG emissions arising from consumption of energy for the uses and sectors defined as being part of the built environment for the purposes of this work.
Scope I, II, III:	This refers to the three classes of GHG emissions as reported under the Greenhouse Gas Protocol. Scope I emissions are direct GHG emissions. Scope II emissions are indirect GHG emissions resulting from purchased electricity, heat or steam. Scope III emissions are other indirect GHG emissions such as those associated with the extraction and production of purchased materials and fuels, and other activities not directly controlled by the reporting entity.
SMEs	Small and medium enterprises.
TW	Terawatts; a unit of power.
TWh	Terawatt hours; a unit of energy.
VOA	Valuation Office Agency

1 Introduction

Energy consumed in constructing, maintaining and using the built environment – our buildings and infrastructure – is a significant contributor to greenhouse gas (GHG) emissions. It is estimated² that energy use (regulated and unregulated) in domestic and non-domestic³ buildings alone accounts for 36% of the UK's GHG emissions. In addition, transport represents 24% of the UK's emissions, while industrial emissions⁴ are about 22%; a considerable portion of these emissions are to support the supply chain and construction activities for the built environment.

The built environment is a sector that presents a strong opportunity to make substantial progress in reducing energy demand, improving process efficiency, and reducing carbon emissions. In turn, this supports efforts to achieve renewable energy generation targets, and develop the green economy by creating jobs, economic growth, opportunities for SMEs and export potential.

The Green Construction Board has developed the Low Carbon Routemap for the Built Environment to serve as a visual tool enabling stakeholders in the UK built environment to understand the measures, decisions, and actions required to achieve the government's 2050 target of 80% reduction in greenhouse gas emissions, and to measure progress over time.

The Routemap includes actions that reflect, strengthen or build upon current and proposed legislation and policies, as well as new initiatives to encourage carbon reduction. The Routemap also provides indicators and targets that can be used to assess progress in meeting the 2050 target. Its scope includes infrastructure and buildings, and addresses operational carbon emissions ("operational carbon") as well as capital carbon emissions ("capital carbon") embedded in construction processes (see Section 2.1 for further details).

1.1 Project Objectives

The development of the Routemap was managed by WRAP, which engaged Arup and the Climate Centre to provide technical support in preparing the Routemap and a model for emissions trajectories to 2050.

The objectives of this project were to:

- Provide a structured and logical Routemap by which to view the timeline to 2050 of key decision points, actions, deadlines and requirements
- Give a strong understanding of opportunities, risks, and gaps in information
- Identify other relevant carbon reduction approaches not currently considered by the GCB
- Improve visibility and coordination of the GCB working groups
- Demonstrate commitment and progress towards achieving a low carbon built environment.

² Percentages are calculated from GHG emissions data *by end user* presented in "2011 UK Greenhouse Gas Emissions, Final Figures; Data Tables", DECC, February 2013.

³ "Service Sector" as presented in DECC ECUK Table 5.6

⁴ Includes "Industrial Process", iron, steel and other industrial combustion and electricity data categories

1.2 Purpose and Structure of Report

This report provides a summary of the approach and methodology used to develop the Low Carbon Routemap for the Built Environment, and the key findings and recommendations. It is intended to accompany the visual Routemap and model found on the website of the GCB (www.greenconstructionboard.org).

The report is structured as follows:

- Chapter 2 discusses the approach to the project, its scope in terms of emissions and sectors covered, the overall context and stakeholder engagement
- Chapter 3 provides a brief analysis of 2010 carbon emissions data for the built environment
- Chapter 4 presents the methodology and analysis used to develop a baseline of carbon emissions in the built environment from 1990 to 2010
- Chapter 5 discusses the methodology, assumptions and analysis used to develop projections to 2050
- Chapter 6 presents the three scenarios considered and the results of each
- Chapter 7 provides some final thoughts on challenges and opportunities to achieve an 80% reduction in carbon emissions in the built environment by 2050

2 Project Approach and Scope

The work was carried out in three phases between August 2012 and February 2013:

- **Phase 1:** Defining the built environment and developing a corresponding baseline emissions level for 1990 to 2010, as well as identification of major policies and initiatives that have been or are being developed to encourage carbon reduction
- **Phase 2:** Development of a model with capital and operational carbon emissions trajectory for the built environment and assessment of the potential to achieve an 80% reduction through key policies and actions
- **Phase 3:** Development of the visual Routemap, a model with a user interface, and a final report detailing the methodology and findings

2.1 Project Scope

The Routemap covers both infrastructure and buildings sectors, and addresses operational as well as capital carbon emission components.

Defining the built environment and the emissions that are included was carried out by stakeholder consultation during Phase 1 by considering control and influence exerted by the industry. Through this process the following scope was defined.

For operational carbon in buildings, *only GHG emissions from regulated energy use are being addressed* in domestic and non-domestic sectors. The term “regulated” refers to the portion of building energy use which is governed by building codes and regulations. It therefore excludes all plug loads in buildings such as computers and servers in offices or televisions and refrigerators in homes. For 2010, the portion of total emissions from domestic buildings which relates to regulated energy use is 72%, while for non-domestic buildings it is 74%.

Operational carbon emissions in infrastructure consists of outdoor lighting, waste from construction, demolition and excavation, and water/wastewater. The *use* of transport infrastructure (by cars for example) is excluded. Any components of infrastructure that include buildings (such as railway stations) are included in the analysis but appear under buildings.

The capital carbon model developed for the carbon routemap is based on the working definition of the ‘UK construction industry’ as reported by the Office of National Statistics (ONS)⁵. It includes all GHG emissions associated with this scope arising from the following components:

- Direct process emissions and emissions from the provision of energy, water, and other resource demands, for the manufacture and production of UK and imported construction materials and products.
- Emissions arising from the transport of materials within the supply chain and to the construction site.

⁵ <http://www.ons.gov.uk/ons/publications/re-reference-tables.html?edition=tcn%3A77-224124>

- Emissions associated with the provisions of professional services in support of construction (these include for example architecture, design and engineering, QS, consulting services etc.).
- All construction and demolition works on site.

Emissions for this scope are included for both buildings and infrastructure and it covers new work, maintenance and refurbishments.

An illustration of this scope can be seen in Figure 3.

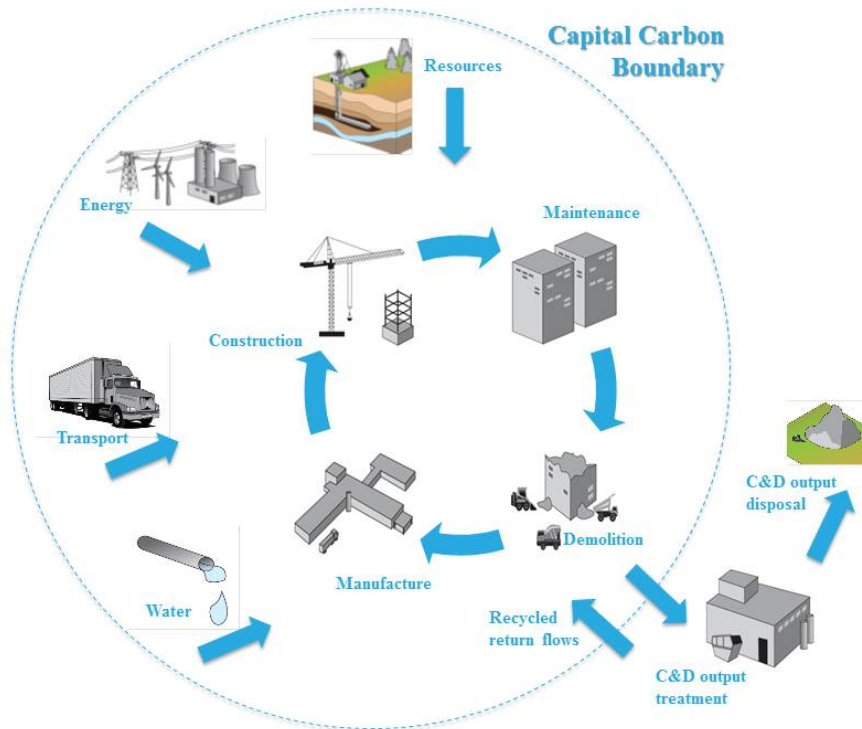


Figure 3: Boundary for capital carbon emissions

Emissions for the treatment and final disposal of any C&D waste (i.e. offsite activities) are excluded from the definition of capital carbon. However, they are accounted for within operational infrastructure emissions.

The scope of emissions covered by the project is summarised in Table 1 below.

For simplicity, the report refers to carbon emissions and GHG emissions; it should be assumed these terms are synonymous unless otherwise stated.

The Routemap does not address actions related to decarbonisation of the electricity grid, and assumes that decarbonisation of the electricity grid proceeds as projected by the Department of Energy and Climate Change and the Committee on Climate Change (see Section 5.1).

Table 1: Scope of emissions in Routemap

High level	Mid level	Capital Carbon	In	Operational Carbon	In
Domestic buildings	Housing	Construction of new housing	✓	Heating	✓
	Refurbishment of housing	Housing refurbishment & maintenance	✓	Cooling	✓
				Hot water	✓
				Ventilation	✓
				Lighting	✓
Non-domestic buildings				Cooking	✗
	Public Buildings	Construction of new public buildings	✓	Other appliances	✗
	Industrial	Construction of new industrial buildings	✓	Heating	✓
	Commercial	Construction of new commercial buildings	✓	Cooling	✓
	Retail and Distribution	Construction of new retail buildings	✓	Hot water	✓
	Refurbishment of non-domestic buildings	Refurbishment & maintenance of non-domestic buildings	✓	Ventilation	✓
				Lighting	✓
				Cooking	✗
Infrastructure				Other appliances	✗
	Infrastructure - Energy	Construction of power stations, energy distribution ¹	✓	Electricity	✗ ²
	Infrastructure - Telecommunications	Construction of communication networks, cabling, masts etc. ¹	✓	Use of telecommunications	✗
	Infrastructure - Water	Construction of reservoirs, pumping stations, treatments works and distribution networks ¹	✓	Use of water	✓ ³
				Use of sewage systems	✓
	Infrastructure - Transport	Construction of roads, rail, bridges, airports, ports ¹	✓	Vehicular emissions	✗
	Infrastructure - Waste	Construction of waste treatment, recycling and incineration facilities ¹	✓	Emissions from waste treatment	✓ ⁴
	Refurbishment Infrastructure	Infrastructure refurbishment & maintenance	✓		

¹ The construction and operation of buildings required to operate the infrastructure, including offices and stations is included in the non-domestic buildings sector.

² Electricity use emissions are assigned to the activities using the electricity.

³ Water use associated with industrial activities will be excluded if data is available.

⁴ Emissions associated with construction and demolition waste only.

2.2 Context

As discussed in Section 2.1, the scope of the Routemap is limited to certain segments of capital and operational carbon emissions within the built environment. Although the Routemap does not cover all sources of carbon emissions within the built environment, it is important to recognise the impact of decisions in the context of overall emission levels. For instance, there is a strong link between capital and operational carbon emissions; decisions which may increase capital carbon may help to directly or indirectly reduce operational carbon emissions and vice versa. This linkage is particularly true in the infrastructure sector where an investment in, for example, expanding mass transport would help reduce the UK's overall transport emissions, but would increase capital carbon emissions for the built environment. To understand this trade-off, a whole lifecycle carbon approach is required.

In addition, although the Routemap does not address emissions from unregulated energy use, it is important to remember there is a link between regulated and unregulated energy use. Unregulated energy use within a building, such as a server room, may drive up regulated energy use in areas such as cooling.

2.3 Stakeholder Engagement

Stakeholder engagement was an essential component of developing the Routemap. Engagement has taken place through meetings with Working Groups of the Green Construction Board, a stakeholder workshop held in London on the 29th of November 2012, and through consultation with key individual stakeholders.

3 2010 Review: Where is the Carbon?

Overall in 2010, the emissions associated with built environment (as defined in this report Section 2.1), were estimated to be about 190MtCO₂e in 2010. The breakdown of these emissions is provided in Figure 4. These emissions have been calculated using the methodology described in Chapter 0.

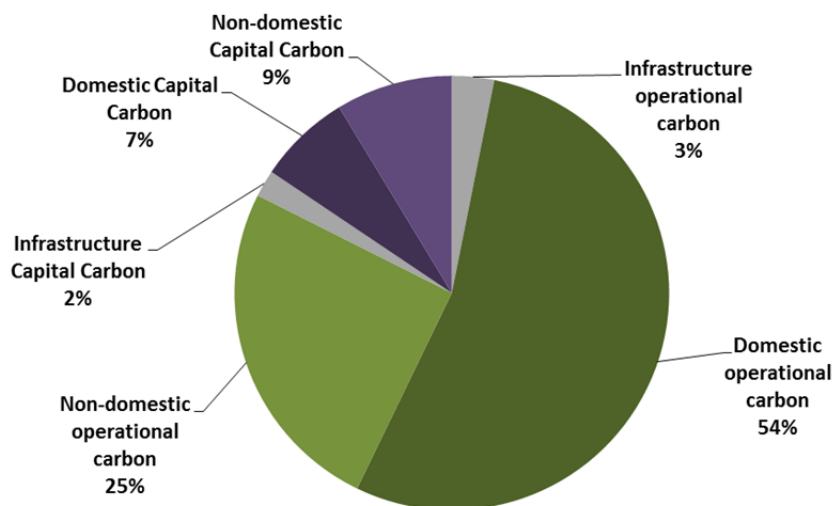


Figure 4: Breakdown of Carbon Emissions in the Built Environment (2010)

As shown in the diagram, domestic buildings are responsible for more than half of the emissions in the built environment. Domestic and non-domestic buildings together account for 79% of emissions. Further breakdown of these figures is provided in the following sections.

3.1 Building Operational Emissions

The following figures for energy use and carbon emissions are derived from data presented in ECUK for energy end-use.

3.1.1 Energy Use in Buildings

For the reference year of 2010, regulated energy use in buildings is estimated to be just over 639 TWh, broken down as shown in Figure 5. Heating is the largest source of emissions, representing nearly 75% of regulated energy use.

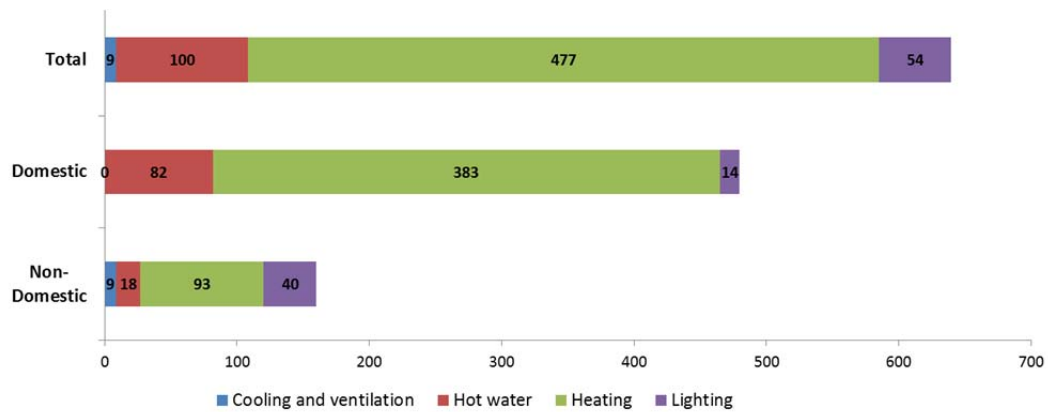


Figure 5: 2010 Regulated energy use in buildings (TWh)

Energy use in non-domestic buildings can be further broken down as shown in Figure 6 below. These building classifications are those used in ECUK. Heating is the most dominant energy use at 58%, but lighting is also significant at 25% of energy use in 2010.

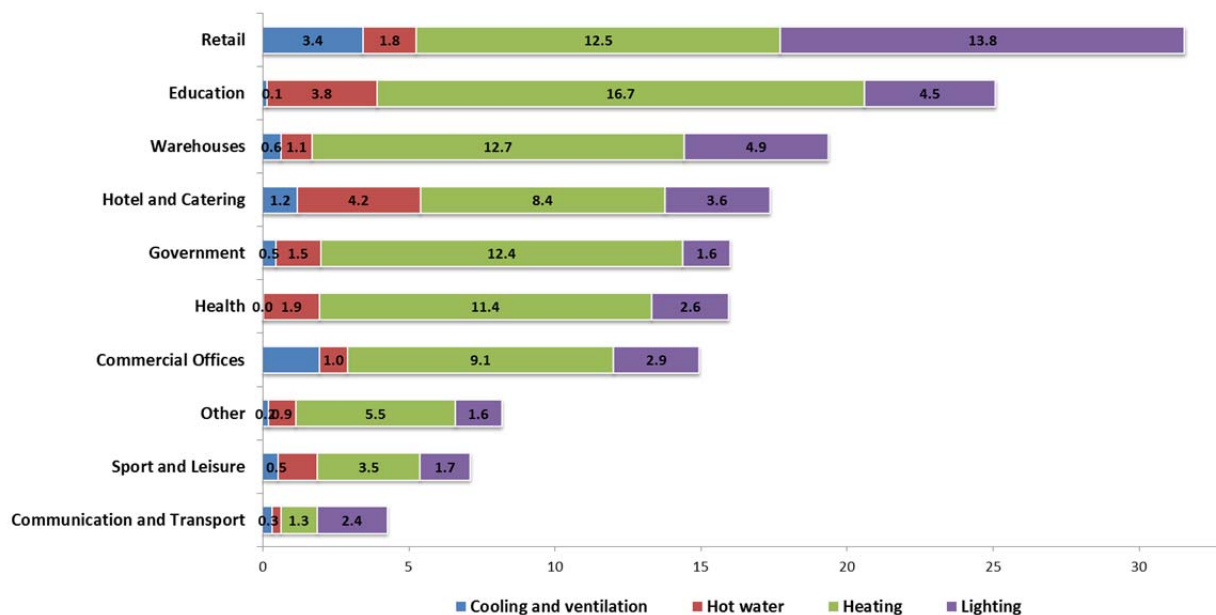


Figure 6: 2010 Non-Domestic Regulated Energy Use (TWh)

3.1.2 GHG Emissions in Buildings

For the reference year 2010, carbon emissions from regulated energy use in buildings is estimated to be 139 MtCO₂e broken down as shown in the figure below. The most significant source of carbon emissions in the built environment is domestic direct emissions from space heating (e.g. oil and gas boilers), followed by non-domestic space heating.

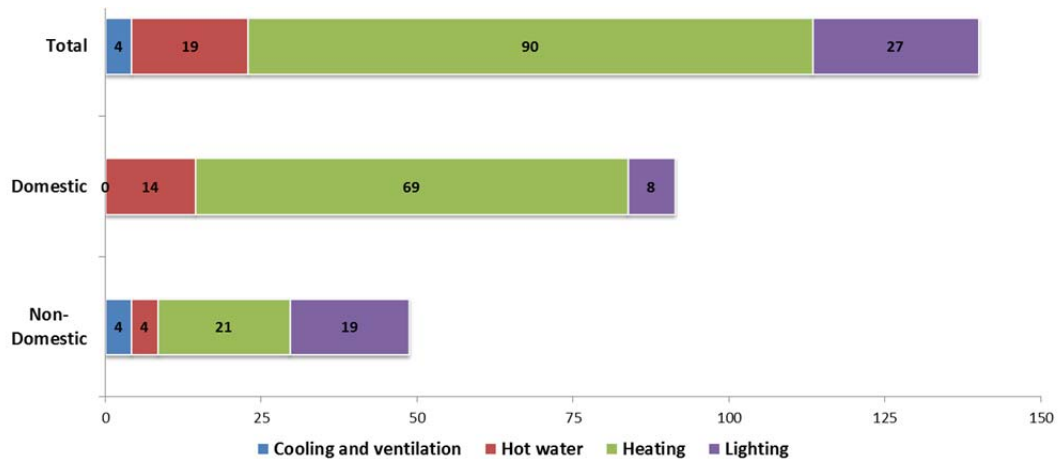


Figure 7: GHG emissions from regulated energy use in buildings (MtCO₂e)

Carbon use in non-domestic buildings can be further broken down as shown below. Ordering the 10 non-domestic building types by most to least carbon emitted shows that the top three emit 50% of the non-domestic carbon and the top five emit 71%. The top five in order of largest to smallest emissions are retail, education, warehouses, hotels and catering and commercial offices. Lighting is a significant source of emissions; it represents nearly 40% of carbon emissions within the non-domestic sector. In the retail sector alone, lighting is responsible for 53% of carbon emissions.

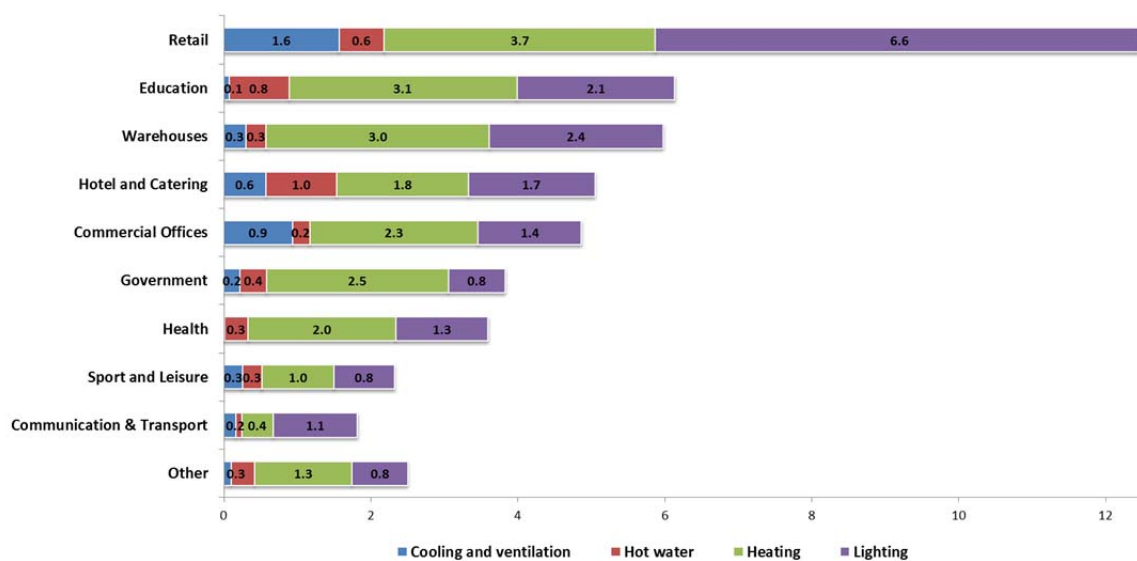


Figure 8: Non-Domestic Regulated Carbon Emissions (MtCO₂e)

3.2 Infrastructure Operational Emissions

As explained in Section 2.1, the Routemap looks at specific segments of infrastructure operational emissions as they relate to the built environment. These segments include public lighting, construction waste, and water and wastewater emissions. The emissions for these three segments of the built environment were estimated to total about 6 MtCO₂e in 2010 or just over 3% of the total emissions for the built environment. The figures have been calculated using the methodology described in Section 0.

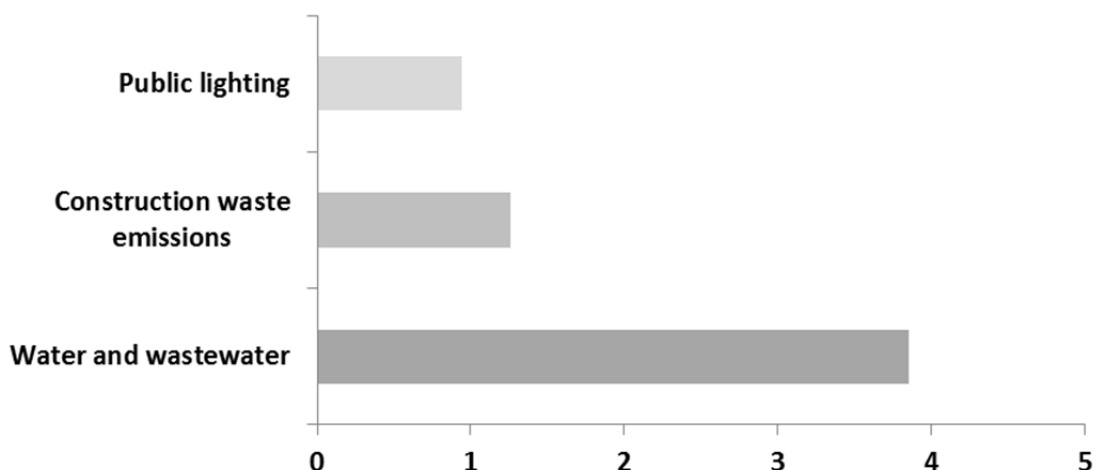


Figure 9: Operational emissions from infrastructure (those addressed by Routemap), MtCO₂e

3.3 Capital Carbon

Capital carbon represents about 18% of the total emissions in the built environment. The breakdown of capital carbon emissions is provided in Figure 10 below. These emissions were calculated using the methodology discussed in Section 5.9. Materials account for over 50% of capital carbon emissions.

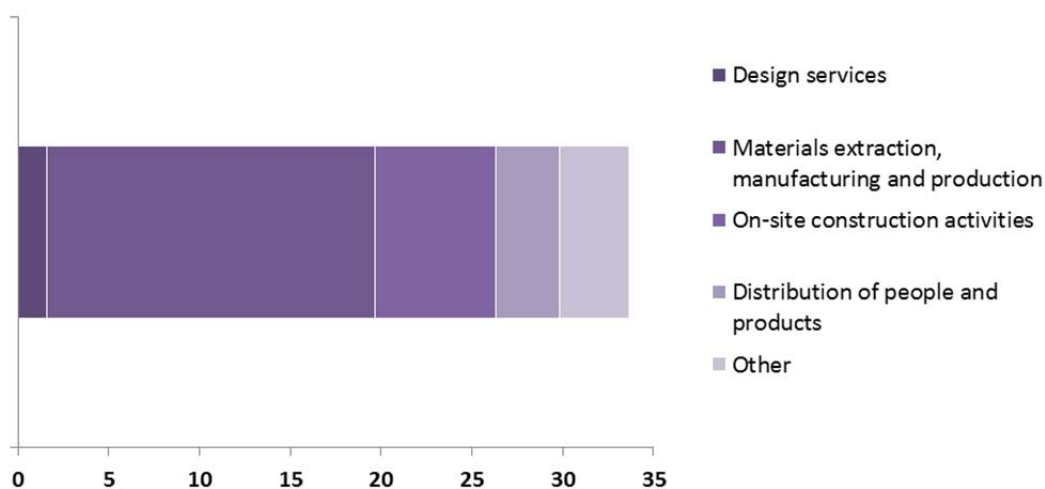


Figure 10: Capital carbon emissions in 2010 (MtCO₂e)

Almost 60% of materials emissions are from two types of materials: metals and cement concrete and plaster, as shown in Figure 11 below.

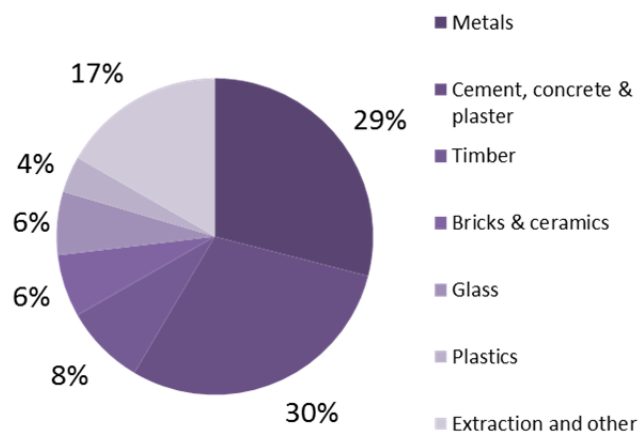


Figure 11: Contribution of material industries to capital carbon in 2010

4 Baseline Carbon Emissions (1990 - 2010)

In order to design strategies to reduce GHG emissions, it is first necessary to understand where GHG emissions are currently generated. This section presents the methodology, data sources, analysis and findings from the development of the model for the baseline GHG emissions. The baseline is an estimate of the capital and operational carbon emissions for which the built environment is responsible, and covers the period from 1990 to 2010. The UK's 2050 target of 80% reduction in GHG emissions is based on 1990 levels; thus, it is essential that the 1990 level of GHG emissions be established for the portion of the built environment that corresponds to the Routemap scope (as explained in Section 2.1)

4.1 Operational Carbon - Buildings

Historic operational carbon emissions operational carbon for the UK built environment are primarily calculated from data on UK energy consumption sourced from the Digest of UK Energy Statistics⁶ (DUKES), produced annually by DECC. Energy consumption data are multiplied by appropriate GHG emissions factors to calculate the operational carbon contribution from various built environment sectors, the most prominent being domestic and non-domestic buildings. Other key data sources are the data tables presented in the 2012 update to "Energy Consumption in the UK"⁷ (ECUK), and the 2011 "Great Britain's Housing Energy Fact File"⁸ (HEFF), as well as the UK Greenhouse Gas Inventory (UK GHGI⁹).

While good quality, suitable data exists across the various operational carbon sectors since approximately 2009, not all datasets present the same resolution back to 1990. As a result, some sectors may not show as detailed an historic emissions breakdown as desired, or sub-sector breakdowns are given as estimates based on suitable assumptions.

The sectors making up the baseline and their relevant sources and core assumptions are presented below.

4.1.1 Domestic Buildings - Direct Emissions

The domestic sector is responsible for a large proportion of overall built environment emissions. "Direct emissions" are defined as the emissions resulting from on-site combustion of hydrocarbons for the purposes of space heating and hot water. It should be noted that gas is also burnt for domestic cooking, but this consumption is excluded from the scope of this research as it represents an area where the industry has limited control and influence.

⁶ Department of Energy and Climate Change (2012), Digest of UK Energy Statistics; <https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/digest-of-uk-energy-statistics-dukes>

⁷ Department of Energy and Climate Change (2012), Energy Consumption in the UK; <https://www.gov.uk/government/publications/energy-consumption-in-the-uk>

⁸ Department of Energy and Climate Change (2011), Great Britain's Housing Energy Fact File; <https://www.gov.uk/government/publications/great-britains-housing-energy-fact-file-2011>

⁹ Department of Energy and Climate Change (2011), UK GHGI Data Tables (1990-2010); <https://www.gov.uk/government/publications/uk-greenhouse-gas-inventory>

DECC UK GHG figures¹⁰ report all historic emissions resulting from domestic combustion, which include those attributed to cooking. To disaggregate this sector, DECC ECUK Table 3.7 is used, which presents annual energy consumption by fuel and end use historically from 1990 onwards. Multiplying the demand of solid, liquid and gaseous fuels for space heating, hot water and cooking by the appropriate emissions factors leads to total domestic direct emissions that agree closely with DECC figures, differing by no more than 2%. This allows for a high degree of confidence when choosing to discard direct emissions due to domestic cooking.

4.1.2 Domestic Buildings - Indirect Emissions

“Indirect emissions” are defined as those resulting from the off-site combustion of fossil fuels to provide for energy demands in buildings. These are primarily the emissions associated with producing electricity but also heat from external sources (i.e. Scope 2 emissions). DUKES Table 5.1.2 gives figures for total historic consumed domestic electricity, which can be multiplied by historic grid carbon intensities to give annual domestic indirect emissions. These do, however, include emissions associated with demand for domestic appliances and cooking, which are outside of the scope of the built environment.

ECUK Table 3.10 presents annual domestic electricity demand for lighting, cold and wet appliances, consumer electronics, home computing, and cooking. ECUK Table 3.7, meanwhile, presents electricity demand for space heating and hot water (as well as cooking and an aggregated lighting and appliances figure).

A difference in modelling methodology and accountancy between the two tables results in slightly different estimates of total demand for lighting and appliances; if summing space heating and hot water electricity demand (Table 3.7) along with individual appliance demands (Table 3.10), total domestic consumption is up to 15% less than total reported consumption in DUKES.

Currently the majority of appliances are considered outside the scope of the built environment, with only lighting demand contributing to the model’s operational carbon section. The baseline model uses lighting demand as presented in ECUK Table 3.10, but this is scaled according to total lighting and appliances demand as given in ECUK Table 3.7 so that it better represents its portion of total UK consumption. Heating and hot water demand is taken from ECUK Table 3.7. These “regulated” domestic emissions components contribute between 46% and 55% of historic domestic indirect emissions. Analysis of this method indicates that there is a potential under-reporting of total electricity of average 4% between 1999 and 2011, but between 1990 and 1999 the data are perfectly aligned. It is likely that future revisions of ECUK will allow for a more accurate measure.

4.1.3 Non-domestic Buildings - Direct Emissions

The most complete historic dataset publicly available for calculating non-domestic direct emissions is DUKES. As an initial estimate for the non-domestic sector, demand for all solid, liquid and gaseous fuels presented in DUKES is

¹⁰ Department of Energy and Climate Change (2013), Statistical Release: 2011 UK Greenhouse Gas Emissions, Final Figures; <https://www.gov.uk/government/publications/final-uk-emissions-estimates>

taken to estimate direct emissions. An issue with the various datasets for fuel consumption within DUKES is that not all are available to the same resolution, or are not available as far into the past as each other.

Non-domestic coal consumption is taken as the category “other” in DUKES Table 2.1.2, which covers consumption that is not for industrial or domestic uses. As such, this includes agricultural use and “miscellaneous” sources that may not exist within the scope of the built environment.

Non-domestic liquid fuels consumption from 1990 to 2010 is taken from DUKES Table 3.1.2 as petroleum consumption by “other final users”, which includes agriculture, public administration, commerce and other services. To provide a disaggregated estimate for built environment-relevant sectors, DUKES Tables 3.2-3.4 provide petroleum products consumption from 1998 to 2010 for public administration and commercial sectors. The trends in percentage contribution to total petroleum contribution for these two sectors are then used to project their values backwards from 1997 to 1990. Note that these figures do not include fuel consumption in public or commercial sector vehicles; this is reported separately in the “Road Transport” category of DUKES statistics.

Non-domestic natural gas consumption is handled in a similar manner, taking data from 1990 to 2010 from DUKES Table 4.1.1 for the “services” category, which includes public administration, commercial, agricultural and miscellaneous consumption. Data from 1996 to 2010 for commercial and public administration sectors is taken from DUKES Table 4.2 and used to estimate consumption for each sector from 1990 to 1995.

Gas consumption in industry, such as the chemical process sector, is not included within the scope of the built environment. Commercial gas consumption figures are primarily for space heating use, although it is possible a small proportion of non-space heating consumption is captured in this reporting sector as well.

Agricultural fuel consumption figures are excluded from the baseline. Whilst some portion of agricultural fuel consumption might be for space heating as opposed to other agricultural processes, it is not currently possible to determine this value far into the past. However, the size of overall agricultural gas consumption is low enough for this unknown portion to be considered insignificant.

While the above method gives a good estimation of total direct emissions in the non-domestic sector, it is not readily possible to disaggregate the emissions within this sector by end-use, for instance to remove emissions due to cooking, back as far as 1990. ECUK Tables 5.6 and 5.6a provide breakdowns of energy consumption by sub-sector and fuel for 2010 and 2011 respectively, and are used on the assumption that catering natural gas demand (8.1% of total gas demand in both years) as a percentage of total demand has been relatively stable between 1990 and 2009, to give an indication of total non-domestic direct, regulated emissions.

Should better quality data become available in future, these values can be updated as appropriate.

4.1.4 Non-domestic Buildings - Indirect Emissions

Total electricity consumption for public administration, transport, agricultural and commercial sectors from 1990 to 2010 is presented in DUKES Table 5.1.2. Information in DUKES Table 5.1 allows this to be disaggregated into public administration and commercial sectors as far back as 1998; before this time it is estimated based on the visible later trends. The model contains electrical demand estimates for all sources, but only reports emissions resulting from regulated energy use.

For further disaggregation into energy end-use, estimates are only available for 2010 and 2011, as provided in ECUK Tables 5.6 and 5.6a (data is presented for the “service” sector, excluding agriculture). Currently these breakdowns are being used to project individual components back to 1990, assuming that the ratio of individual contributions have not varied in time. This is undoubtedly a false assumption, as appliance use has seen great growth in recent years, and heating demand has previously been shown to exhibit significant annual variation depending on weather conditions; further work would be necessary to assess the likely contributions of each end-use in the baseline year. Despite this uncertainty, a notable observation is that computing and “Other” electrical energy demands do not make up the majority of energy consumption in 2010-2011.

Should better quality data become available in future, these values can be updated as appropriate.

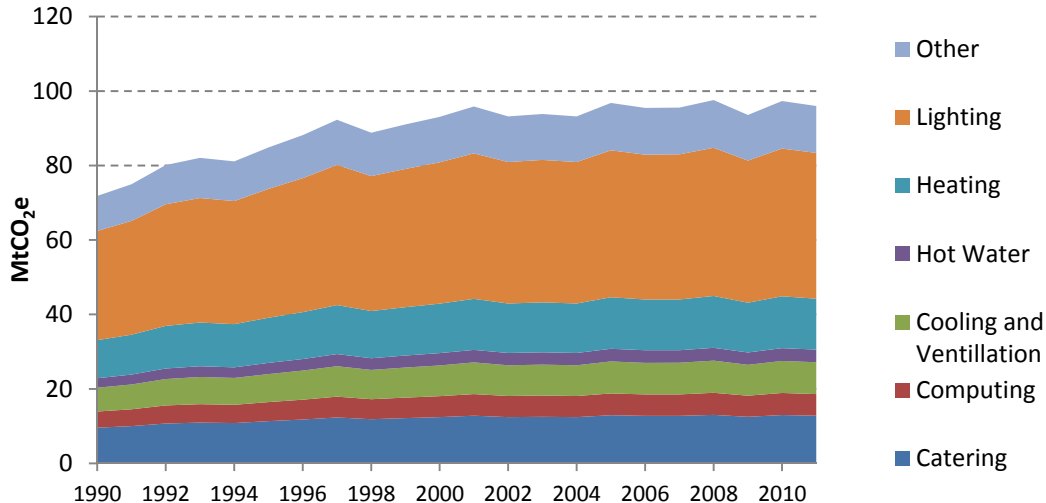


Figure 12: Indicative historic contributions of electricity consumption demands in non-domestic sector by end-use (TWh)

4.2 Operational Carbon - Infrastructure

A number of other operational carbon streams are included in the model; these are presented below.

4.2.1.1 Public Lighting

Taken from public sector data in DUKES Table 5.1, public lighting, which is understood to include space lighting and that on roads and motorways, is reported separately in the model. The dataset is only available back to 1998, but demand is shown to be stable at just over 2 TWh per year in this period; this value is projected back to 1990 and is deemed sufficient for current purposes.

4.2.1.2 Water and Wastewater

Historical emissions for the water and wastewater sectors were obtained from ONS environmental accounts data (Greenhouse Gas Emissions by Industry and Gas, 1990-2010). It should be noted, the ONS data is calculated on a UK resident basis. In addition, a small portion of these figures may be from sources outside the scope of the built environment as defined in the Routemap (such as wastewater from industrial sources).

4.2.1.3 Waste

Historic waste arisings data was obtained from the Office of National Statistics¹¹ as summarised in Table 2.

Table 2: Historic waste generation in construction industry

	Total waste arisings in construction and demolition (million tonnes)						
	Paper and card	Animal and vegetable	General & mixed	Metal & scrap	Mineral	Chemical & other	Total
1998/9	0.2	0.1	5.3	1.0	93.7	0.0	100.3
2002/3	0.3	0.1	6.4	1.2	114.1	0.0	122.1
2006	0.6	0.1	10.9	2.2	130.9	0.0	144.6
2008	0.1	0.1	3.8	0.5	121.5	0.0	126.1

To create a carbon impact per tonnes of waste generated approximations of current waste diversion rates were combined with DEFRA factors for the treatment of waste.

Table 3: Current waste diversion rates

	Paper and card	Animal and vegetable	General & mixed	Metal & scrap	Mineral	Chemical & other
Landfill	29%	29%	100%	1%	5%	100%
Incineration	25%	25%	0%	0%	0%	0%
Recycle	46%	46%	0%	94%	95%	0%
Reuse	0%	0%	0%	5%	0%	0%
	* Assumed same as timber		* Assumed worst case			* Assumed worst case

¹¹ <http://www.ons.gov.uk/ons/rel/environmental/environmental-accounts/2011/rftwaste.xls>

4.2.1.4 Transport

Non-traction (i.e. buildings/facilities) electricity consumption by the transport sector is presented in DUKES Table 5.1, and is only available from 1998 onwards. For the purpose of future projections, this portion of operational carbon is assumed to be included in the non-domestic buildings category.

The energy used by vehicles (cars, trucks, airplanes, trains, etc.) is not included as it is out of the scope of the Routemap.

4.3 Capital Carbon

Base data relating to the capital carbon of the UK built environment was obtained from a database developed by the University of Leeds and the affiliated Centre for Sustainability Accounting (CenSA)¹². The database is founded on a multi-regional input output (MRIO) model and is the most comprehensive UK inventory of historical annual GHG scope 3⁽¹³⁾ emissions.

An introduction to MRIO modelling can be found in Murray (2010)¹⁴ and their appropriateness for economy wide and sector level modelling is further documented in detail in Wiedmann and Barrett (2011)⁴.

CenSA's input-output model is a two-region model that uses input-output tables for UK domestic demand, including direct territorial activity and imports from the rest of the world. A major benefit of this is that the data can be segmented by streams relating to origin, i.e. it includes imported emission due to products and services procured from outside the UK and is economy wide and boundary free.

The core MRIO model is based on supply and use tables, data which is publically available from the ONS. Annual sectorial GHG emissions taken from the UK national environmental accounts and published by ONS are added to the time series economic input-output tables. A similar extension is developed for the rest of world table based on information from a range of sources.

In total, 246 economic sectors and product groups are distinguished in the model, 123 for UK commodities and 123 for imported commodities. Sector 88 relates to goods consumed by the construction industry. This commodity breakdown includes categories for all principle materials used for construction and maintenance of the built environment as well as general construction activities as defined under the 'Construction' Standard Industrial Classification class 42.

Using this data for the period 1990 to 2009 we have a historical built environment capital carbon footprint, shown in Figure 13.

¹² <http://www.censa.org.uk/>

¹³ GHG Protocol, Product Life Cycle Accounting and Reporting Standard, 2011. World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), In: <http://www.ghgprotocol.org/standards/product-standard>

¹⁴ The sustainability practitioners guide to input-output analysis, Murray, J., and Wood, R., Common Ground, 2010

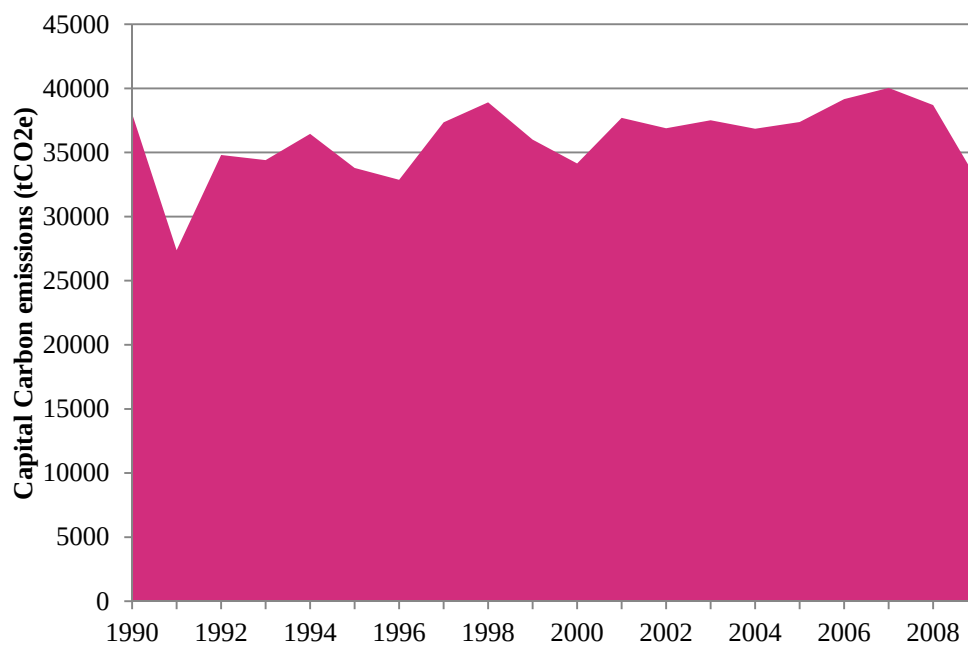


Figure 13: Historical capital carbon emissions for the UK built environment

4.3.1 Capital carbon emissions: sector breakdown

The MRIO data used as the base line capital carbon emissions data was only available at whole construction industry level. In order to gain a perspective of the relative impact of the emissions from domestic buildings, non-domestic buildings and infrastructure sectors a means of disaggregating the data was required.

Comprehensive annual output data is available through the ONS for UK economic activities. The 'construction industry' is represented in this economic 'output'¹⁵ data. The records represent spend on construction including labour, materials, overhead and profit¹⁶. This data provides a high degree of granularity and can be separated into different sectors of construction such as infrastructure, domestic buildings and non-domestic buildings and therefore provide a platform from which to look at specific sub-sector activity.

By combining the MRIO GHG emission model with the construction spend data and relating annual datasets it has been possible to create a historical relationship profile, where there is a consistent trend between the value of output of the construction industry and the resulting capital carbon GHG emissions.

This approach uses two different sets of economic data both representing the construction sector and both in part originally recorded by the ONS. Although recorded annual figures differ between each dataset, this is expected because the boundaries associated with each dataset are different. The ONS construction sector spend information which represents economic output is a record of the

¹⁵ ONS construction output tables <http://www.ons.gov.uk/ons/rel/construction/output-in-the-construction-industry/september-and-q3-2012/stb-construction-output-2012-q3.html>

¹⁶ Some small scale construction is excluded such as repair and maintenance by local authority teams and construction in-house by organisations. In addition, payments to sub-consultants such as quantity surveyors, architects and consultants are not included in this data.

direct spend on building and infrastructure (labour, materials, overhead and profit). By contrast the data in the MRIO model measures all economic activity associated with the UK construction industry including indirect activities such as design services as well as those which might occur up stream within the supply chain.

In applying this approach we have a method to apportion capital carbon to the different sectors (and sub-sectors) which are of interest to the GCB Routemap. The ONS output data provides a split between sectors in terms of £million output. It has been assumed that there is the same ratio of GHG emissions to £million spent within the different sectors. This is a limitation but is viewed as appropriate for the purposes of the model.

Using this assumption, the historical split in capital carbon CO₂e emissions for the built environment and headline sectors can be presented and is shown in Figure 14.

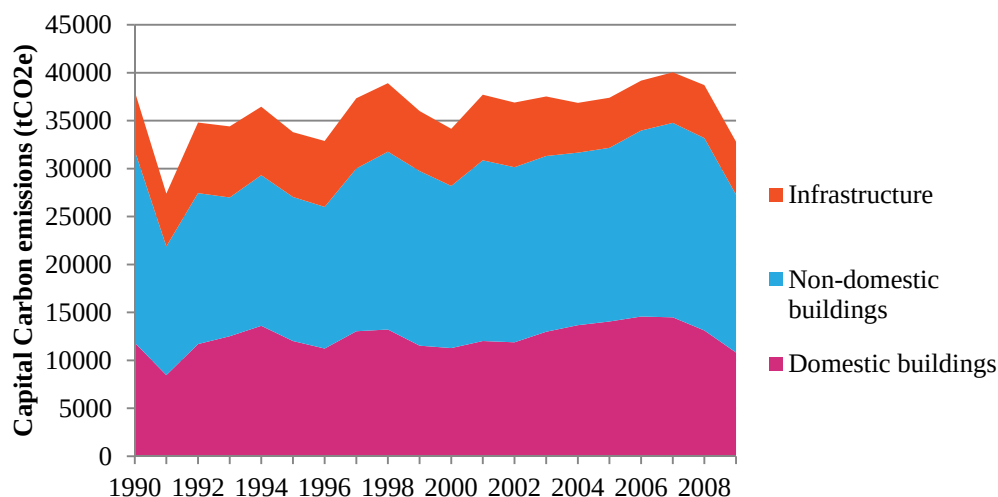


Figure 14: Historical baseline of capital carbon emissions by sector

4.4 Emissions Intensity from Energy Supply

Baseline electricity grid GHG intensity is sourced from Defra data¹⁷, and is calculated as the total GHG emissions produced from electricity in a given year (including imports) divided by total consumption. As such, this includes the effects of transmission and distribution losses.

¹⁷ Defra / DECC (2012). *2012 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting*. <http://www.defra.gov.uk/publications/files/pb13773-ghg-conversion-factors-2012.pdf>

4.5 Baseline Emissions for the Built Environment (1990-2010)

Figure 15 gives the estimate for built environment baseline operational carbon and capital carbon in 1990, and shows how this has changed moving forwards to 2010.

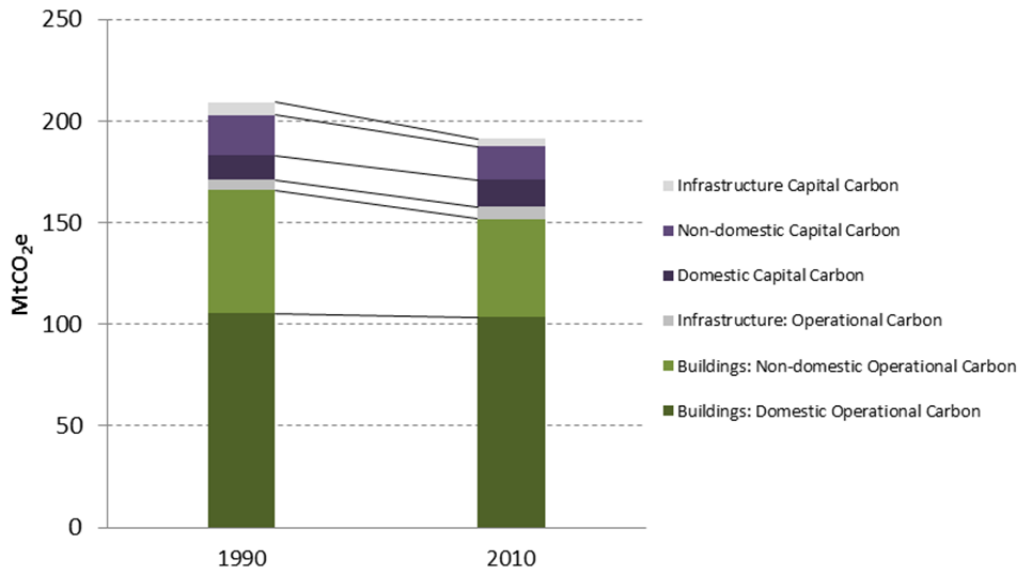


Figure 15: Baseline Emissions for the Built Environment (MtCO₂e)

GHG emissions were approximately 209 million tonnes in 1990, and reduced by approximately 9% to 191 million tonnes in 2010. It can be observed that the majority of emissions reductions occurred in the domestic operational carbon sector, with non-domestic operational carbon also playing a significant role. There were slight increases in infrastructure operational carbon and domestic capital carbon, meanwhile, showed the only increase, whilst simultaneously decreasing its capital carbon contribution.

To achieve the 80% reduction target by 2050, total operational carbon and capital carbon from the built environment will need to decrease to 42 million tonnes, or an additional 78% from 2010 levels.

5 Methodology and Assumptions for 2050 Projections

This section provides an overview of the methodology used to produce forward projections of operational carbon and capital carbon sectors to 2050.

5.1 Electricity Grid Decarbonisation

For the purposes of enabling a consistent focus on measures that can be taken to reduce GHG emissions within the built environment, all scenarios in the Routemap are based on the same assumption about the declining carbon intensity of the electricity grid by 2050. This assumption is based on DECC projections and data and validated against other sources where available. The timeframe for decarbonisation is 40 years (2010 to 2050).

5.1.1 Methodology

Since decarbonisation of the grid will be incremental in nature, the rate at which it takes place will correlate principally with the roll-out of new electricity generation, as well as the demand from non-power producing sectors (domestic / non-domestic sectors). Therefore, it can be inferred that the rate of change in grid intensity¹⁸ is dependent upon the balance between investment in generation (supply) and economic growth (demand). Many institutions have published forecasts of the rate of grid decarbonisation. A review of the existing literature has been carried out during the course of the analysis.

To calculate grid intensity, a suitable long term forecast of electricity generation, consumption and emitted carbon is required. An estimate of grid intensity can be calculated, by taking total forecast annual CO₂e emissions from power generation and dividing by total annual electricity consumed. This approach accounts for losses in energy generation, transmission and distribution.

5.1.2 Grid Carbon Intensity Factor Estimates

A CO₂e emission factor of grid electricity is integral to generating a forecast of GHG emissions from buildings due to electricity consumption. If there is an increase in the use of low carbon generation, then it can be expected that the carbon intensity of grid electricity will decrease overtime.

The most recent and comprehensive data available is published by DECC in the annual carbon report, “*Updated Energy and Emissions Projections (2012)*”¹⁹ (UEP). The data provide an indication of the expected change in electricity production and consumption from power stations and associated carbon for the next 20 years (2010 to 2030). Importantly it takes into account the effect of recent changes in climate policy and estimates of generation mix (2010 to 2030).

The DECC data provides five scenarios for carbon and energy production, each which is a variant on a ‘Central’ forecast and takes into account variations to

¹⁸ Grid intensity refers to the GHGs emitted per unit of energy supplied. It is usually expressed as grams of CO₂-equivalent (CO₂e) divided by kWh energy use.

¹⁹ <https://www.gov.uk/government/publications/2012-energy-and-emissions-projections>

energy prices, economic growth and environmental policy. Following the methodology outlined above, Arup has estimated a grid intensity factor for the Central UEP forecast equal to 184g CO₂e/kWh by 2020 and 105g CO₂e/kWh by 2030. It should be noted that post-2022, DECC's published forecast data is absent of any new climate change policy, in anticipation of the upcoming Energy Bill.

The Central forecast has been compared with forecasts produced by other organisations, as shown in Table 4. While these estimates are useful benchmarks for the analysis, they may not necessarily reflect recent changes in policy and generation mix. The University of Manchester, for example, developed estimates in 2009 for grid carbon levels based on separate assumptions of generation mix from SKM (2008) and Redpoint (2008); these grid carbon estimates range from 294 to 362g CO₂/kWh by 2020. In 2010, the Committee on Climate Change (CCC) forecast grid intensity to reach 323g CO₂e/kWh by 2020 and 39gCO₂e/kWh by 2030. Meanwhile Defra's Market Transformation Programme estimated in 2008 that the grid intensity would be 423 gCO₂e/kWh by 2020. As shown in Table 4, emissions in the Central forecast are lower than other forecasts. However, by 2030 the Central emissions estimate is above that produced by the CCC. It should be noted, Arup was not asked as part of this project to provide an independent projection, but simply to extrapolate from DECC's own published data.

Table 4: Grid carbon factor estimates (gCO₂e/kWh)

Forecast	2020	2030
Market Transformation Programme (MTP 2008)	423	n/a
University of Manchester (2009)	294 – 362	n/a
CCC (2010)	323	39
Arup 'Central' based on DECC (2012)	184	105

Figure 16 plots the grid intensity estimate for the CCC forecast, the Central forecast and scenarios that vary from the Central forecast (2010 – 2030)²⁰. The scenarios are based on high and low variants to fossil fuel prices and economic growth. The term "low fossil fuel price" represents low demand for energy below the Central forecast; "high fossil fuel price" implies high demand for global energy. Under a high fossil fuel price scenario, the increase in demand would be met through increased generation, which proportionately would come more from fossil fuel generation. The economic growth scenarios have the same high / low effect on energy demand.

²⁰ The 'Baseline' forecast is based on the same pricing and growth assumptions as the 'Central' scenario. It does not include policy which existed before the 2009 Low Carbon Transition Plan (LCTP).

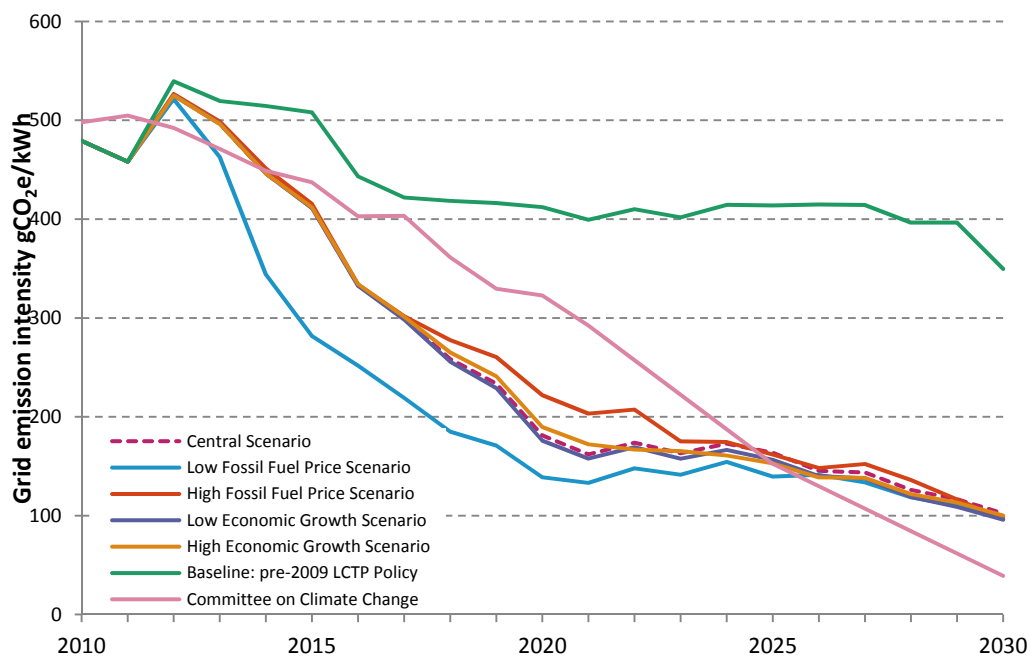


Figure 16: Grid decarbonisation scenarios based on DECC Data²¹

5.1.3 Non-CO₂ Greenhouse Gas Emissions

An issue with the data currently available is that the DECC UEP tables only give CO₂ emissions associated with power generation, i.e. the contribution of other greenhouse gases (methane, SF₆, N₂O, CFC's etc.) is not included. The UEP tables provide individual emissions data for the full basket of GHG emissions, however these are not broken down into their contribution from power generation sources. Power station emissions are included within the "Energy Supply" category of the UEP data, which also includes other emissions sources such as solid fuel production and refineries. However, the breakdown of emissions for the energy supply category is not available.

Accordingly, an estimate of the contribution of non-CO₂ greenhouse gases to total future power generation emissions has been made. Figure 17 below shows recent historical trends in non-CO₂ emissions. There is an observable downward trend in non-CO₂ greenhouse gas emissions between 1990 and 2010. Non-CO₂ greenhouse gas emissions are a minor contributor when compared to direct CO₂ emissions (1.02 MtCO₂e vs. 145 MtCO₂e in 2010). However, as CO₂-only emissions decrease in the future, the significance of non-CO₂ greenhouse gases is set to increase if they are maintained at the current level.

Analysis of emissions from power plants from 2000 to 2010 shows that non-CO₂ greenhouse gas emissions from fossil fuels are an average 0.67% of total CO₂-only emissions (R² value of 0.933). Non-CO₂ greenhouse gas emissions for the years 2011 to 2030 are therefore estimated by multiplying UEP CO₂ values by 0.67%. Prior to 2000, the correlation between CO₂ and non-CO₂ emissions is less strong, and non-CO₂ emissions are a higher proportion of total emissions. This reflects the significant shift in the UK generation mix over this period from heavy

²¹ As described in Section 5.1.3, the DECC forecast scenarios are for CO₂ emissions only and exclude non-CO₂ emissions.

coal-fired generation to combined cycle gas turbine power generation, which now dominates fossil-fuelled generation.

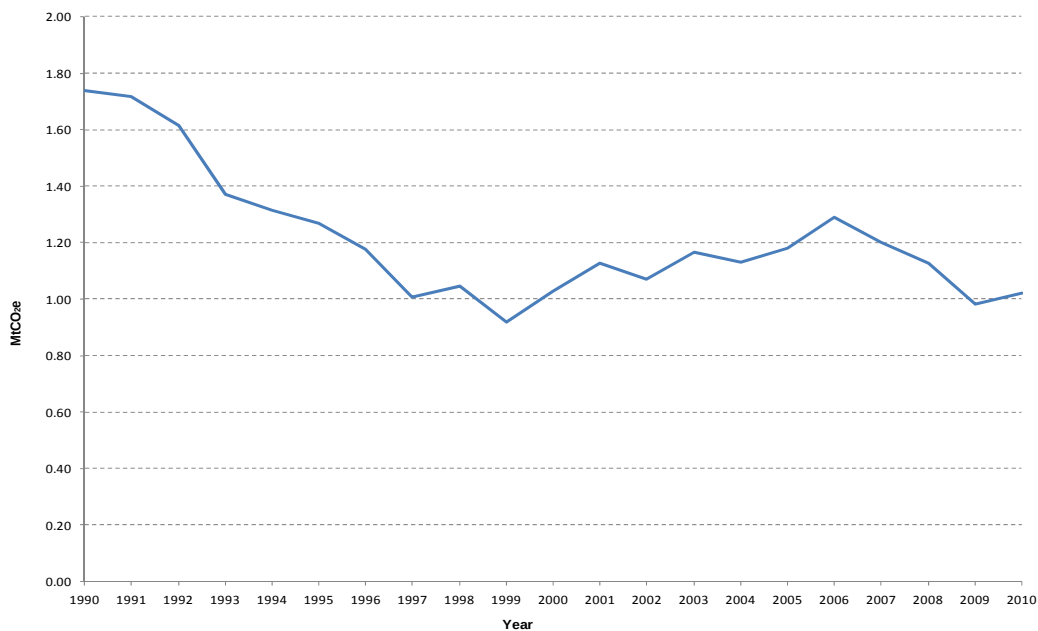


Figure 17: Historic variation²² in non-CO₂ GHG emissions

Applying the 0.67% value to the Central scenario forecasts indicates that non-CO₂ component of emissions would be 1.02g CO₂e/kWh in 2010 and reach 0.25g CO₂e/kWh by 2030. In reality, the 0.67% would shift based on the relative contribution of non-CO₂ emissions from coal versus gas. Correspondence between Arup and DECC indicates that DECC estimate the non-CO₂ portion of emissions to reach as low as 0.2% by 2030, indicating a potential over-estimate. This is addressed in Section 5.1.5, but does not represent a material effect on emissions trajectories.

5.1.4 Change in Grid Intensity

It should be noted that growth in generation capacity will take place between 2012 and 2020. New policy and fiscal incentives including the Renewables Obligation and Feed-in Tariffs are expected by DECC to facilitate up to 30% of electricity supply from renewables by 2020. Post-2020 Electricity Market Reform (EMR) is expected to become the main support mechanism to deliver new generation. DECC's current proposals for EMR are still in consultation. DECC's expectation is for an increase in renewable generation, which will lead to a reduction in the size of the electricity market for fossil fuel generation and a fall in associated CO₂ output.

²² Historic non-CO₂ greenhouse gas emissions are calculated as the difference between historic greenhouse gas emissions from power stations presented in the UK Greenhouse Gas Inventory (UK GHGI), and historic CO₂-only emissions from power stations as given in the UEP.

The data indicates that electricity demand will continue to fall until 2017, under the influence of energy savings programmes in the non-power producing sector. Demand is then expected to stabilise and increase post-2022, which represents the declining impact of policy measures. The overall result of these forecasts indicates a sharp decrease in power station CO₂ emissions and grid intensity, as indicated in Figure 18 below.

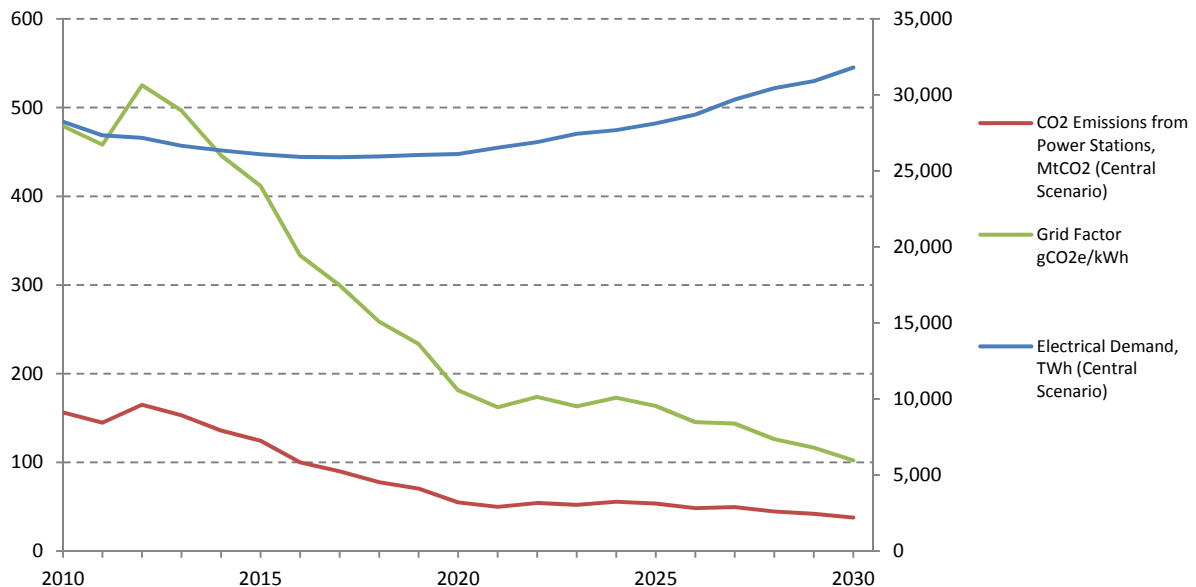


Figure 18: UK Power station CO₂ emissions and electrical demand (source: 2012 UEP¹⁹), with corresponding grid carbon intensity in full CO₂-equivalents as calculated by Arup.

5.1.5 Selected Scenario to 2050

Based on the analysis carried out here, Arup recommended that the project adopt the DECC Central Scenario forecast to 2030 for modelling emissions due to built environment electricity demand. This projection has been produced using the best available data and most up-to-date forecast of generation, consumption and emissions.

This projection was further refined as described below:

- A factor of 0.67% was initially applied to the Central forecast to account for the non-CO₂ component of GHG emissions from 2010 onwards. In reality, the 0.67% will shift over time based on the relative contributions of non-CO₂ emissions from coal and gas generation. Correspondence between Arup and DECC indicates that DECC estimate the non-CO₂ portion of emissions to reach as low as 0.2% by 2030. Although DECC estimates the proportion of fossil fuel generation from coal versus gas will be higher in the shorter term (up to 2016) and lower in the long term (after 2016), it is proposed for simplicity that the 0.67% be applied as a constant factor to 2016, decreasing linearly to 0.2% in 2030 and remaining at this level until 2050. As discussed in Section 5.1.3, this does not represent a material impact on overall grid emissions intensity. 5.1.2

- With respect to calculating emissions beyond the Central forecast end date of 2030, it was assumed that grid emissions would continue to decrease at a pace equal to the five years leading up to 2030 (i.e. 2025-2030, which represents a 9% annual decrease).²³

The final emissions trajectory that has been used for the Routemap is provided in Figure 19 below.

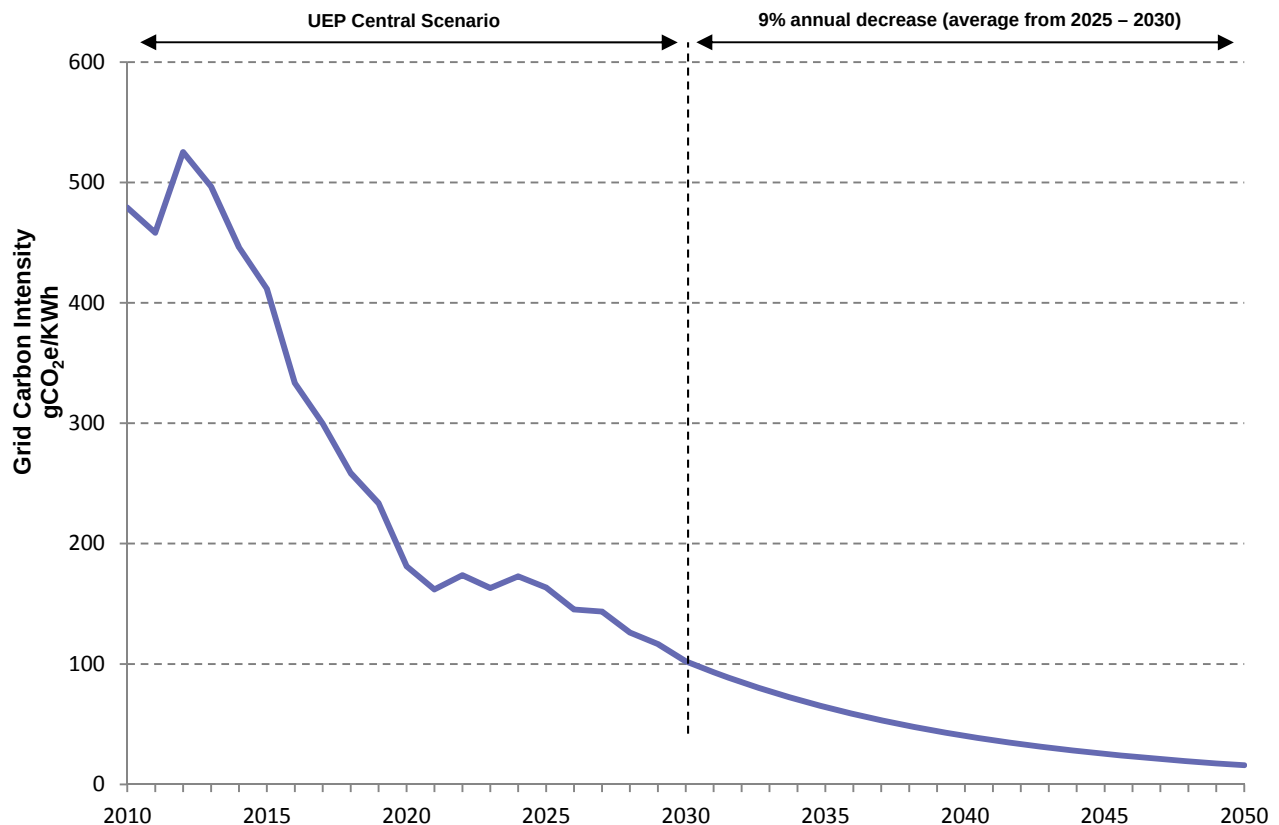


Figure 19: Decarbonisation scenario to 2050 used for the Routemap model

5.2 Domestic Building Stock Growth Projections

New build stock growth is estimated using a similar method as that in the Pathways Calculator. Projections for total residential stock to 2030 are estimated from an assumed growth rate (1% is the default, which is consistent with historical trends²⁴), and an assumed demolition rate of existing buildings (0.1% is the default as per the Pathways calculator, equating to roughly 26,000 households per year).

²³ Note that, as stated previously, the years from 2022 have not had any possible future policies mapped onto them, and the speed of emissions intensity reductions slows somewhat. Given the pace of decarbonisation expected by DECC up to 2022, it could be suggested that the intensity would reach even lower levels by 2030 than those currently indicated.

²⁴ The Pathways Calculator originally used ONS projections for total domestic stock to 2030, projecting to 2050 with an assumed 1% annual growth rate from 2030 as per historical trends. For simplicity and the option of user control, the Routemap model assumes a 1% annual growth rate from 2012, which produces very similar total estimates for the stock in 2050.

5.3 Non-domestic Building Stock Growth Projections

Projections for growth of the non-domestic building stock are a key component underpinning the Routemap model. The two primary data sources used to estimate growth in floor space were the VOA²⁵ and CLG²⁶, with compound annual growth rates derived from these. It should be noted that neither of these sources covers the entire range of buildings typologies considered to make up the built environment in this work, hence growth rates determined here have been used as proxies. A better understanding and publication of non-domestic floor areas by occupancy would in future benefit further, more detailed analysis.

Data from the VOA only covers floor space for “Retail”, “Offices”, “Industrial” and “Other” building typologies. Data from CLG was used to add further granularity to the “Offices” category, providing data for “commercial” and “non-commercial” offices. Whilst the VOA data covers the years from 2000 to 2012, CLG data was only available between 1998 and 2008, giving an eight year overlap ending at the start of the financial crisis. Whilst VOA data shows sustained growth in Retail, Offices and Other building types, the relatively higher rates in the period 2000-2008 might lead to over-estimates.

Table 5 shows the growth rates assumed for the various sectors, and the non-domestic building typologies assigned to each.

Table 5: Sector growth rates assumed and the building typologies assigned to each

Sector name	Growth rate to 2050 (%)	Non-domestic building types assigned
Retail	0.6	Retail, Hotel and Catering, Communication and Transport
Commercial offices	2.7	Commercial Offices
Non-commercial offices	0.3	Government, Health, Education
Industrial	-0.2	Warehouses
Other	1.5	Sports and Leisure, Other

5.4 Infrastructure Growth Projections

This section provides a summary of projections for infrastructure spending in the UK to 2050. The methodology of forecasting based on an analysis of historic data is well established as an effective means to establish trends over long periods of time. As a significant focus of the Routemap is on the delivery of infrastructure, the scope of the forecasts includes the following types of infrastructure: water and sewerage (water); electricity and gas (energy); roads, railways, harbours and air (transport); and communications.

In order to develop a comprehensive view of the level of future spend, a top-down assessment approach is taken. The analysis seeks to make best use of data that is available and identify long-run trends. Each infrastructure sector will vary depending on their specific characteristics, such as investment levels and policy support.

²⁵ http://www.voa.gov.uk/corporate/statisticalReleases/120517_CRLFloorspaceReleaseNotes.html

²⁶ CLG (2008). Statistical Release: Floor space and Rateable Value of Commercial and Industrial Properties

Given the forecast for infrastructure spend, annual GHG emissions can also be estimated by combining the trend rate of growth of infrastructure spend with the trend rate of carbon intensity of infrastructure in each sector (CO₂e/£). The trend of the carbon intensity of infrastructure was estimated separately.

5.4.1 Methodology

The timeframe under consideration is roughly 40 years to 2050. This period has implications for the type of trends and drivers to be considered. For example, construction spend in energy appears to be cyclical. Investment in transmission and distribution infrastructure takes place over a 5 year cycle, aligned to regulatory reviews, while investment in generation responds to longer cycles in energy prices; the introduction of incentives to invest in renewable generation also contributes to the present high level. Over the long run cyclical peaks in investment may well have little significance for the 40 year trend. Current rates of growth are in most cases significantly different from the respective trend values. The long term forecast can be expected therefore to return to a long term trend. The key drivers which will influence future infrastructure deployment are:

- Government policy on delivering new infrastructure;
- The role of economic regulators (Ofwat, Ofgem etc) to incentivise delivery;
- The rate of growth in the UK economy;
- Trends in prices and productivity.

A large portion of infrastructure spend can be related to these key influences. Economic growth is correlated with increasing demand for energy; government policy will influence environmental legislation and the level of investment in new energy infrastructure. In effect a long-run baseline has to be established and demonstrate what the future would look like if trends were to continue at present. It should be noted that this approach will not capture sector-specific changes in infrastructure technology, but will capture past rates of technological change and the general improvements in productivity.

5.4.2 Data

Data on new construction spend for the period 1980 to 2011 (value of construction for building and civil works) are available in constant prices from the ONS²⁷ under Table 5 of “*Output in the Construction Industry*”. The definition of construction output covers expenditure on new buildings, civil engineering works and allied activities. Importantly it provides data across the infrastructure categories: water; sewerage; electricity (electrical undertakings, power stations, etc); railways; harbours; roads; and other (air transport, gas and communications)²⁸. We have grouped these categories into water, energy, transport, and communications. For comparative purposes we have adjusted the spend data for inflation and indexed to 2010 prices, using an RPI index²⁹. Appendix A contains graphs with this data for each sector analysed.

²⁷ ONS: Value of New Construction Output in Great Britain, September 2012.

²⁸ Spend on air, gas and communications (other) has been calculated using historic data from Table 2.4, ONS 2012 Construction Annual (1997 – 2011).

²⁹ Our normal approach would be to adjust constant prices using CPI, however this index only available from 1996.

5.4.3 Infrastructure Trends

To estimate GHG emission from infrastructure the key metric is spend on infrastructure. In some cases the long-run trend has been obscured in recent years by cyclical variation in investment. For all infrastructure, the long-run growth rate is 2% p.a. For each sector different growth rates can be observed. It is noted that since privatisation water and sewerage (1989), railways (1993-97), aviation (1986), gas (1986) and electricity (1990) have all seen an increase in spend. The exception is investment in harbours which has remained relatively flat since privatisation. The following provides examples of trends in infrastructure spend observed:

5.4.3.1 Electricity

Between 2009 and 2011 investment in electricity infrastructure increased sharply from £1.2bn to £2.0bn per annum, against an annual range of £0.8bn to £1.2bn in the previous 30 years. In short, what is influencing current investment is government policy toward renewables and low carbon generation. Over the period 1990 to 2009 the observed growth rate is approximately 1.2% p.a. The current high growth rate of 9% p.a. can be linked to the introduction of RO 'banding' in 2006. It is expected that this high rate of growth will continue until RO is abolished in 2017. We then expect spend to return to its long-run rate of 1.2% p.a.

5.4.3.2 Transport

Over the last 30 years investment in rail has grown, while a cyclical but flat trend can be observed in road building and harbours. Road building remains under public sector ownership and is subject to cyclical investment every ten years, following government policy.

5.4.3.3 Water & Sewerage

Immediately before privatisation there was a downward trend in water and sewerage infrastructure spend. Investment in water and sewerage since privatisation has led to a stop-start cycle within the water sector supply chain, with projects being delivered within the middle three years of a five year cycle. The cyclicity can be seen largely as a response to the price review process. The observed rate of growth in the water and sewerage sectors over the whole period is 3% and 0.6% p.a. respectively.

Table 6 below provides the initial growth factors for the spend forecast. Using this growth factor, the quantum of future GHG emissions can be established by applying the estimated rate of change in CO₂e/£. (See section 5.9)

Table 6: Infrastructure Forecast Factors (%) 2012 – 2050

Infrastructure Sector	Growth Factor
Water	3.2%
Sewerage	0.6%
Electricity	9% to 2017, 1.2% post-2017
Roads	0.0%
Railways	1.7%
Harbours	0.0%
Aviation* (Other)	1.3%
Gas * (Other)	1.3%
Communications * (Other)	1.3%

5.5 Operational Carbon – Domestic Buildings

This section provides an overview of the methodology used to model energy demand and the impact of retrofit measures of the existing domestic building stock in the context of the built environment.

Much of the modelling of future energy demand for this project has been based on a hybrid, deconstructed version of the DECC 2050 Pathways Calculator³⁰, which contains an efficient spreadsheet methodology for calculating the energy demands of existing and new-build domestic building stock.

As a default, three or four scenarios for each of a range of supply and demand trajectories are “hard-wired” into the spreadsheet. For the purposes of the routemap, the majority of these scenarios have been bypassed and manually adjusted to reflect the results of the interventions developed by the Arup modelling team, with corresponding demands by fuel source output based on assumptions of energy delivery method split, efficiency etc. In some cases it has also been necessary to adjust key figures to account for the reduced scope of the built environment used for this study.

The key deviation from the Pathways Calculator is the method for calculation of space heating demand in domestic buildings. For new and existing domestic buildings, a range of energy efficiency retrofit and new-build fabric efficiency scenarios to 2050 was developed by DECC, but the impact of these on the “average thermal leakiness” (building thermal losses, W/K) of the total UK domestic building stock was modelled separately. The resultant average heat loss profiles were then input into the model as fixed parameters. As a result, it is not readily possible to investigate the potential of additional retrofit measures or intermediate penetrations of individual measures with the original Pathways Calculator.

An additional challenge was the need to develop a tool that could easily be manually updated by the GCB in future years to reflect real-world changes, different assumptions, and the actual future energy performance of the UK, but with a minimum of specialist technical knowledge being required. This necessitates a move away from proprietary software, subroutines or Visual Basic macros (as were used in the DECC Calculator) that can potentially be difficult to audit or understand.

³⁰ <http://2050-calculator-tool.decc.gov.uk/>

Accordingly, a new housing model in Excel spreadsheet form has been developed, based on some of DECC's original inputs to the housing model, as well as a methodology for a similar model produced for the Energy Saving Trust³¹, to allow for a more flexible basis for development of the Routemap.

Much of the Routemap operational carbon model originated in the modelling paradigm presented in the DECC 2050 Pathways Calculator. Whilst every attempt has been made to ensure that excellent piece of work was faithfully adapted, this work has selectively extracted the core components required for its own needs, and functionality is now considerably altered. Any shortcomings in the work presented here do not reflect on the DECC modelling team.

5.5.1 Dealing with Existing Stock and New-Build

Figure 20 below outlines the methodology used to allow for modelling of future domestic operational carbon emissions. The domestic operational carbon sector is split into the performance of the building stock existing in 2010 and the new-build stock from 2011 onwards, both going forwards to 2050.

A pair of modified Pathways Calculator modules is used to combine service demand trajectories for domestic lighting (appliances demand has been removed from the calculator), heating and hot water, and, based on modelled trajectories of service delivery split (i.e. boilers, CHP, heat pumps, geothermal for heat etc.), calculates total energy demand by fuel type. Emissions factors and the chosen grid decarbonisation trajectory are then used to calculate CO₂e emissions by demand type.

The modelling of existing stock begins with a snapshot of the UK domestic stock in 2010, and treats this separately from subsequent new-builds.

³¹ Energy Saving Trust, 2010, The Energy Saving Trust Housing Energy Model; Assumptions Document

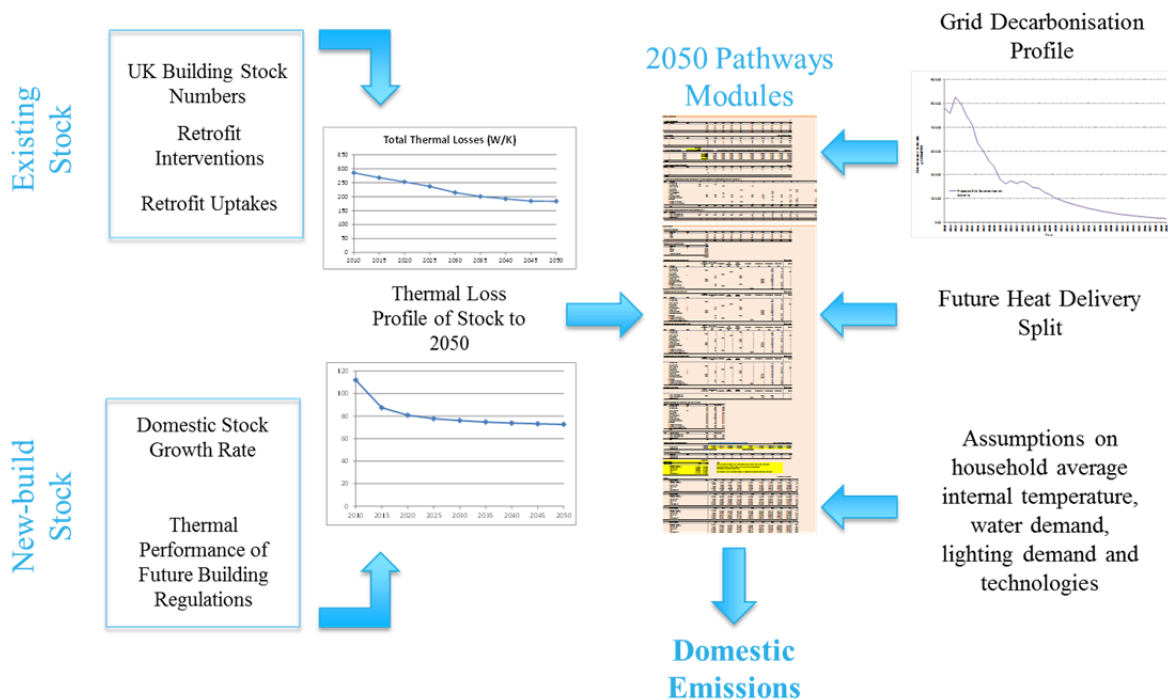


Figure 20: Methodology outline for modelling future domestic operational carbon

5.5.2 Methodology: Status of Existing Stock

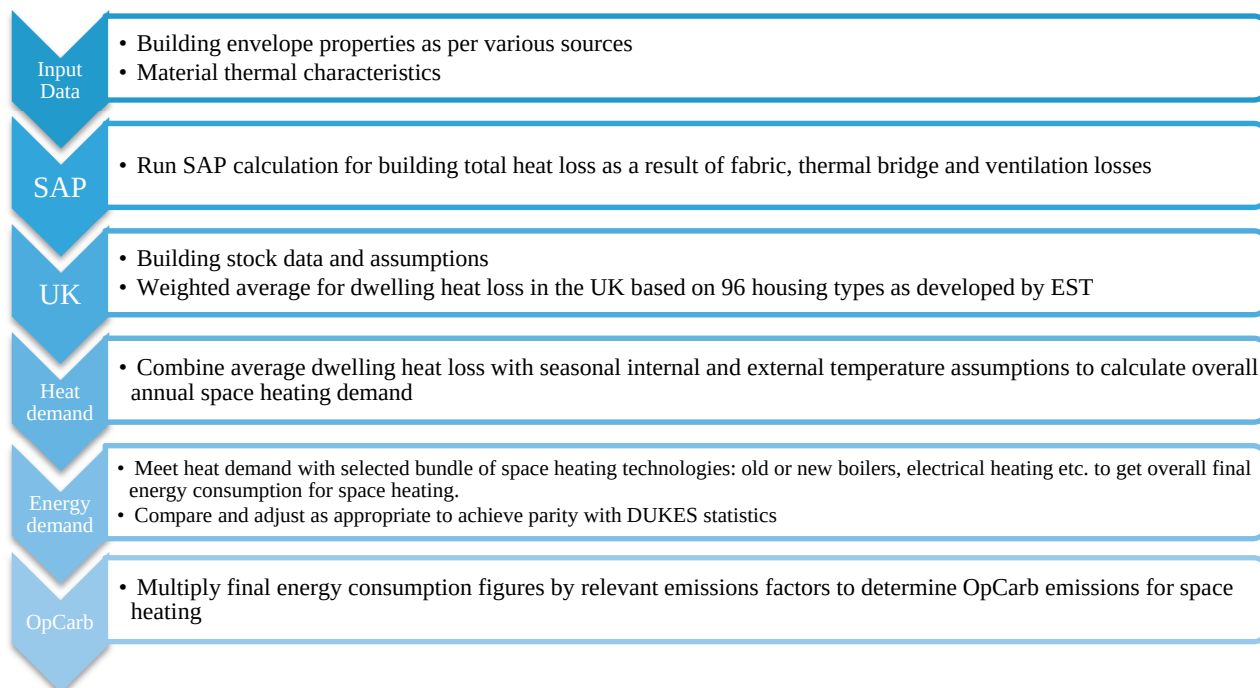
Existing domestic per household demand for hot water (by energy vector, i.e., fuel source) and lighting (electricity) was taken from DECC⁷ figures.

As mentioned previously, one of the main requirements for modelling the domestic building stock is an understanding of space heating demand. To understand heat demand, three main variables are required: external temperatures, average internal temperatures, and the thermal losses incurred by building fabric.

Internal desired temperatures can be estimated based on recent trends (and are increasing), but are ultimately a product of user behaviour and preferences. Some degree of anthropogenic external warming is expected, and a modest rise in seasonal temperatures is assumed, with the seasonal temperature profile projections kept as those originally used in the 2050 Pathways calculator, derived from Defra's UK Climate Projections (note that the impacts of future temperature changes can have significant impacts on future service demands, e.g. greater cooling demand, lower heating demand etc., but only this one scenario is used for this work). The Routemap model allows users to vary the desired internal temperature, which allows for some understanding of the sensitivity of the system to temperature differentials. Building fabric losses are building-specific, and prone to wide variation due to the differing construction materials and techniques employed over the last century and a half, and must be modelled based on an understanding of the UK building stock's characteristics.

The below flowchart indicates the overall process for deriving thermal demand estimates for the existing UK domestic stock, which is the basis for future modelling of the impacts of retrofit interventions.

Figure 21: Fabric thermal characteristics modelling procedure



The model calculates the average thermal losses for each of the building types, and then multiplies these by the total number of each building type to derive an average value for thermal losses (W/K) of the entire stock. This loss can then be used in the 2050 pathways model to estimate seasonal per household heat demand.

Core to the methodology is a spreadsheet that has been developed according to the calculations detailed in the Government's Standard Assessment Procedure (SAP; BRE, 2009) for building (energy) performance. This sheet is fed by a 96-building type estimate of the profile of the UK domestic stock, as originally developed by the Energy Saving Trust (EST, 2010) from English Housing Survey data. Some of the main assumptions used in that original methodology are described in the following section. This methodology is very similar to that employed by DECC when developing the 2050 pathways calculator. Whilst the thermal loss model was not made public, through correspondence with DECC a copy of the core modelling input assumptions was made available (referred to hereafter as the DECC inputs), which was used to further reinforce the assumptions made in this modelling.

5.5.3 Assumptions and Raw Data Used for Thermal Demand Calculations

The majority of assumptions used in the 2010 baseline were consistent with those described in the 2010 EST energy model methodology report, so are only briefly discussed here. Any changes or additions to these assumptions are, however, indicated.

The UK domestic stock is subdivided into 96 types according to their age (pre-1919, 1919-1980, and post-1980), size (flat, terraced, semi / detached), tenure

(owner occupier, private landlord, social) and quality of building fabric (poor, good).

Initially, as per EST, all buildings were assumed to be cuboid-shaped, with flat roofs and floors in contact with the ground. These assumptions led to unreasonably high estimates of average losses for the entire stock (relative to previous DECC publications), as flats in particular have more sheltered and non-external walls than semi / detached houses, hence exhibit relatively lower losses. This was compensated for by adapting external wall areas, sheltered walls, and floor area in contact with the ground for different typologies to better reflect the DECC inputs. Flats were assumed to have three sides sheltered, with terraced houses and semi / detached houses having two sides sheltered, treated as party walls. Similarly, flats were assumed to have no floors in contact with the ground.

Table 7: Total floor average floor area (m²) and house footprint (m²) for each of the categories investigated

Total average floor area (m ²)	Owner Occupier			Private Landlord			Social		
	Flats	Terraced	Semi / detached	Flats	Terraced	Semi / detached	Flats	Terraced	Semi / detached
Pre 1919	74.3	90.2	139.9	63.2	78.6	113.3	56.3	74.5	104.3
1919 - 1980	60.6	82.3	109.2	57.6	75.2	101.4	53.8	68.1	76.7
Post 1980	60	78.5	123.8	52.3	62.4	98.4	47.5	67.8	78.5
Assumed Footprint* (m²)									
Pre 1919	74.3	45.1	69.95	63.2	39.3	56.65	56.3	37.25	52.15
1919 - 1980	60.6	41.15	54.6	57.6	37.6	50.7	53.8	34.05	38.35
Post 1980	60	39.25	61.9	52.3	31.2	49.2	47.5	33.9	39.25

* This is based on the assumption that terraced and semi / detached houses have two floors, while flats have just one.

Table 8: Assumed net areas (m²) and chimneys

		Flats	Terraced	Semi / detached
		m ²		
Net window area	Door Area	1.85	3.7	3.7
	Pre-1919	10.5	14	23
	1919 - 1980	10.5	14.5	20
	Post 1980	7.5	10.5	17.5
		No.		
Number of chimneys	All ages	0	1	1

Flats are assumed to have one door and no chimney, whilst terraced and semi / detached houses are assumed to have two doors and a single chimney. Window areas are based on weighted averages of the various DECC inputs.

Table 9: Assumed fabric U-values ($\text{W/m}^2\text{K}$)

Parameter		Values	
		Good	Poor
Door U-Value ($\text{W/m}^2\text{K}$)		3	3
Window U-Value ($\text{W/m}^2\text{K}$)		2.3	4.8
Floor U-Value ($\text{W/m}^2\text{K}$)	Pre-1919	0.7	0.7
	1919 - 1980	0.6	0.6
	Post 1980	0.6	0.6
Wall U-Value ($\text{W/m}^2\text{K}$)	Pre-1919	2.2	2.2
	1919 - 1980	0.48	1.46
	Post 1980	0.38	0.5

For ventilation heat losses, a Q50 air permeability value of $12 \text{ m}^3/\text{m}^2\text{hr}$ was assumed. Flats were assumed to have three sides sheltered, with terraced houses and semi / detached houses having two sides and 1.75 sides sheltered respectively. In all cases one intermittent fan was assumed and ventilation case D (equation $24d_m$) of the SAP protocol was used. Flats were assumed to have no chimney, while the other two building types each have one.

5.5.4 Retrofit to 2050

To estimate the performance of the existing building stock up to 2050, the following potential energy efficiency retrofit measures were considered (as used in the 2050 Pathways Calculator):

- Solid wall insulation
- Cavity wall insulation
- Super-glazing
- Loft insulation
- Floor insulation
- Draft-proofing

Each measure is assigned to a relevant building type in the stock (i.e. cavity wall insulation to properties with cavity walls). In any given year the model calculates the reduction in average U-value (or air permeability) for a particular fabric item (walls / lofts etc.) resulting from the increased penetration of energy efficiency measures for each building group.

The model considers easy to treat and hard to treat properties separately, and assumes two separate delivery periods for retrofit insulation of each, as indicated below. It is assumed that measures for all easy to treat properties are delivered over a ten-year period ending in 2023, whilst hard to treat properties are addressed between 2020 and 2030. The total number of each type of measure delivered in each period is individually controllable by the (super) user as required.

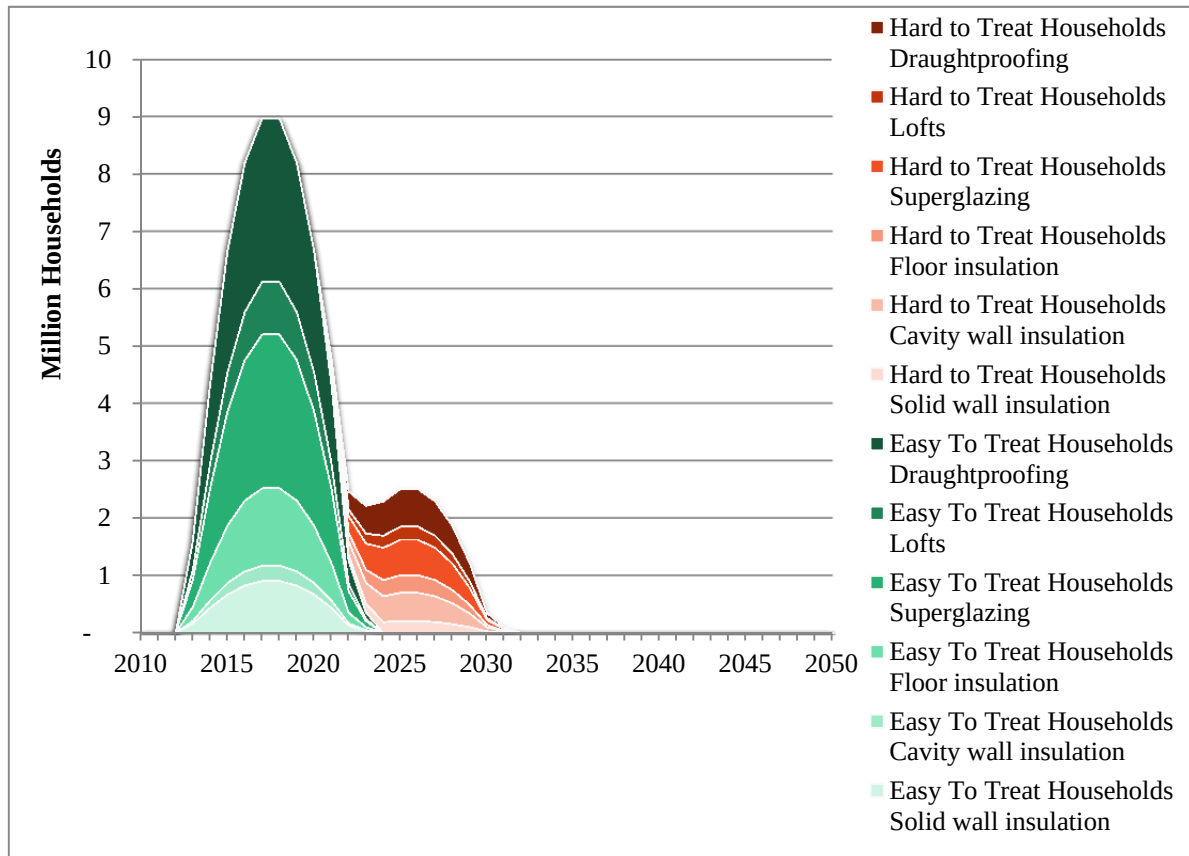


Figure 22: Annual retrofit measures delivered to the existing domestic stock by easy to treat and hard to treat properties (80% scenario)

A typical technology adoption curve is utilised, which maps the regularly observed trend in the adoption or acceptance of new technologies, innovations, and concepts. If looking at trends in total uptake of a given technology, early innovators and adopters will generally start a gradual upward trend in the curve. Early and late majority adopters then cause a sharp increase in uptake rate, with uptake rate later slowing down again as the last “laggards” embrace the technology as well. This curve generally follows an “S” profile over time, with the maximum uptake and time to reach this maximum being products of a number of sociological factors.

The model automatically spreads the uptake of a given efficiency measure across the entire stock, i.e. it is not possible to target, say, solid wall insulation at only the very oldest solid-walled buildings. This assumption is necessary, as sufficiently detailed data on the individual thermal performance of specific domestic building categories is not currently publicly available. As near-complete insulation retrofit of the entire residential stock is required by 2050 for the 80% scenario, overall the impact of this assumption is viewed as acceptable.

The assumed maximum possible penetration by 2050 of each of the measures is shown in Table 10. These have been derived from DECC insulation statistics³² and existing figures within the Pathways Calculator regarding remaining potential.

Table 10: Maximum penetration of domestic retrofit measures, as per 2050 Pathways Calculator

Retrofit Measure	Number of Households (Millions)	
	Easy to Treat	Hard to Treat
Solid wall insulation	6.1	1.5*
Cavity wall insulation	1.8	3.6
Floor insulation	9.1	2.3*
Super-glazing	18.2	4.5*
Lofts	6.2	1.7
Draught-proofing	19.3	4.8*

**Where undefined by DECC estimates, it is assumed that 20% of total remaining potential properties are hard to treat. This estimate can be refined when better data becomes available; comprehensive monitoring of potential is an important recommendation of this work.*

In the absence of published figures on the subject, it is assumed that full draught proofing and modern floor insulation of appropriate buildings starts largely from zero penetration, as indicated by DECC estimates in the Pathways Calculator.

5.5.5 New-build Domestic Buildings to 2050

The same method as that outlined above for retrofit in the existing building stock is also applied to calculate the average thermal performance of the new build stock.

As per EST figures for new-build houses in 2006 & 2007³¹, the following average size distribution for new homes each year is as shown in Table 11 below.

Table 11: Average size distribution of new-build homes in 2006 & 2007 (EST)

Flats	Terraced	(Semi-)detached
33%	20%	47%

Assumed internal areas and footprints are as for post-1980 existing buildings.

Thermal performance has been modelled for homes adhering to 2006, 2010 and 2016 building regulations, depending on the year they are built. The U-values and permeabilities assumed for each building type are given below in Table 12.

³² DECC (2013). Estimates of home insulation levels in Great Britain.

http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/en_effic_stats/home_ins_est/home_ins_est.aspx

Table 12: Thermal properties for new-build houses

Retrofit Measure	U-Value (W/m ² K) / Permeability (m ³ /m ² hr)		
	2006	2010	2016
Walls	0.28	0.15	0.15
Doors	1.8	1.8	1.8
Floors	0.2	0.15	0.1
Windows	1.8	0.8	0.8
Lofts	0.15	0.13	0.13
Draught-proofing	10	3	1

Whilst some degree of retrofit of the new-build stock is possible before 2050, this model does not attempt to take this into account, i.e. the average performance of the new-build stock is locked in, and only dependent on assumptions around fabric properties, new-build growth rate, and the years that new building codes come into effect.

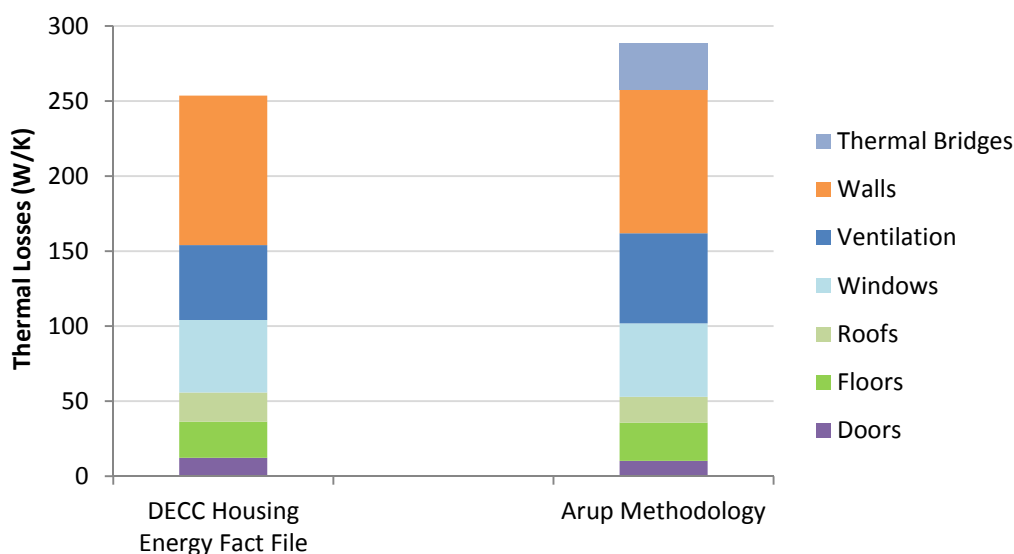
5.5.6 Additional Validation

The method for calculating building thermal losses methodology closely resembles that employed by Cambridge Architectural Research Ltd. (CAR) to produce statistics for DECC's Energy Consumption in the United Kingdom and Housing Energy Fact File (DECC; 2012b, 2011) publications on UK domestic building stock energy performance.

The CAR 2010 Cambridge Housing Model uses a spreadsheet version of SAP 2009 (identical in its core components to that used by Arup for the Roadmap thermal loss model). It runs a subroutine on an extensive, detailed housing typology dataset derived from the 2010 English Housing Survey (EHS) and surveys from preceding years to calculate entire energy consumption for each building type detailed in the survey. The data contained in the EHS is not currently publicly available, otherwise it could be used to refine estimates for this work.

As shown in Figure 23, the Arup thermal loss estimation comes within 2% of the DECC estimate for 2008 when not including thermal bridges. The thermal bridges are a notable difference with DECC estimates; it is not currently apparent whether these are bundled up into the losses for walls or other fabric in DECC estimates, perhaps to aid interpretation of the figures by the general public. This may indicate that Arup has over-estimated thermal losses.

Figure 23: Comparison of Arup housing thermal losses as modelled compared to those presented in DECC's Housing Energy Fact File 2012 (for 2008)



Further validation for the Arup methodology comes when comparing the combined thermal losses of existing and new-build stock in the UK to 2050 with the pathways proposed in the DECC 2050 pathways calculator. Figure 24 shows an example pathway to maximum penetration of domestic retrofit measures and new-build fabric quality compared to that given in the 2050 Pathways Calculator. The profiles depend on the uptake of measures in a given year. In the Arup trajectory this example shows a 100% uptake over a 35 year period from 2015, using a simple experience curve. Importantly, the end values are within 3% of each other.

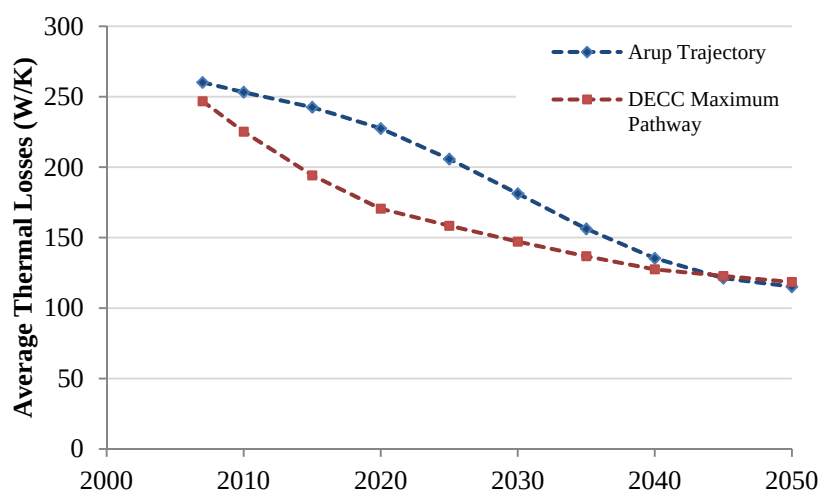


Figure 24: Comparison of DECC 2050 Pathways Calculator thermal loss trajectory with Arup model results for same final penetrations of measures (excluding thermal bridges)

5.5.7 Domestic Hot Water and Lighting Demand

Other than space heating, the only other sources of domestic operational carbon that the Routemap is concerned with are domestic hot water (DHW) and lighting.

The model uses a slightly adapted Pathways Calculator module to calculate each, separating the demands of the existing and new-build stock.

In the case of DHW, a per-household demand for energy is assumed, starting at approximately 3,000 kWh per household in 2010 as per ECUK. This can be increased or reduced by a user-controlled percentage change up to 2050 to take into account a combination of shifts in housing occupancy and overall per capita change in demand for DHW as a service.

Total lighting demands are similarly calculated, starting from per-household lighting demand figures as presented in ECUK. To take into account the importance of an approaching shift to low energy lighting (primarily LED) and the use of smart controls, per-household demand figures are modulated by a linearly increasing efficiency to 2050. Estimates (e.g. The Climate Group³³) indicate that indoor lighting demand could be cut by between 50% and 70%. Additionally, the option for a further manual reduction in demand for lighting as a service is given – a reduction would indicate public acceptance for lower lighting levels or less of their houses being lit at a given time.

5.5.8 Domestic Renewables Use

Pathways Calculator modules (IV.a and IV.b) for distributed solar photovoltaic (PV) and solar thermal generation have been used in the Routemap. These remain the same as in the original calculator, but split the building stock into existing and new-build houses, to allow the differing uptakes of technologies in each to be accounted for³⁴. The only core change is an update to the PV module to incorporate the recent rapid growth in domestic PV installation as a result of feed-in tariffs; in 2012 there were over 344,000 homes with PV installed, up from approximately 17,000 in 2010³⁵.

5.5.9 Performance Gap

The Routemap model has built in the effect of the performance gap in domestic retrofit and new-build. The performance gap represents the difference between the expected impact of an intervention and its actual measured impact after installation. In the case of domestic retrofit, a series of “in-use” factors has been applied to those retrofit interventions applied from 2010 onwards. The values used for these factors are based on those outlined by DECC³⁶, and are shown below in Table 13. The performance gap has a significant impact on energy use and carbon emissions; a gap of 30% means that 30% of expected energy use reduction was not delivered.

³³ Lighting the clean revolution: The rise of LEDs and what it means for cities (2012), The Climate Group.

³⁴ I.e. planning requirements can and will greatly encourage new-build residential buildings to maximise the use of on-site renewables, whilst lower uptakes are to be expected in the existing domestic sector on average.

³⁵ <https://www.renewablesandchp.ofgem.gov.uk>

³⁶ DECC (2012): How the Green Deal will reflect the in situ performance of energy efficiency measures

Table 13: In-use (performance gap) factors applied to domestic retrofit measures

Retrofit Measure	Assumed In-Use Factor
Solid wall insulation	30%
Cavity wall insulation	35%
Floor insulation	15%
Super-glazing	15%
Lofts	35%
Draught proofing	15%

In the model the user is given control over the value of these in-use factors in 2050, with a simple linear interpolation being applied for measures installed in the intervening years.

While the mechanism of the performance gap in new-builds is considered to be slightly different from that in the case of existing retrofit, an assumed equivalent in-use factor of 15% is assumed for new buildings, with the gap in 2050 again being controlled by the user.

5.6 Operational carbon – Non-Domestic Buildings

This section provides an overview of the methodology used to model energy demand of existing non-domestic buildings stock in the context of the built environment.

5.6.1 Identification of Potential

There currently exists no standard, publicly available model for analysing the UK non-domestic building stock. Aggregate figures for total annual consumption of fuels and electricity are available in DUKES and other DECC statistical publications, and are used to model the current profile and future behaviour of the sector.

The core dataset used as the basis for the non-domestic sector is Energy Consumption in the UK 2012 (DECC). Data from ECUK Table 5.6 (energy demand in the service sector by end use and fuel) is taken for 2010, the crossover year from historical data to forward model projection.

The fuel demand characteristics for each building in the non-domestic sector (referred to as the “service sector” in ECUK, see below for categories) have been used to develop a “model building” for each sector, for which the potential improvements from a range of energy saving measures can be assessed.

These model buildings reflect a typical building for each of the sectors listed in Figure 25 below. Each of the typical buildings was modelled using a spreadsheet-based energy model, and input data from a range of sources, including CIBSE Guides A and F³⁷, and Energy Consumption³⁸ (ECON) Guides. ECUK provides data on energy consumption for each sector, broken down into four end-use

³⁷ CIBSE Guides A, F (Environmental Design, Energy Efficiency in Buildings) 2006, 2004, The Chartered Institute of Building Services Engineers.

³⁸ Energy Consumption Guides 19, 36, 54, 78, 82, 82 (2003, 1993, 1997, 2001, 2002, 2004), The Carbon Trust.

categories (cooling and ventilation, hot water, heating, lighting). Predicted consumption from the models for each end use category was then compared to the DECC data. As there is no area information for the ECUK data, this comparison was limited to the relative magnitudes of each end use.

Generally, reasonably good agreement was found between the typical building models and the ECUK data, and some modifications were made to the modelling assumptions to improve the correlation. There was a considerable variation between the building categories, in terms of the range of building types covered, the clarity of definition, and the extent of available reference data. This range is illustrated in Figure 25. Categories further down the list reflect an increased uncertainty in the modelling. For example ‘Communication and Transport’ could range from a large airport to a small bus station. While this may distort the results of the analysis, the overall impact may only be minor given that the more uncertain sectors represent a smaller proportion of energy use in the UK (as presented in Section 4.1)

This analysis could be improved in the future with more granular data on the energy performance of buildings within each type.

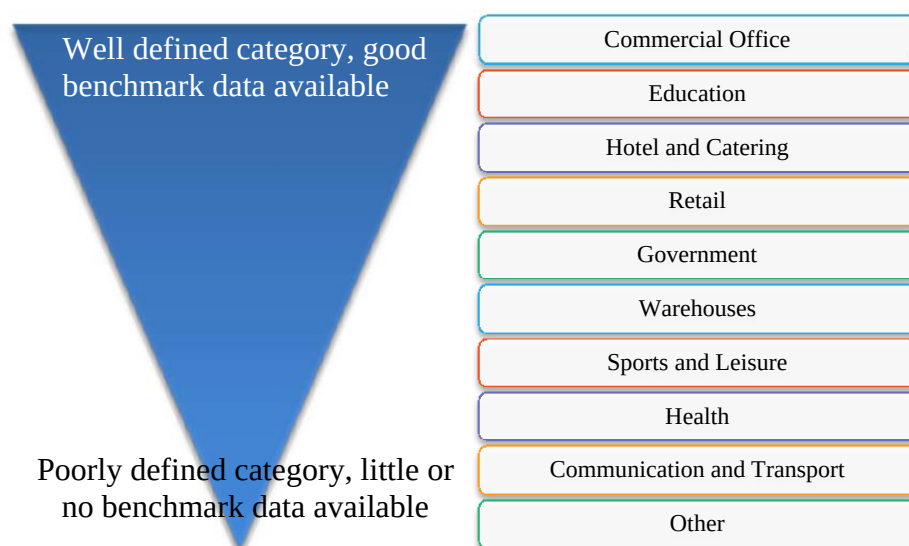


Figure 25: Building categories as given in ECUK, and used in the Routemap model.

These detailed models have allowed for the separate assessment of a range of potential energy saving measures that will contribute to total energy demand reductions by sector, Table 14. With such a variation in buildings in each category, it is clearly not possible to cover all the measures that may be applicable to any of those buildings. The list presented is intended to represent the typical nature and extent of retrofit opportunity across the sector. These measures have been applied at different rates and with different expected benefits (i.e. energy savings) to all non-domestic buildings.

Improvements in fabric performance lead to percentage improvements in energy demand for space heating, as indicated in Table 14 below. System replacement interventions lead to improvements only for the relevant fuels and end-uses. The

improvements resulting from sub-metering and re-commissioning are assumed to apply for any fuel consumption for space heating, water heating and cooling and ventilation demands.

Table 14: Retrofit measures for non-domestic buildings considered by Arup

		Retrofit Action	Description of Measures	Technology improvements in 2012 vs. BAU
Building Envelope	1.1	Improve solid element u-values	Increase / replace insulation to wall and roof areas	25% improvement in wall U-values, 15% improvement in roof U-values
	1.2	Improve glazing U-values	Replace glazing for more efficient glazing	25% improvement in glazing U-values
	1.3	Improve glazing solar performance	Either as part of above or by adding solar film	35% improvement in G-values
System Replacement	2.1	Voltage Optimisation and Power Factor Correction	Reducing building incoming voltage to European standard 220v, and where appropriate applying power factor correction to minimise the impact of inductive loads	5% improvement in efficiency
	2.2	Heat recovery ventilation	Improve the heat recovery within the ventilation systems	25% improvement in heat recovery
	2.3	New lighting and controls	Modern LED lighting and controls / timers / sensors	Improvement dependent on building typology (commercial, educational etc. (W/m ²))
System Optimisation	3.1	Sub-metering & re-commissioning	Installation of sub-metering of all heating, cooling and power requirements	3% improvement

5.6.2 Modelling Future Non-Domestic Emissions

Shown in Figure 26 is the approach used to model non-domestic emissions. As with domestic operational carbon modelling, the performance of existing non-domestic building stock is treated separately from new-build non-domestic buildings in the model of the trajectory to 2050.

The data presented in ECUK for the non-domestic sector is used to model the response of energy demands in the existing stock to retrofit measures through 2050. ECUK data is also the starting point for modelling the performance of new-build stock up to 2050. Both are strongly dependent on the assumed growth and demolition rates for each non-domestic sector (see Section 5.3 for more information regarding assumed growth).

The effect of retrofit interventions and their different uptake rates across the non-domestic sectors is calculated, producing demand estimates on a per-demand type, per-fuel basis. New-build non-domestic buildings instantly benefit from new technologies and fabric standards.

Assumptions around technology improvement potential are also incorporated, meaning those buildings installing heat pumps, for example, twenty years into the future will benefit from improved coefficients of performance (COP).

Performance gaps have been modelled in a two stage process, based on the quality of specified interventions relative to best practice, and the failure of a building to perform as expected once commissioned.

The following sub-sections provide more information about the modelling methods and assumptions used.

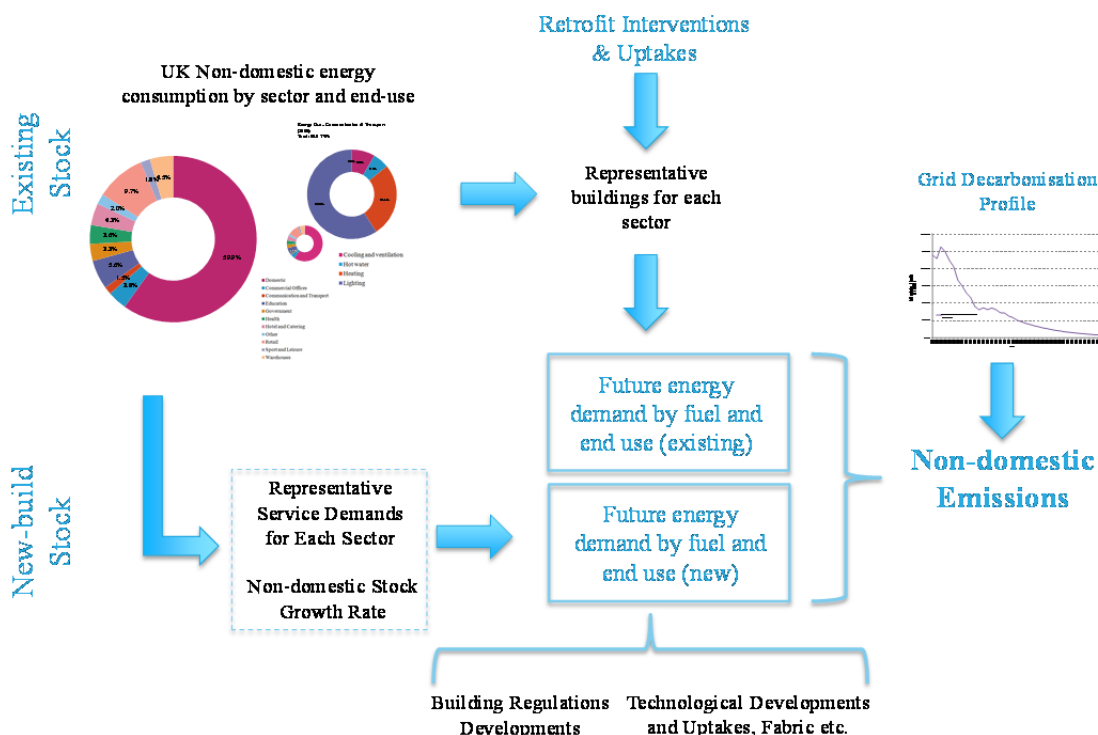


Figure 26: Core modelling methodology for non-domestic buildings sector

5.6.3 Projection Start Year

The modelling starts “forward” projection retrospectively, from a 2010 baseline derived from ECUK Table 5.6 (2010 service sector final energy consumption by sub-sector and end use by fuel), and holds the data indicated in Table 15, below. 2011 data is also presented in ECUK, and overrides the model data for that year; future publications of ECUK could similarly be used to chart actual performance of the non-domestic sector.

Table 15: Data contained within ECUK Table 5.6 for 2010 UK Service sector final energy consumption. “x”s indicate data availability

<i>Data in TWh</i>	Cooling and Ventilation						Hot Water	Heating	Lighting
	Electricity	Natural Gas	Oil	Solid fuel	Heat Sold	Bioenergy and Waste	<i>Etc.</i>	<i>Etc.</i>	<i>Etc.</i>
Commercial Offices	x	x	x	x	x	x	x	x	x
Communication and Transport	x	x	x	x	x	x	x	x	x
Education	x	x	x	x	x	x	x	x	x
Government	x	x	x	x	x	x	x	x	x
Health	x	x	x	x	x	x	x	x	x
Hotel and Catering	x	x	x	x	x	x	x	x	x
Other	x	x	x	x	x	x	x	x	x
Retail	x	x	x	x	x	x	x	x	x
Sport and Leisure	x	x	x	x	x	x	x	x	x
Warehouses	x	x	x	x	x	x	x	x	x

The model takes this information and converts it into one data series for 2010. The central principle of the model is that these figures represent the demand of the sector at the baseline year (consistent with the rest of the model), and that after this point demand can only decrease or increase as a product of retrofit measures, changes in behaviour or building demolition. Note that forward projection is unable to account for potential annual fluctuations in space heating / cooling demand, which have historically been shown to vary quite significantly year-to-year in response to weather conditions.

5.6.4 Model Inputs for Retrofit

Separate analysis (as discussed in Section 5.6.1) has identified the absolute energy savings potential of a range of retrofit measures across the ten main building types in the non-domestic sector (referred to as the “service” sector in ECUK). The sector is broken into the following building typologies:

- commercial offices
- communication and transport
- education
- government
- health
- hotel and catering
- retail
- sport and leisure
- warehouses
- other

For a given intervention, the model has been developed to allow the user to: choose the building typology it applies to (if it applies to multiple typologies, the intervention must be input separately); input a description of the policies or actions used to deliver the intervention; input the initial year of implementation and the expected timeframe to reach maximum potential; input the estimated uptake of the intervention as a percentage of the total potential; choose an uptake curve for the intervention, i.e. linear, exponential or technology adoption curve (which is the default curve).

The impact of a given intervention can be entered as a percentage reduction (or increase) in electricity, natural gas, oil, solid fuel, heat sold, or bio-energy and waste demand of cooling and ventilation, hot water, heating or lighting in the building typology in question.

Note however, that for the published Routemap model “casual” users will not be able to utilise this full functionality, with this reserved for super-users. Casual users will still have control over a number of other inputs, and will be able to view the results of the three core scenarios presented.

5.6.5 Asset Replacement Lifecycles

The non-domestic sector model differs somewhat from the domestic model by placing a greater emphasis on the use and understanding of asset replacement lifecycles for different sector types. Depending on commercial priorities, different sectors can be expected to replace their systems, fabrics, and indeed buildings on different timeframes.

For each of the core fabric and systems assets as introduced in Table 14 previously, the model is able to investigate the impact of different asset replacement patterns for each sector. For the purpose of the published Routemap model, these have been simplified to three replacement profiles: slow, medium and fast, with timeframes as given in Table 16 below.

Table 16: Asset replacement lifecycle profiles used in the non-domestic model

Asset	Profile: Replacement Time (years)		
	Slow	Medium (average)	Fast
Solid elements	55	40	25
Glazing	55	40	25
Voltage Optimisation	40	25	15
Heat recovery	40	25	15
Lighting and Controls	15	10	5
Sub-metering and re-commissioning	40	25	15

The model assigns a default profile to each of the non-domestic sectors, as shown below in Table 17. The user is, however, able to investigate the impact of changing the profile of individual sectors.

Sensitivity analysis has shown the assumed profile has significant implications on operational carbon, but also an inverse impact on capital carbon. Any improvement over a Business as Usual profile, whilst offering improved efficiencies, and so reduced operational carbon, will necessitate greater expense on equipment, and so increased capital carbon.

Table 17: Assumed asset replacement lifecycle profiles for non-domestic sectors

Building Typology	Assumed Profile	Rationale
Commercial Offices	MEDIUM (average)	Focus on cost-effectiveness and maintaining acceptable working conditions
Communication and Transport	MEDIUM (average)	Average asset use assumed
Education	SLOW	Largely reliant on public sector funds. Likely to “sweat assets” to the maximum.
Government	SLOW	Largely reliant on public sector funds. Likely to “sweat assets” to the maximum.
Health	MEDIUM (average)	Largely reliant on public sector funds. Likely to “sweat assets” to the maximum, however, intense use necessitates faster replacement.
Hotel and Catering	FAST	More intense use of assets. Emphasis on providing good customer experience and appearing “modern” results in rapid replacement of assets
Other	MEDIUM (average)	Average asset use assumed
Retail	FAST	More intense use of assets. Business models in retail focused on short term investment decisions.
Sport and Leisure	MEDIUM (average)	Average asset use assumed
Warehouses	MEDIUM (average)	Average asset use assumed

5.6.6 Sector Tendencies on Technology Choices

Whilst Arup modelling has produced performance models based on “best practice” intervention choices, it is acknowledged that all sectors will on average (by definition) fall short of specifying equipment at this best practice level. Therefore, a percentage reduction has been applied to the performance of newly installed interventions to account for the average distribution.

This method also effectively accounts for the difference between minimum specified standards, and the best technology available; if minimum standards improve, the average specified performance of new equipment will similarly improve.

This average performance of equipment chosen relative to best practice has been set at 65% (i.e. a 35% reduction over maximum technical potential) for all sectors in 2012. It can be adjusted for individual sectors individually if suitable empirical evidence becomes available. The model allows the user to set the average performance of equipment chosen relative to best practice in 2050, to give an understanding of the impact of improved standards and industry responsibility.

5.6.7 Performance Gap

An additional percentage reduction is taken from new equipment performance to account for the observed gap between expected buildings and equipment performance compared to that predicted by energy modelling and equipment specifications. This phenomenon is known to occur in all sectors, and is not fully understood, but is believed to be the product of a number of factors, such as poor construction, poor commissioning, and building models that inadequately represent final occupancy, amongst others. By default, this performance gap is set at 35% on average in 2012 (as for many domestic retrofit interventions), with the user being able to specify scenarios to 2050 by individual sector. Note, however, that data³⁹ indicate that in isolated circumstances the gap for regulated energy alone can be as high as 50% in new-builds.

Note that the combination of this performance gap factor and the technology choice factor used here is somewhat a product of the modelling method used and does not necessarily equate to the industry-accepted understanding (or lack thereof) of the performance gap, particularly as a combined principle is used for new-build and retrofit.

5.6.8 New-Build Non-Domestic

The modelling for the new-build non-domestic sector begins with the same core data as that used for the existing stock; ECUK Table 5.6. Individual fuel source demands for the various services in question are converted into demands for the actual services for each building type, i.e. heat, hot water, cooling, and light, through assumed efficiencies and coefficients of performance for the relevant technologies. These assumptions are highlighted in Table 18 below, and are largely kept as those used in the original Pathways Calculator.

Table 18: Assumed efficiencies of core energy delivery technologies used to derive current sector by sector service demands⁴⁰

Technology	Assumed Efficiency
Average existing gas boilers	76%
Resistive heating	100%
Oil-fired boilers	97%
Solid-fuel boilers (coal or biomass)	87%
District heating (delivered heat only)	90%
Existing air conditioners	250%

Depending on the growth and demolition rates assumed for each sector, extra “demand” for space heating, DHW, cooling and light is added to the system, and met through modern energy delivery and fabric technologies.

All energy delivery technologies, fabric and building systems have technology improvement profiles mapped on to them (user-adjustable), such that new demands added to the stock consume less energy.

³⁹ CarbonBuzz (2013), RIBA & CIBSE; <http://www.carbonbuzz.org>

⁴⁰ These are not the same efficiencies as those used for new-build or retrofit installations.

Going forwards, it is assumed that there will be no new oil-fired capacity installed (as this technology is unacceptably high in carbon emissions), with heat either being delivered through gas (boilers or CHP technologies), electricity (resistive or heat pumps) or district heating.

As with non-domestic retrofit, the new-build model takes into account the assumed differences in asset replacement lifecycle in the various sectors, and assumed performance gaps.

5.6.9 Demand collation

Final heating, DHW, cooling and ventilation fuel demands for existing and new-build stock are calculated in individual Pathways Calculator modules (variants of module IX.c). Individual non-domestic sectors are calculated separately from each other to allow for the carbon to be reported with sufficient granularity.

5.6.10 Model Outputs

Based on the user inputs, the model outputs a number of time series from 2010 to 2050 for energy demand, based on building typology, demand type (heating, cooling etc.), and fuel source. These energy vectors are then multiplied by their respective emissions factors (Table 19 below) to derive CO₂e emissions, which are reported for individual building types, demand types, or fuel type as required.

Table 19: Emissions factors used to calculate CO₂e emissions from the existing non-domestic buildings sector (as used in 2050 Pathways Calculator)

Fuel	Assumed emissions factor (MtCO ₂ e/TWh)
Solid / manufactured fuels	0.312
Petroleum	0.255
Gas	0.185

Figure 27 and Figure 28 below show an example emissions trajectory for the non-domestic sector existing buildings. A simple observation at this point is that the profile of the trajectory is dominated by the assumed profile of decarbonisation of the electricity grid, and that the vast majority (up to 2/3 in the case of the 80% scenario) of emissions reductions come through decarbonisation of electricity rather than reduction in on-site fuel consumption; this is particularly highlighted in Figure 28.

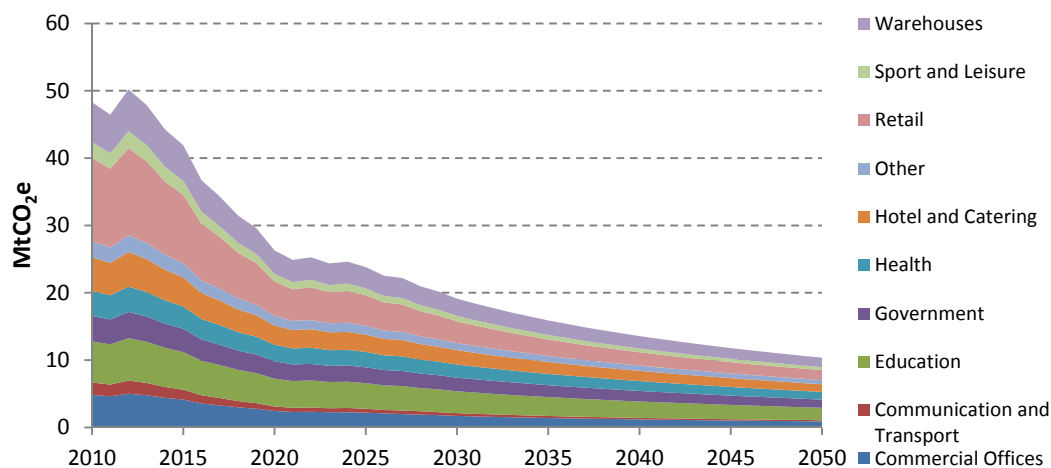


Figure 27: Example of an emissions trajectory for the non-domestic sector: emissions by building type

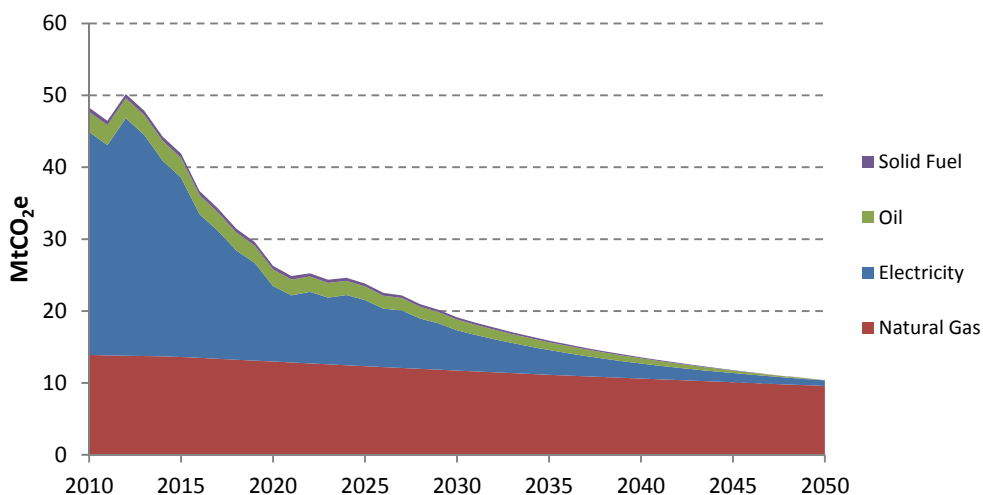


Figure 28: Example of an emissions trajectory for the non-domestic sector: emissions by fuel source

5.7 Dealing with Zero Carbon Standards

From 2016 in the domestic sector, and 2019 in the non-domestic sector, new buildings will be required to be “zero carbon” as far as regulated emissions are concerned. To achieve this it will be necessary to maximise the use of efficient fabric and energy delivery technologies, as well as the use of low or zero-carbon energy technologies such as renewables.

Whilst efficiency and maximising on-site renewables will go some way towards achieving “zero carbon”, it is understood (and the Routemap model confirms this) that there will be some degree of emissions remaining, not least because of the relatively poor national solar and micro-wind resource.

The official framework for dealing with these remaining emissions is not yet finalised, and is the subject of discussion and study nationwide, but it is likely that

a system of “Allowable Solutions” will be implemented to tackle them. Allowable Solutions, as the concept currently stands⁴¹, lets building developers fund renewables, district heating, or carbon offsetting projects locally and nationally, such that the remaining emissions from the building in question are effectively offset.

The Routemap model mimics the likely development of these standards in the future, utilising efficient fabric types and allowing the use of low-carbon heating options, as well as on-site micro-renewables to reduce carbon emissions. The supply-side projects which Allowable Solutions itself funds, however, are beyond the scope of this research.

For new domestic and non-domestic buildings built after 2016 and 2019 respectively, the model calculates all remaining emissions following efficiency and on-site renewables use, reports these and subtracts them from the final reported emissions data, such that the buildings are effectively carbon-neutral (in regulated emissions).

5.7.1 Zero Carbon Homes and Buildings Policy: Issues

Currently, much on-site renewables activity for new developments is focussed around electricity generation, such as micro-PV or micro-wind. Emissions savings are therefore tied to the carbon intensity of the electricity grid, as it is electrical generation which is displaced. However, the electricity grid is set to decarbonise in line with government policy and expected investment in large-scale renewables generation capacity, which presents a challenging scenario.

While the concept of Zero Carbon Homes and Buildings is moving towards a low-carbon future for the United Kingdom, the concept currently presents the possibility in certain situations that there is no net benefit to the system, IF:

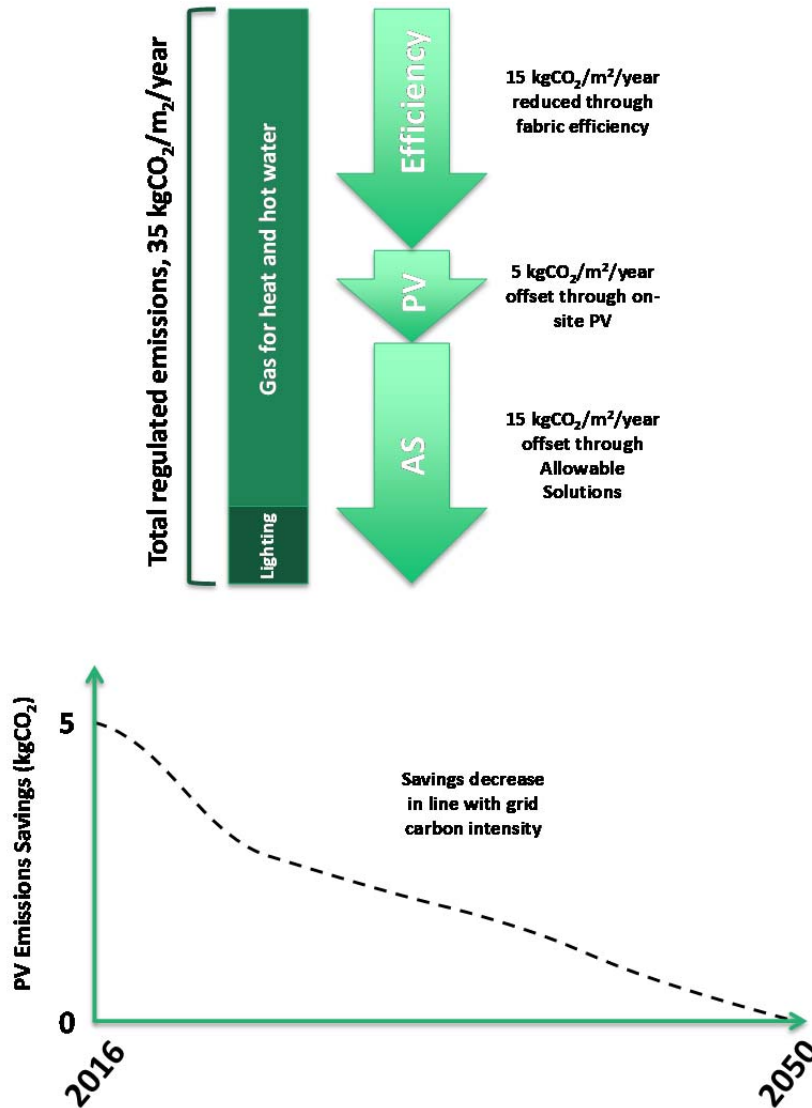
- On-site fossil-fuelled generation is still used to provide heat in new-build domestic and non-domestic buildings.⁴²
- Renewable *electricity* (rather than heat) generation is used on-site or off-site through allowable solutions to offset on-site emissions from fossil-fuel *heat* provision.

Current planning regulations are such that the emissions to be offset are only calculated for the year of construction⁴¹. Under the above conditions, which reflect the current trend, the result could see almost zero savings by 2050 if the grid were to decarbonise completely, putting those “zero carbon” buildings back to a pre-renewables state, as indicated in Figure 29 below.

⁴¹ Zero Carbon Strategies for Tomorrow’s New Homes (2013), Zero Carbon Hub; <http://www.zerocarbonhub.org>

⁴² Particularly in Zero Carbon Homes, following fabric energy efficiency, most regulated emissions to be offset to achieve the required standards will in the near-term likely come as a result of direct, on-site combustion. Commercial buildings are somewhat more reliant on electricity for regulated energy, but also currently have a significant amount of on-site gas combustion.

Figure 29: Illustrative scenario showing the effect of PV used as an emissions offset for a home, where gas boiler emissions are offset through electricity generating (e.g. PV) renewables.



Micro-generation accountancy

The scenario outlined in Figure 29 hints at an innate challenge with carbon accountancy of micro-generation. What is this electrical renewable generator offsetting? It exceeds the lighting electrical demand, but lighting demand and sunshine do not normally coincide. If it is offsetting grid supply, what kind of generation, and emissions is it offsetting today? What is it going to be offsetting in the future? Currently, planning regulations do not fully address this problem, but an understanding of the reference system that is used is crucial when assessing the emissions offsetting potential of micro-generation⁴³.

⁴³ Making the transition to a secure and low-carbon energy system; UKERC Energy 2050 Project (2009), UKERC

5.7.2 Potential Solutions

Whilst the aforementioned issue is outside of the scope of this Routemap, there are some potential solutions to the dilemma described below, which can be investigated to some extent by users of the Routemap, through the manual inputs option.

1. **Move to all-electrical provision of heat:** doing so permanently links heat delivery emissions to the grid decarbonisation trajectory, and allows for the possibility of zero-carbon heating in the future. A key issue with this strategy, as outlined by DECC⁴⁴, is that national peak heat demands are today far in excess of the capacity of the UK electricity system, as indicated in Figure 30 below. Such a move would potentially require a monumental increase in electricity generation capacity.

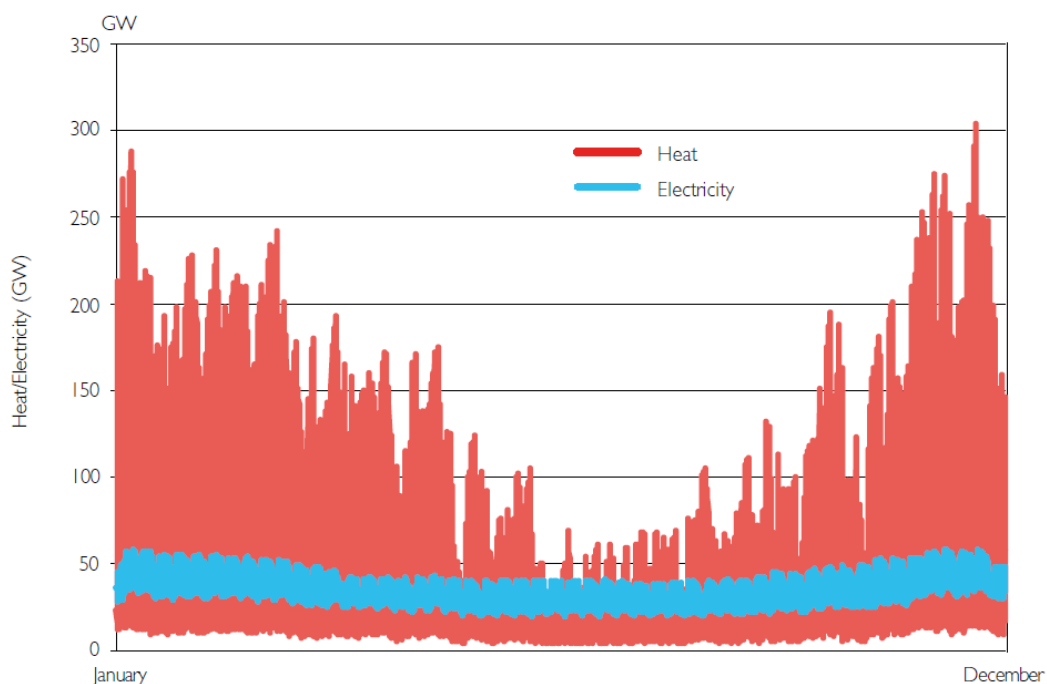


Figure 30: Illustrative example of the difference between annual domestic and commercial heat and electricity demands during 2010⁴⁴.

2. **OR, focus on like-for-like offsetting through Allowable Solutions:** by offsetting on-site fossil fuel emissions for heat through investment in renewable heat generation projects elsewhere. For example a biogas CHP or biomass with CCS district heating or CHP plant, or large scale solar water heating. This would ensure savings remain as initially calculated into the future.
3. **OR, make planning requirements for Zero Carbon standards take into account some element of time:** mandating the use of an accepted grid decarbonisation profile and the accounting of emissions a number of years into the future.

⁴⁴ DECC, 2012: The Future of Heating: A strategic framework for low carbon heat in the UK, Crown Copyright

It should be emphasised, however, that there are of course a number of other benefits in on / near-site renewable generation. For example, there are cost savings or investment delaying benefits for transmission and distribution infrastructure. For any time micro-renewables exceed domestic demand and export to the grid, they are contributing to a decrease in grid carbon intensity. Wholesale decarbonisation of the electrical grid would necessitate massive investment, and the Allowable Solutions framework could potentially be a key means of delivering on this crucial part of the low-carbon agenda.

With careful consideration given in the implementation of regulations, and close monitoring, it is felt that the risk of Zero Carbon Homes potential not being reached can be minimised.

5.8 Operational Carbon – Infrastructure

This section gives a brief overview of the modelling methodology for other infrastructure operational carbon sectors considered as part of the built environment. These have been shown to be relatively insignificant today, but not addressing these in the future would otherwise see their relative significance increase.

5.8.1 Public Lighting

As described in 4.2.1.1, the demand for public lighting is expected to stay relatively constant over the coming decades. For forward projection the model considers the annual demand to be constant, but includes a reduction of up to 59% by 2050, based on published savings for cities around the world⁴⁵, to account for the uptake of highly energy efficient lighting technologies and improved lighting controls, such as motion sensitivity, timers, and automatic dimming.

5.8.2 Water and Wastewater

GHG emissions in the waste and wastewater sector are primarily due to energy use⁴⁶. To develop emissions projections from water and wastewater to 2050, trends in energy use for operational purposes (water and wastewater pumping and treatment) were reviewed. The data was sourced from review of several years of Water UK Sustainability Reports⁴⁷. According to Water UK data, it takes 2-3 times more energy to treat a megalitre of wastewater versus to supply a megalitre of water. The higher carbon intensity of wastewater treatment means energy use in the future could be driven more by external factors such as the frequency, volume and intensity of stormwater flows, all of which could become more common with climate change.

The Water UK data shows operational energy use in water/wastewater has been slightly increasing but has averaged about 0.13 per 1000 residents over the last 5 years. This figure was used to project energy use to 2050, considering population growth projections developed by the ONS. Energy use figures were then

⁴⁵ The Climate Group, 2012. Lighting the Clean Revolution: The rise of LEDs and what it means for cities.

⁴⁶ Environment Agency, 2009. Evidence: A Low Carbon Water Industry in 2050

⁴⁷ www.water.org.uk

multiplied by GHG emissions factors to determine approximate GHG levels to 2050. Due to the uncertainty of predicting energy

This figure may under or overestimate emissions depending on factors such as precipitation levels, industry innovation and technological advancement, investment in energy intensive projects (such as Thames Tideway Tunnel or reclaimed water plants).

5.8.3 Waste

In order to forecast the future emissions due to construction and demolition waste, a relationship was established between construction spend and C&D waste generation. This was based on the historic data available. This has then been linked to the predicted construction spend.

It was assumed that by 2050 there would be a 50% reduction in the amount of C&D waste sent to landfill and an elimination of 'general' waste sent to land fill.

5.9 Capital carbon – Buildings and Infrastructure

Delivering an 80% reduction in GHG emissions in the built environment requires that the model be capable of handling changes in a range of different variables, such as a change in the growth rate for investment in infrastructure into the future.

The capital carbon emissions will be driven by the demand for new building and infrastructure, as described in Chapters 5.2 to 5.4 of this report, and by the carbon intensity of the construction activities. While the demand projections are fixed between different scenarios there is potential to reduce the carbon intensity of the collective scope of defined capital carbon activities. While the demand projections are fixed between different scenarios there is potential to reduce the carbon intensity of construction per unit output.

There are two key areas that will affect the intensity of capital carbon looking forward:

- **Supply chain change:** this occurs through technology shift and process efficiencies, delivering greater material and energy efficiency in manufacture and supply, i.e. delivery of more for the same or less GHG.
- **Design and construction change:** this delivers material efficiency gains in asset realisation and occurs through improvements in design and by better construction practice (this aspect also includes the potential for material substitution).

In addition, **grid decarbonisation** will also impact on the carbon intensity of construction. This is discussed in section 5.1.

To understand the potential of these aspects to deliver GHG reduction a more detailed view of the composition of the built environment and its capital carbon footprint is required. This is achieved by looking at the activities of design and construction and the materials used in the built environment.

The MRIO model is organised into 123 industry sectors. Working from this level of detail a simplified grouping of activities relevant to the built environment has

been created. This represented the upstream activities relevant to the construction and maintenance of constructed assets and includes:

On-site construction activities

- Materials extraction, manufacturing and production
- Distribution (transport) of both goods and people

This analysis which can be seen in Section 5.9.2 provides a basis from which to consider the change strategies identified above.

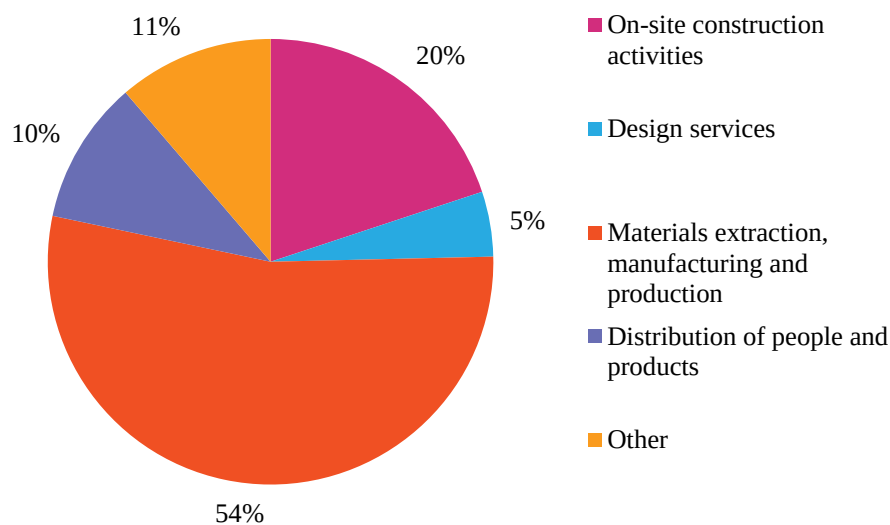


Figure 31: Contribution of activities to capital carbon emissions in 2010

5.9.1 Supply Chain Change

The majority of the capital carbon emissions associated with the built environment can be attributed to materials extraction, manufacturing and processing. The footprint associated with these activities can be studied in more detail by considering individual material sector emission allocations. A disaggregated look at this is possible by separating the materials extraction, manufacturing and production category into principle material classes such as metals, concrete & cement, extractive, chemicals, brick, etc. this is shown in Figure 32.

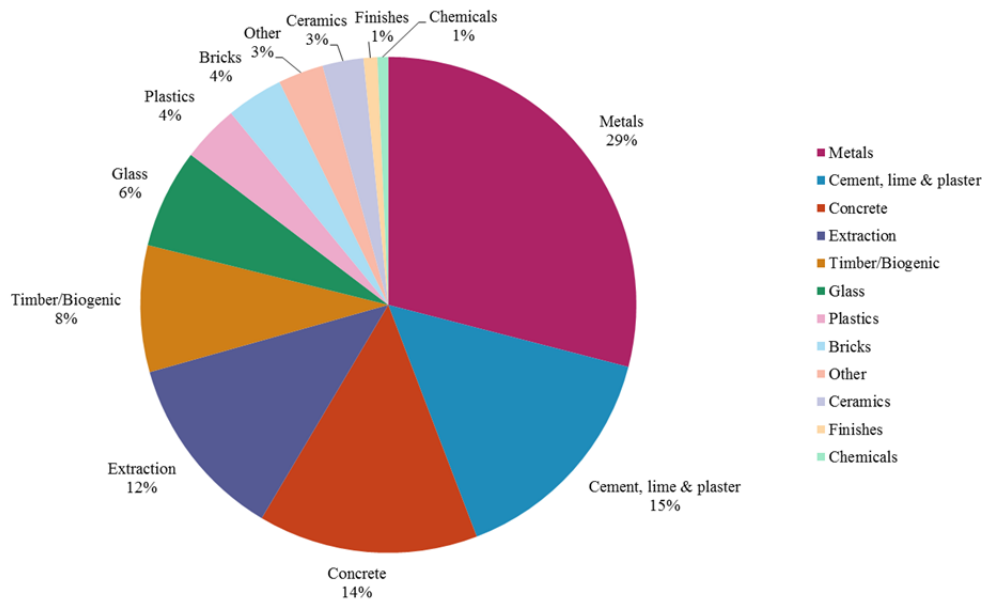


Figure 32: Disaggregation of 'materials extraction, manufacturing and processing' into material types

Potential improvements in technology and material efficiency in material production can then be considered for each materials industry, and the GHG emissions benefit of these actions shown based on a percentage reduction over time.

The model has studied these actions in key material industries representing over 90% of total supply chain GHG emissions;

1. Metals (steel)
2. Concrete and cement
3. Timber
4. Brick and ceramics
5. Glass
6. Plastics

A range of reference information has been used to understand the potential for reductions in each of these areas and what it means for built environment capital carbon footprint. Each of these material industries is discussed in the sections below and carbon capture and storage (CCS) is also considered as a separate topic in section 5.9.1.7. In each case the potential reductions that could be expected by 2050 are identified. In the model these are applied as linear reduction between 2010 and 2050. The scenarios used are summarised in section 6.1.4.

5.9.1.1 Metals (steel)

Steel and aluminium and particularly steel are the dominant metals used in the construction industry. Data gathered by the University of Cambridge, published in 'Sustainable Materials with Both Eyes Open' quantified globally the amount of these two metals used in construction, combining this information with typical

carbon intensities for these two metals found that aluminium accounted for only 6% of the emissions of these two metals combined.

Therefore, for the Routemap modelling process, efficiencies in the steel industry have been the focus the investigation and it has been assumed these can be and have been applied to the ‘metals’ proportion of the material impact emissions. Table 20 summarises the data found in relation to the potential process efficiencies that could be realised in the steel industry.

Table 20: Process efficiencies in the steel industry

Source	Reduction Potential
Sustainable Materials with both eyes open. (SMWBEO)Allwood, Cullen. UIT Cambridge (2012)	24-43% energy efficiency, process change & fuel substitution
Energy Technology Transitions for Industry. International Energy Agency. (2009)	5% material use and efficiency 32% other fuel efficiency & fuel switching Figure 2.3 CCS approx. 16%
Technology Innovation for Energy Intensive Industry in the United Kingdom. Centre for Low Carbon Futures. (2011)	22% to current best practice 30% to current best technology 90% lowest possible (either through substitution and CCS or through electrolysis & grid decarbonisation)

From these reference sources the proposed reduction percentages are:

Minimum = 0%, Maximum = 43% (SMWBEO), Default = 22% (Best practice TifFII)

5.9.1.2 Concrete and cement

Cement is well known for being carbon intensive; this is partially because CO₂ is released during the chemical reaction which creates it, as well as having the normal emissions associated with energy use in manufacture, and those from transportation, which exist for other materials as well. As such there is much interest in ways to reduce its carbon intensity.

Table 21 summarises the potential process efficiencies that could be realised in the cement industry from a number of sources, including an industry road map.

Table 21: Process efficiencies in the cement and concrete industry

Source	Reduction Potential
Sustainable Materials with both eyes open. Allwood, Cullen. UIT Cambridge (2012)	17% Energy Efficiency 5% fuel substitution 9% Substitution Read from Figure 20.9
Energy Technology Transitions for Industry. International Energy Agency. (2009)	9% Energy Efficiency 4% fuel substitution 28% CCS Read from Figure 3.11
Technology Innovation for Energy Intensive	10% Energy Efficiency

Industry in the United Kingdom. Centre for Low Carbon Futures. (2011)	35% fuel substitution 10-20% Substitution
WBCSD Cement Technology Roadmap (2009)	3% Energy efficiency 8% alternative fuels 3% clinker substitution 20% CCS

From these reference sources the proposed reduction percentages are:

Minimum = 0%, Maximum = 31% (SMWBEO), Default = 14% (WBCSD)

5.9.1.3 Timber

No information was found for anticipated process efficiencies in the timber industry and GHG emissions savings potential. This was surprising given that notable emissions can be associated with the sector. Given no clear evidence base was found no reduction potentials have been proposed in the model.

5.9.1.4 Brick and ceramics

The model developed for brick and ceramic is summarised as follows.

Table 22: Process efficiencies in the brick and ceramic industry

Source	Reduction Potential
Technology Innovation for Energy Intensive Industry in the United Kingdom. Centre for Low Carbon Futures. (2011)	8% Energy/process efficiency 19% fuel substitution (Brick industry only) Not suitable for CCS
Cerame-Unie, The European Ceramic Industry Association. Paving the way to 2050. The Ceramic Industry Roadmap. (2012)	Kiln Electrification 28% Available technology 7% Breakthrough technology syngas/biogas 14% Other breakthrough technology 12% CCS 3%

From these reference sources the proposed reduction percentages are:

Minimum = 0%, Maximum = 61%, Default = 27%

5.9.1.5 Glass

The model developed for glass is summarised as follows.

Table 23: Process efficiencies in the glass industry

Source	Reduction Potential
Technology Innovation for Energy Intensive Industry in the United Kingdom. Centre for Low Carbon Futures. (2011)	Process change 7.5% Process change 15-30% Very early stages of development Not suitable for CCS

From these reference sources the proposed reduction percentages are:

Minimum = 0%, Maximum = 30%, Default = 7.5%

5.9.1.6 Plastics

The model developed for plastic is summarised as follows.

Table 24: Process efficiencies in the plastics industry

Source	Information
Technology Innovation for Energy Intensive Industry in the United Kingdom. Centre for Low Carbon Futures. (2011)	Process change 7.5% Process change 15-30% Very early stages of development Not suitable for CCS

From these reference sources the proposed reduction percentages are:

Minimum = 0%, Maximum = 15%, Default = 7.5%

5.9.1.7 Carbon capture and storage (CCS)

The potential reductions that could be achieved through carbon capture and storage for each material type have been recorded in the sections above. These are summarised in Table 25.

Table 25: Summary of reduction potentials through carbon capture and storage for each material

Material	Reduction (of remaining impact if maximum efficiency applied)
Steel	45%
Cement	17%
Timber	We have assumed not suitable for CCS
Brick & Ceramics	Not suitable for CCS
Glass	Not suitable for CCS
Plastics	Not suitable for CCS

It must be acknowledged that CCS technologies are not yet ready to be implemented on a wide scale and could be 10-15 years away from commercial deployment⁴⁸. Based on this it has been proposed that any CCS deployment should not start to be implemented in the model until 2020. In theory the options for CCS should range from 0-100% where 100% correlates to the percentage maximums defined in Table 25.

5.9.2 Design and Construction change

This includes three distinct components including improvements delivered by design, site efficiency gains and transport efficiency.

⁴⁸ Technology Innovation for Energy Intensive Industry in the United Kingdom. Centre for Low Carbon Futures. (2011)

5.9.2.1 Materials efficiency realised through design processes

Changes in design processes may result in a lower use of materials per delivered function. Sources covering the reduction potential possible through these activities are limited; references found are documented in Table 26.

Table 26: Summary of reduction potentials through material efficiency in design

Source	Information
Sustainable Materials with both eyes open. Allwood, Cullen. UIT Cambridge (2012)	40% of concrete mass “in places” – assumed predominantly beams and columns. Optimizing rebar 30% of rebar mass Optimizing steel beams 50% of beam mass 14% reduction in CO ₂ steel use in design
Meeting the UK climate change challenge: The contribution of resource efficiency. WRAP. (2009) NOTE: all goods/products, not just construction	Lean production: best practice, material requirement reduced by 50%, beyond best practice, 75% Material substitution: best practice, 20% all materials replaced with the lowest carbon intensive material, beyond best practice, 40% Strategies for sustainable building: best practice, 5% of construction market is met by modular building design, beyond best practice, 10%

Assuming the steel and concrete material reductions suggested in SMWBEO are achieved, with no other material reductions, this would result in an approximately 18% CO₂ reduction (based on 2009 figures). However this assumes the 40% reduction of mass could be applied across all applications which is not practical or what is proposed by the reference.

Therefore it has been proposed that a more realistic value might be a 5% maximum reduction across all materials and that half of this is used as a default. Based on this the proposed reduction percentages are:

Minimum = 0%, Maximum = 5%, Default = 2.5%

5.9.2.2 Improvement in site efficiency

A Strategic Forum for Construction (SFfC) study⁴⁹ into reducing the carbon emissions associated with the construction process attributed 1,710,000 tonnes of CO₂ to site activities in 2008. This study is observed to cover a similar scope to our definition of site activities. The actions identified in Table 27 were suggested to be effective strategies in the report.

⁴⁹ Carbon: Reducing the footprint of the construction process, An Action Plan to reduce carbon emissions Prepared by Joan Ko on behalf of the Strategic Forum for Construction and the Carbon Trust (2010)

Table 27: Action proposed by SFfC to reduce site activity carbon emissions

Action	Targeted industry adoption rate by 2012	Annual carbon saving by 2012 (tonnes CO ₂)
Energy efficient site accommodation	65%	200,000
Efficient use of construction plant	65%	84,000
Earlier connection to the grid	35%	45,000
Good practice energy management on site	75%	28,000
Good practice energy management on site offices	75%	28,000

The magnitude of these reductions is equivalent to 23% of the quoted 1,710,000 tonnes. If the selected measures were adopted by 100% of the industry, this would result in a 37% reduction in total emissions. The majority of these actions are to affect the efficiency of site accommodation as opposed to plant.

Based on the exploration of reductions in the transportation sector (in section 5.9.2.3), a range of 26-50% reduction in carbon intensity of plant could potentially be achieved through technical solutions. This is assuming that site combustion powered plant will have a similar transition to low carbon technologies as that anticipated of road vehicles.

No data was found which showed the proportion of construction site emissions attributable to these different activities. The MRIO data showed that the majority of emissions on site (90%) are attributable to non-electricity sources. As no further data was available it has been assumed that all electricity use is site accommodation, all non-electricity is combustion powered plant.

Based on this the proposed reduction percentages are:

Minimum = 0%, Maximum = 49%, Default = 26%

5.9.2.3 Reduction in carbon intensity of transportation of both goods and people

The SFfC report estimated the quantity of emissions due to transportation in the construction industry, summarised in Table 28.

Table 28: Transportation emissions in the construction industry

Activity	tonnes of CO ₂ e
Freight transport	1,620,000
Waste removals	525,000
Business travel	732,000
Total	2,877,000

The report also identifies a number of measures to reduce this impact, Table 29.

Table 29: Actions proposed by SFfC to reduce transportation carbon emissions

Action	Targeted industry adoption rate by 2012	Annual carbon saving by 2012 (tonnes CO ₂)
Fuel efficient driving – freight	75%	120,000
Fuel efficient driving – waste removal	75%	38,000
Renewable Transport Fuel Obligation – freight and waste removal	100%	25,000
Reducing the transport of waste	100%	25,000
Renewable Transport Fuel Obligation – business travel	100%	8,000
Smart driving training for business travel	65%	44,000
Fleet conversion to fuel efficient passenger vehicles	40%	68,000
Restricting domestic flights	50%	26,000
Total		354,000

These magnitudes of reductions are equivalent to 12% of the total figure above. If the selected measures are adopted by 100% of the industry; this would result in a 19% reduction in total emissions.

Other studies have looked at the transportation sector on a wider scale, one such study is summarised in Table 30 below.

Table 30: Summary of reduction potentials in transportation of both goods and people

Source	Information
Carbon: Reducing the footprint of the construction process. An action plan to reduce carbon emissions. (2010)	12-19%, see below for derivation
Towards the decarbonisation of the EU's transport sector by 2050. EU Transport GHG: Routes to 2050? http://www.eutransportghg2050.eu/cms/eu-transport-ghg-routes-to-2050-project-reports/ (2010)	Substituting conventional fuels with biofuels = 26%. Technical energy efficiency of vehicles (electrification) = 50%. Biofuels were used to reduce the GHG intensity of fuels, in addition to very significant improvements to the technical energy efficiency of vehicles = 63% Non-technical options were taken up in addition to technical options = 89%

Based on this the proposed reduction percentages are:

Minimum = 0%, Maximum = 89%, Default = 50%

5.9.3 Grid Decarbonisation in the Capital Carbon Model

The assumed grid decarbonisation model for UK electricity is discussed in section 5.1. This same reduction scenario has been assumed to apply to all UK electricity emissions associated with the capital carbon. In addition, the capital carbon also incorporates emissions occurring in other countries. The perspective the MIRO model creates on this is illustrated in Figure 33.

The MRIO model data shows that the largest emission contribution comes from the UK. After this South Africa and China are the next biggest contributors. These allocations are based on total emissions data and not just those associated with electricity generation.

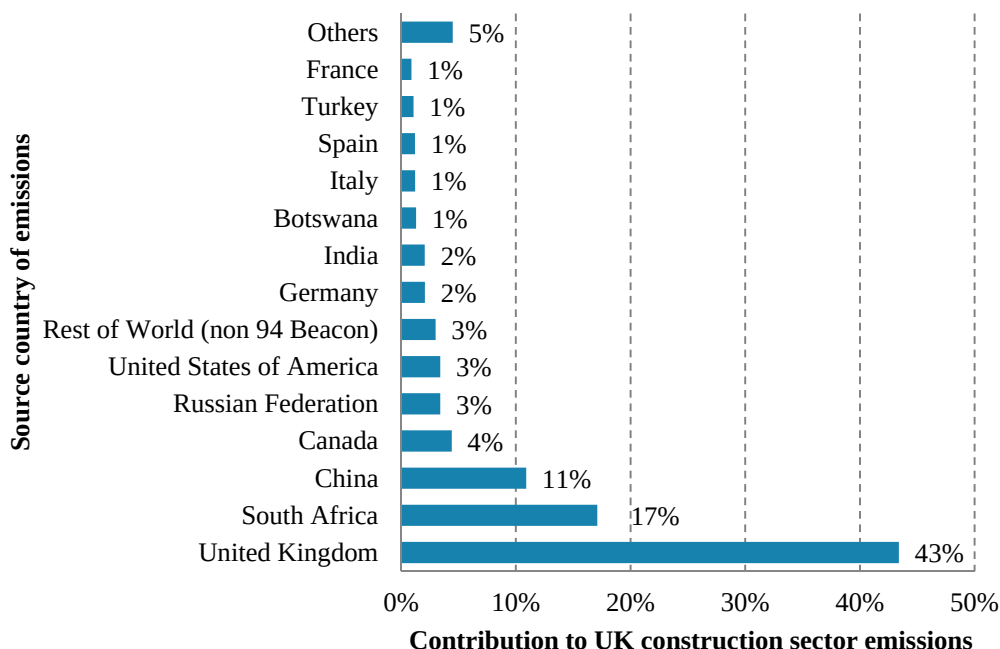


Figure 33: Source of UK construction sector emissions by country (Source: 57 sector x 94 region global model, Leeds University / CenSA)

The Routemap model took a simplified approach and assumed that of the ‘imported’ electricity emissions, 50% originated from South Africa and 50% from China.

A report by PriceWaterhouseCoopers⁵⁰ has summarised the emissions reduction commitments and policy actions from around the globe. The data for South Africa and China has been extracted, shown in Table 31. These changes in carbon intensity of electricity have been linearly applied to the imported electricity emissions and applied in the model.

Table 31: Carbon intensity reduction commitments

Country	Commitments for 2020 (or earlier)	Commitments to 2050
South Africa	10% above 2003 levels in 2020	30-40% below 2003 by 2050.
China	40-45% reduction in carbon intensity by 2020	

5.9.4 Combining reduction strategies

The initial capital carbon intensity of the UK built environment was assumed to be the 2009 figure and composition. As previously described, this has been related to the annual output in the construction industry in terms of £million.

⁵⁰ PriceWaterhouseCoopers. Low Carbon Economy Index. (2009)

The reduction strategies described above cannot be applied in an additive manner. The carbon intensity of the construction industry has been calculated by applying the selected reductions in a hierarchical fashion.

Firstly, the material efficiency reduction is applied, then the individual material sector process efficiencies, transportation efficiencies and site efficiencies. Finally carbon capture and storage is applied to the direct emissions and the UK and international grid decarbonisation applied to the indirect emissions.

6 Scenarios to 2050

Three scenarios were developed to explore the potential for carbon reduction:

1. A **Business-as-Usual (BAU) scenario** representing the status quo. The BAU scenario reflects continuing the trends and patterns prior to 2010. We see a continuation of energy-intensive behaviour and no change in the pace of retrofit.
2. A **Central Scenario**: this scenario represents carbon reduction that is achievable if measures that have a positive return on investment over their lifetime or are reasonably feasible to implement are implemented (e.g. installation of low energy lighting). It is important to distinguish that although these measures are feasible, there is no strong financial driver or business case to implement all of them in the current policy context.
3. An **80% Carbon Reduction Scenario** which includes maximum uptake of low carbon technologies from the central scenario, as well as significant uptake of measures that do not have a positive return on investment (such as large scale retrofit of hard to treat domestic properties).

6.1 Scenario Assumptions

Assumptions for each of the three scenarios are provided below. These assumptions have been developed through review of existing data and reports and expert opinion.

It should be noted the analytical approach and the backbone data used in the model is the same for all three scenarios. *Thus any assumptions or inputs not listed here are common to all three scenarios.* For example, in the non-domestic sector, assumptions have been made about asset lifecycle replacement within each sector (see Section 5.6.5); these assumptions have not changed between the three scenarios.

6.1.1 Domestic Sector

Figure 34 shows how the core assumptions differ between the three domestic scenarios.

Scenario 1 maintains the status quo. It sees no further penetration of domestic renewables in new-build or existing properties and no reduction in the upward trends of energy demands. Heat is delivered overwhelmingly by gas boilers, and no novel systems are implemented. In the retrofit sector, only a fraction of the total technical potential for insulation installation is realised. Performance gaps do not reduce.

Scenario 2 represents a modest effort being made to decarbonise the domestic sector. Overall growth in service demands is capped, and renewables (solar PV and solar thermal) have a significant role in both new-build and existing stock. There is a significant move towards heat pumps in heat delivery, with district heating playing a strong role. In 2050 gas CHP is still being used to supply a portion of total heat network heat delivery. Retrofit of easy to treat properties is nearly complete, but no hard to treat households are addressed. The performance gap more than halves.

Scenario 3 gives conditions that assist in delivering an overall 80% reduction in emissions. Behavioural change leads to moderately reduced service demands compared to those today. Domestic solar PV and solar thermal capacities are approaching maximum potentials in new and existing houses. Heat networks are responsible for delivery of large quantities of heat, and in new-builds in particular, ground and air-source heat pumps are responsible for the largest proportions of heat generation. The performance gap narrows significantly.

Domestic Buildings

	Scenario Conditions		
	Business as Usual	Central Scenario	Scenario to deliver 80%
General Assumptions			
Mean internal building temperature by 2050 (°C)	18	18	17.5
Change in average per household water demand by 2050 (vs. 2010)	10%	0%	-10%
Decrease in per household lighting levels	0%	0%	-10%
Performance gap in 2050 (across all domestic interventions)	35%	15%	10%
Solar thermal area installed per household by 2050 (average m ²)	0.0	1.5	3
Existing Building Assumptions			
Solar PV Area installed per household by 2050 (average m ²)	0.2	2.5	5
Heat delivery split by 2050:			
Gas boiler (new)	90%	66%	46%
Resistive heating	10%	8%	6%
Stirling engine µCHP	0%	0%	0%
Fuel-cell µCHP	0%	0%	0%
Air-source heat pump	0%	14%	30%
Ground-source heat pump	0%	5%	10%
Geothermal	0%	0%	1%
District heating from gas CHP	0%	3%	0%
District heating from zero carbon sources	0%	4%	7%
Penetration by 2050 of retrofit initiatives:			
<i>Easy to Treat Households: percentage of maximum potential</i>			
Solid wall insulation	60%	85%	95%
Cavity wall insulation	60%	85%	95%
Floor insulation	60%	85%	95%
Superglazing	60%	85%	95%
Loft insulation	60%	85%	95%
Draughtproofing	60%	85%	95%
<i>Hard to Treat Households: percentage of maximum potential</i>			
Solid wall insulation	0%	0%	70%
Cavity wall insulation	0%	0%	70%
Floor insulation	0%	0%	70%
Superglazing	0%	0%	70%
Loft insulation	0%	0%	70%
Draughtproofing	0%	0%	70%
New Building Assumptions			
Heat Delivery Split by 2050:			
Gas boiler (new)	90%	50%	30%
Resistive heating	10%	15%	5%
Stirling engine µCHP	0%	0%	0%
Fuel-cell µCHP	0%	0%	0%
Air-source heat pump	0%	15%	29%
Ground-source heat pump	0%	12%	25%
Geothermal	0%	0%	1%
Community scale gas CHP	0%	4%	0%
District heating from low carbon sources	0%	4%	10%
Total solar PV area installed per new household by 2050 (m ²)	0	5	10

Figure 34: Domestic sector scenario assumptions

6.1.2 Non-Domestic Sector

Figure 35 shows how the core assumptions differ between the three non-domestic scenarios.

The performance gap gets progressively lower moving from Scenario 1 to Scenario 3. In all scenarios, asset replacement speeds and technology performance improvements by 2050 are unchanged. There is no change in the proportion of maximum energy reduction potential typically achieved by for sectors in Scenario 1, but in Scenario 3 this is improved to 90% of best-practice potential on average.

For heat delivery, Scenario 1 maintains the status quo for existing buildings, and places a heavy emphasis on gas boilers for new-build. Scenario 2 reduces the proportions of gas boilers used for new-build and existing buildings, and more than doubles the penetration of heat delivered district heating. Scenario 3 builds on this and in particular sees a significant growth in the penetration of heat pumps. Notably ground-source heat pumps do not achieve the same level of penetration as for the domestic sector. In all cases cooling is delivered by modern air conditioners.

Non Domestic Buildings

	Scenario Conditions		
	Business as Usual	Central Scenario	Scenario to deliver 80%
Assumptions Common to all Non-Domestic Buildings			
Performance gap in 2050	35%	15%	5%
Asset replacement speed			
Commercial Offices	MEDIUM	MEDIUM	MEDIUM
Communication and Transport	MEDIUM	MEDIUM	MEDIUM
Education	SLOW	SLOW	SLOW
Government	SLOW	SLOW	SLOW
Health	MEDIUM	MEDIUM	MEDIUM
Hotel and Catering	FAST	FAST	FAST
Other	MEDIUM	MEDIUM	MEDIUM
Retail	FAST	FAST	FAST
Sport and Leisure	MEDIUM	MEDIUM	MEDIUM
Warehouses	MEDIUM	MEDIUM	MEDIUM
Percentage increase in performance of technology by 2050			
Solid element u-values	50%	50%	50%
Glazing u-values	25%	25%	25%
Glazing solar performance	50%	50%	50%
Voltage Optimisation and Power Factor Correction	20%	20%	20%
Heat recovery ventilation	20%	20%	20%
Lighting and controls	20%	20%	20%
Sub-metering & recommissioning	20%	20%	20%
Proportion of maximum energy reduction potential typically achieved by sector (based on technology choice)	75%	85%	90%
Existing Building Assumptions			
Heat delivery split by 2050:			
Gas boiler (new)	74%	63%	51%
Resistive heating	23%	15%	15%
Stirling engine μ CHP	0%	0%	0%
Fuel-cell μ CHP	0%	0%	0%
Air-source heat pump	0%	9%	17%
Ground-source heat pump	0%	2%	6%
Geothermal	0%	0%	1%
Community scale gas CHP	0%	4%	0%
District heating from low carbon sources	3%	7%	10%
Cooling delivery split by 2050			
Air conditioning	100%	100%	100%
Absorption chiller	0%	0%	0%
New Build Assumptions			
Heat delivery split by 2050:			
Gas boiler (new)	90%	48%	35%
Resistive heating	10%	16%	14%
Stirling engine μ CHP	0%	0%	0%
Fuel-cell μ CHP	0%	0%	0%
Air-source heat pump	0%	15%	28%
Ground-source heat pump	0%	3%	7%
Geothermal	0%	0%	1%
Community scale gas CHP	0%	8%	0%
District heating from low carbon sources	0%	10%	15%
Cooling delivery split by 2050			
Air conditioning	100%	100%	100%
Absorption chiller	0%	0%	0%

Figure 35: Non-domestic sector scenario assumptions

6.1.3 Infrastructure

The assumptions for growth in spending in the infrastructure sector have been maintained across all three scenarios. In outdoor lighting, it has been assumed there is a higher growth rate in the BAU vs other scenarios. In waste, it has been assumed for all scenarios that by 2050 there will be a 50% reduction in the

amount of C&D waste sent to landfill and an elimination of ‘general’ waste sent to land fill. In the water and wastewater sector, due to uncertainty, all three scenarios have the same growth profile for emissions.

Infrastructure

General Assumptions

Infrastructure spend growth forecast

Water
Sewerage
Electricity
Roads
Railways
Harbours
Air
Gas
Communications

Annual growth in outdoor lighting demand

Savings achievable from new outdoor lighting technologies

Scenario Conditions

Business as Usual	Central Scenario	Scenario to deliver 80%
3.2%	3.2%	3.2%
0.6%	0.6%	0.6%
1.2%	1.2%	1.2%
0.0%	0.0%	0.0%
4.9%	4.9%	4.9%
0.0%	0.0%	0.0%
1.3%	1.3%	1.3%
1.3%	1.3%	1.3%
1.3%	1.3%	1.3%
1.0%	0.5%	0.0%
70.0%	70.0%	70.0%

Figure 36: Infrastructure scenario assumptions

6.1.4 Capital Carbon

In capital carbon, the scenarios differ based on efficiency gains and CCS. The BAU scenario assumes no change in process or site efficiency, while the Central and 80% scenario assume increasing levels of efficiency. In terms of CCS, the BAU assumes no investment in CCS, while the Central and 80% scenario assume CCS will have a much more significant impact.

Capital Carbon

General Assumptions

Industry based process efficiency; reduction in intensity by 2050:

Metals (steel) industry
Cement & concrete industry
Timber industry
Brick & ceramic industry
Glass industry
Plastics industry

Carbon capture and storage in materials sector by 2050

Materials efficiency realised through design processes

Improvement in site efficiency

Reduction in carbon intensity of transportation of both goods and people

The year CCS starts to have an impact on materials

Scenario Conditions

Business as Usual	Central Scenario	Scenario to deliver 80%
0%	22%	43%
0%	14%	31%
0%	0%	0%
0%	27%	61%
0%	8%	30%
0%	8%	15%
0%	25%	100%
0%	3%	5%
0%	26%	49%
0%	50%	89%
2050	2020	2020

Figure 37: Capital carbon scenario assumptions

6.2 Scenario 1 Results

This scenario represents the status quo. It is based on continuing the existing trend in operational and capital carbon emissions in the years prior to 2010. Scenarios 1, 2, and 3 all share common assumptions about grid decarbonisation, growth of the building stock and growth of infrastructure.

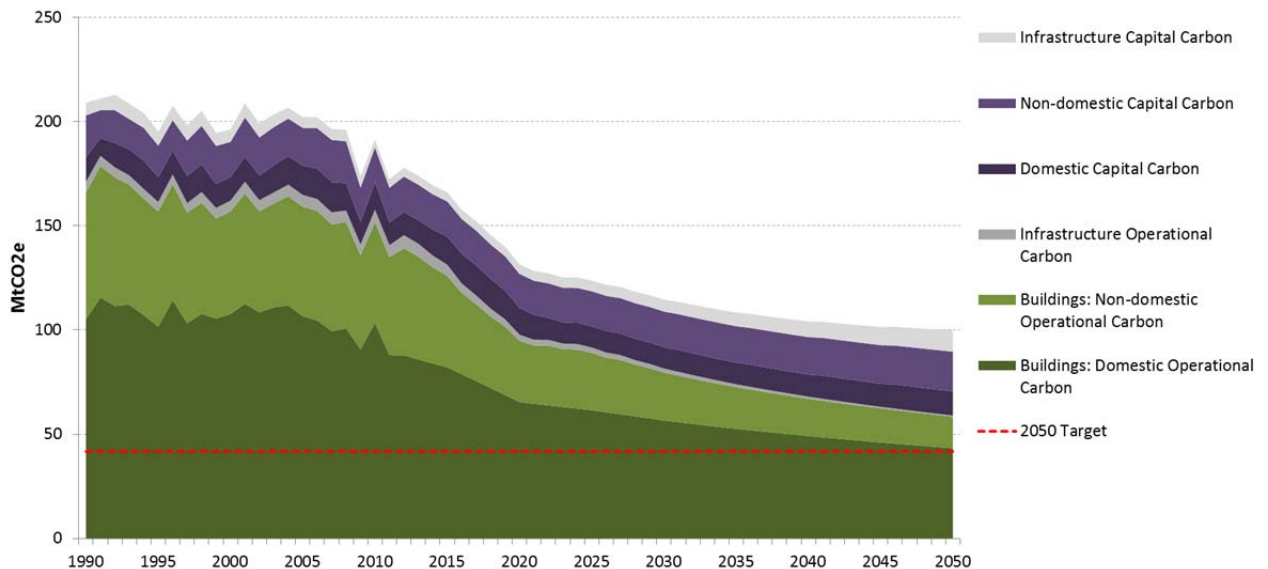


Figure 38: Built environment carbon emissions to 2050 under the Business as Usual Scenario

6.2.1 Domestic emissions

As indicated in Figure 38 above, under the Business as Usual Scenario the domestic sector sees reductions in operational carbon of approximately 60%. Roughly half of this reduction is achieved through grid decarbonisation, with retrofit and more efficient boilers contributing the remaining half.

Emissions from new-build residences remain negligible, with new stock from 2016 being to a Zero Carbon standard.

6.2.2 Non-domestic emissions

As can be seen from Figure 38, the non-domestic sector achieves greater emissions reductions than the domestic sector under the Business as Usual Scenario, achieving a reduction of around 70%. This is because over 50% of its operational emissions in 2010 are from electricity use, and these are reduced to nearly zero in 2050. Much of the reduction in direct emissions is actually already achieved by 2010 through a reduction in the use of solid fuels, and more efficient boilers.

Emissions from new-build buildings are significant by 2050, making up around 15% of total non-domestic emissions. Whilst after 2019 buildings are of a zero-carbon standard, the growth in stock to 2019, coupled with continued use of gas boilers results in these emissions being locked in.

6.2.3 Capital carbon

It can be seen from Figure 38 that due to the decarbonisation of the grid there is a reduction in the overall emissions associated with the built environment but also that due to the increase in demand the capital carbon emissions actually increase. A more detailed perspective on this is shown in Figure 39.

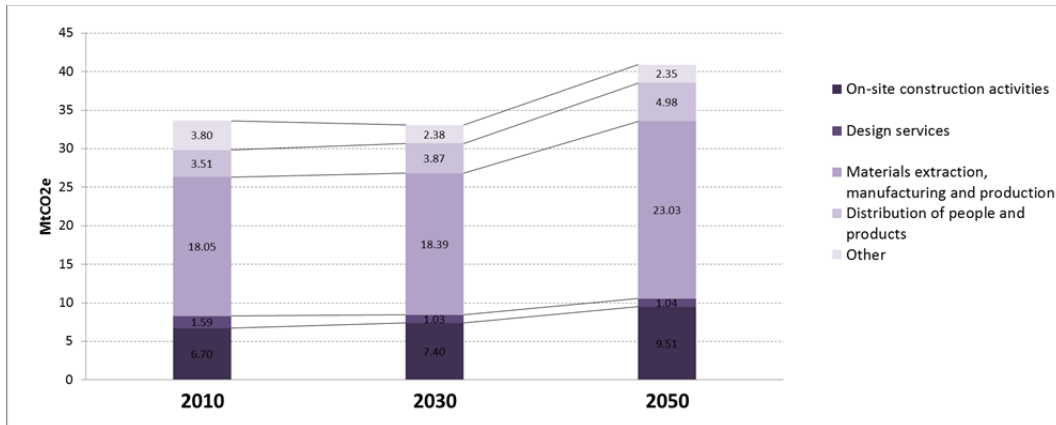


Figure 39: Business as usual capital carbon results

For the period 2010 and 2030, the model has rapid grid decarbonisation, to a large degree this offsets the rise in emissions that would be generated due to the increased demand projections. This means the carbon emission level rises are marginal over the period.

Beyond 2030 as demand continues to increase and the grid decarbonisation plateaus, a marked increase in emissions can be seen.

Over the 2010 to 2050 period the industry sees a marginal reduction in the capital carbon intensity (per unit output) which can be wholly attributed to the decarbonisation of electricity. Beyond this, the BAU scenario assumes no reduction in material carbon intensity through process efficiency or technology change.

In 2050, reduction achieved is 52.2%.

6.3 Scenario 2: Central Scenario

This scenario represents carbon reduction that is achievable if measures that have a positive return on investment over their lifetime or are reasonably feasible to implement are carried out (e.g. installation of low energy lighting). It is important to distinguish that although these measures are feasible, this does not necessarily mean there is a business case to implement the solution from the perspective of the private sector; private investors may have expectations about the timing and levels of risks and returns which differ. In addition, the current policy context may not provide sufficient driver to the industry to make changes in, for example, reducing process emissions from production of materials.

In this scenario, carbon reduction achieved by 2050 is about 64% reduction.

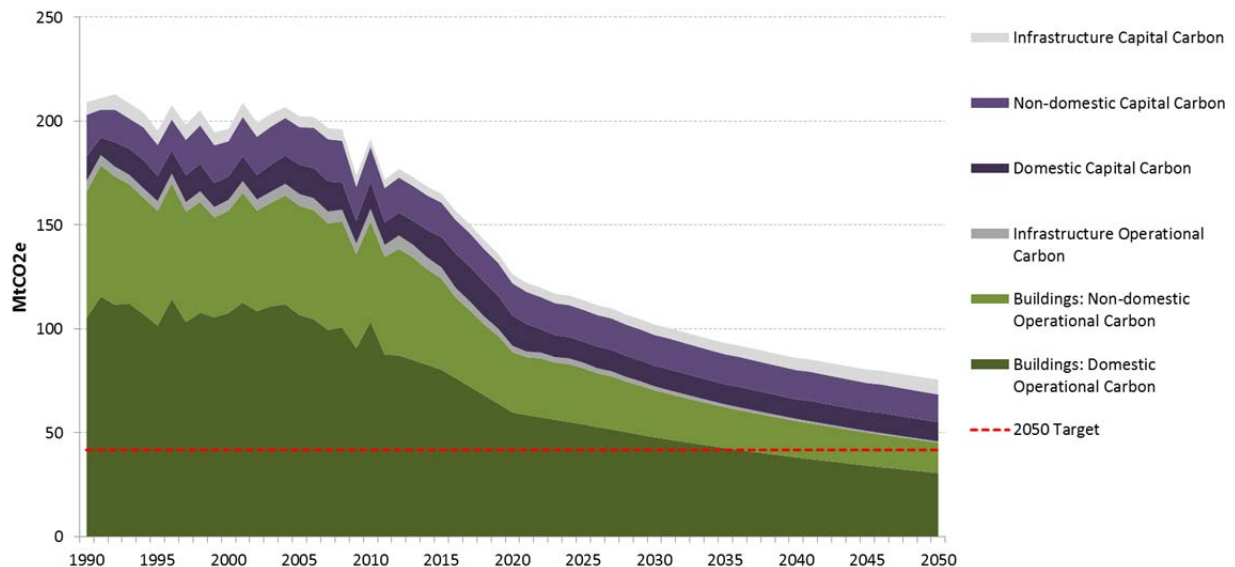


Figure 40: Built environment carbon emissions to 2050 under the Central Scenario

6.3.1 Domestic emissions

As indicated in Figure 40 above, under the Central Scenario the domestic sector sees reductions in operational carbon of over 70%. Grid decarbonisation is again important, with a shift to electrical heating allowing for greater reductions in direct emissions.

As for the Business as Usual Scenario, emissions from new-build residences remain negligible, with new stock from 2016 being to a Zero Carbon standard.

6.3.2 Non-domestic emissions

Again, as can be seen from Figure 40, the non-domestic sector achieves greater emissions reductions than the domestic sector under the Central Scenario. Whilst the reduction is still significant, it is not actually much greater than that achieved under the Business as Usual Scenario, as overall changes in existing building heat delivery still somewhat favour gas-fired generation (through boilers and CHP), resulting in no great additional reduction in direct emissions.

Emissions from new-build buildings are still significant by 2050, making up around 15% of total non-domestic emissions.

6.3.3 Capital carbon

In this central scenario, it can be observed that the capital carbon component is relatively flat, representing only a 14% gross reduction over the 40 year period. This represents a significant improvement (36%) over business as usual but is still significantly less than that which is necessary to achieve the 80% target reduction.

The 2010 to 2030 period sees good reductions due to the efficiency gains and rapid grid decarbonisation.

Beyond 2030 the grid decarbonisation plateaus and the relatively minor efficiency gains continue which are balanced by the increased demand, and therefore emissions can be seen to flatten.

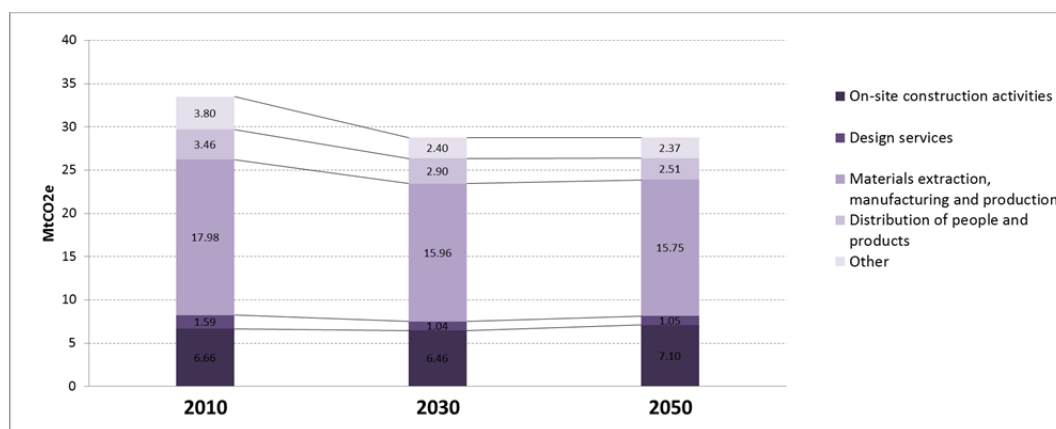


Figure 41: Central scenario capital carbon results

6.4 Scenario 3: Delivery of 80% Reduction Targets

Scenario 3 was designed to achieve an 80% reduction in carbon emissions. The trajectory for carbon emission reduction is shown in Figure 42.

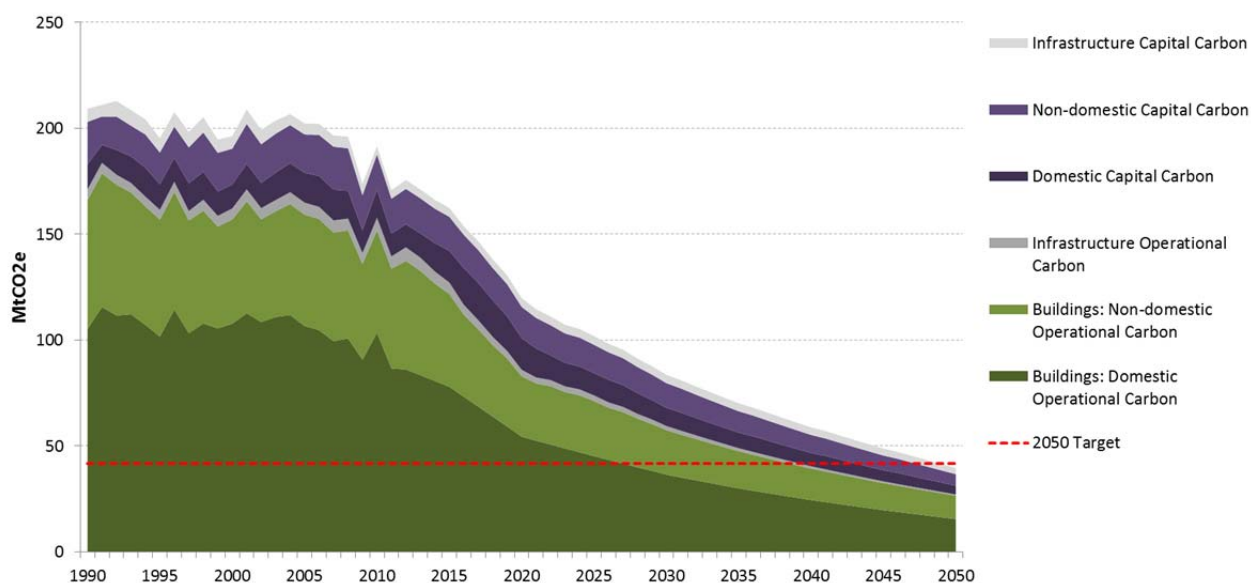


Figure 42: Built environment carbon emissions to 2050 under the 80% Scenario

6.4.1 Domestic emissions in the 80% scenario

As indicated in Figure 42 above, under the 80% scenario the domestic sector sees reductions in operational carbon of over 90%. Grid decarbonisation plays a crucial role, enabling a reduction in heating operational emissions of around 85% (through a switch to electrical heating), and almost 100% for lighting operational emissions (see Figure 43).

As for the previous scenarios, emissions from new-build residences remain negligible, with new stock from 2016 being to a Zero Carbon standard.

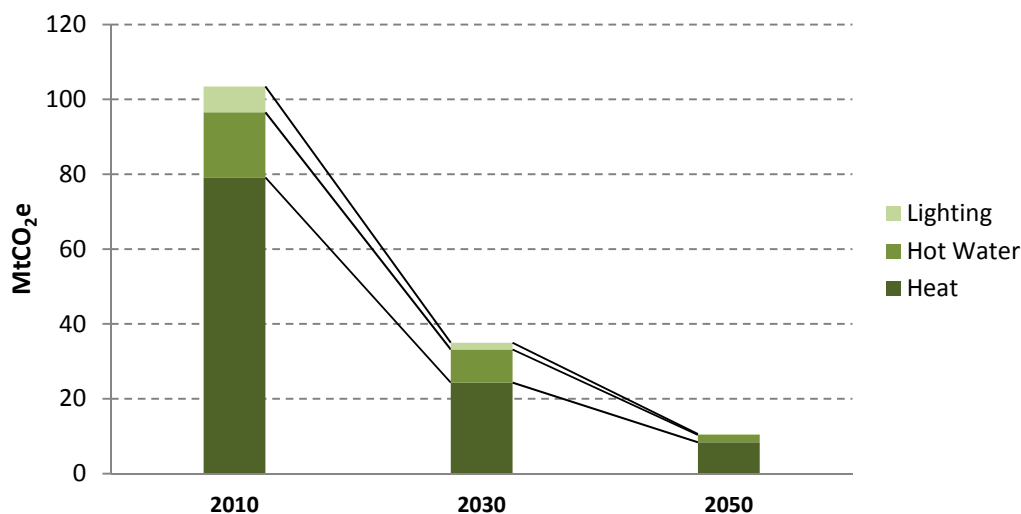


Figure 43: Projected carbon emissions in the domestic sector under the 80% scenario.

6.4.2 Non-domestic emissions in the 80% scenario

As can be seen from Figure 42, the non-domestic sector again achieves significant reductions in operational emissions, but at around 82% these are not as great as those realised by the domestic sector. A shift further towards electric heating and low carbon sources supplying district heating networks serves to reduce direct emissions to around 30% of their 1990 levels.

Emissions from new-build buildings are again still significant by 2050, making up around 15% of total non-domestic emissions. This is the result largely the result of the initial increases in direct emissions that are expected in new-builds up to 2019, which are mostly locked in thereafter. This highlights the importance of promoting high efficiency standards today.

Figure 44 below shows that some of the greatest overall emissions reductions can be achieved from the retail sector in particular, as well as the hotels and catering sector.

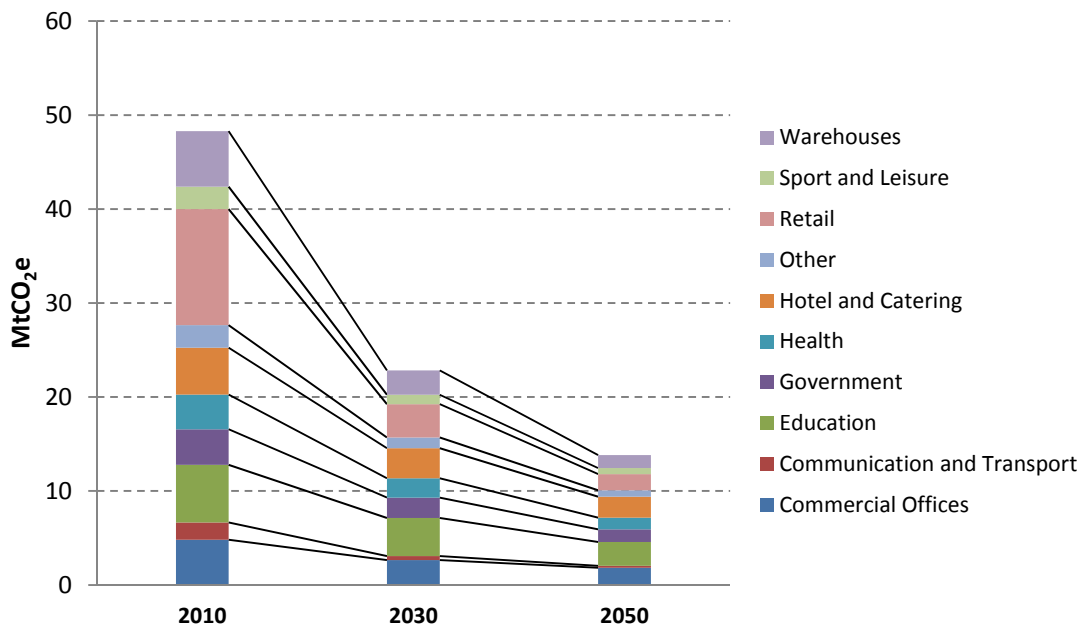


Figure 44: Projected carbon emissions in the non-domestic sector under the 80% Scenario; significant emissions reduction is delivered in the retail sector.

6.4.3 Capital carbon in the 80% scenario

In developing this scenario a range of references were reviewed to determine carbon reduction potential. In creating the scenario upper boundary values were chosen reflective of what is considered technically feasible at this point in time, as we look to the future. In addition maximum deployment of carbon capture and storage (CCS) has been assumed in the sectors to which it is relevant.

In this scenario good reductions are achieved in both the total emissions (62%) and in the carbon intensity of construction (76%).

The 2010 to 2030 period sees good reductions from efficiencies realised in materials production, design and on construction sites. These reductions continue to 2050 are strengthened from 2020 onwards as CCS is deployed in the steel and cement sector.

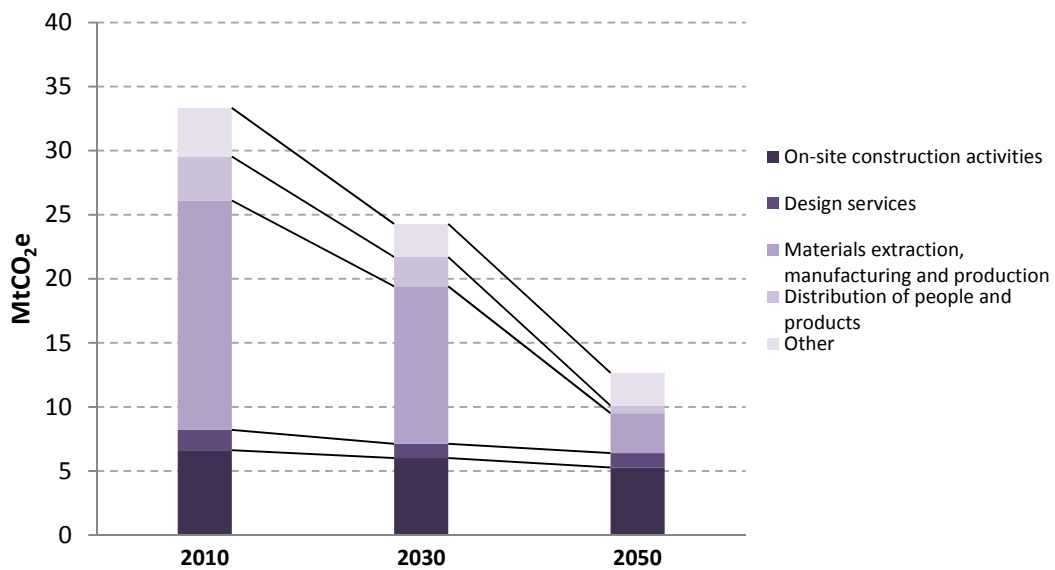


Figure 45: Projected capital carbon emissions under the 80% Scenario

Within the context of the built environment target of 80% reduction on 1990 levels, in this scenario capital carbon has achieved a 66% reduction on its carbon footprint.

6.4.4 Carbon capture and storage

A further scenario was studied which implemented the 80% scenarios assumptions, excluding CCS. This scenario shows the importance of CCS in not only reducing the capital carbon emission, but also in its contribution to meeting the overall target for the UK built environment.

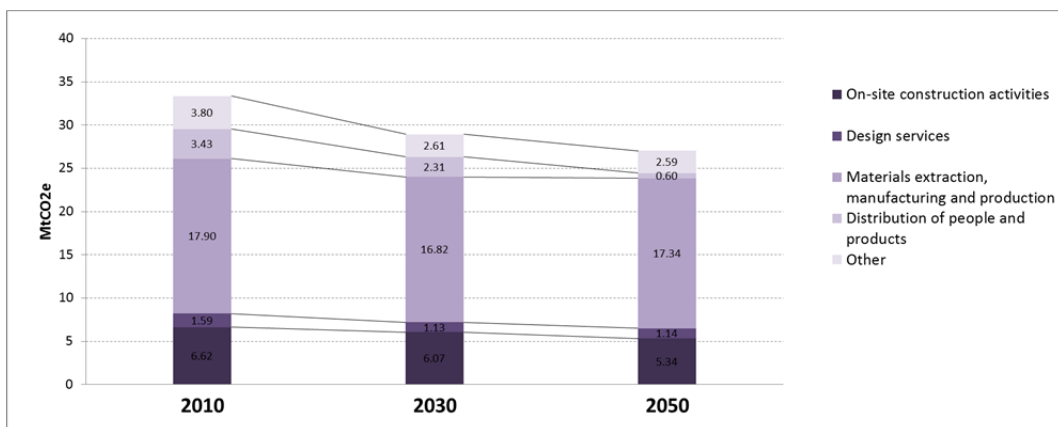


Figure 46: Scenario excluding CCS capital carbon results

Figure 47 shows that if CCS technology is not successfully deployed then only a 78% reduction is achieved; the built environment misses the 2050 target.

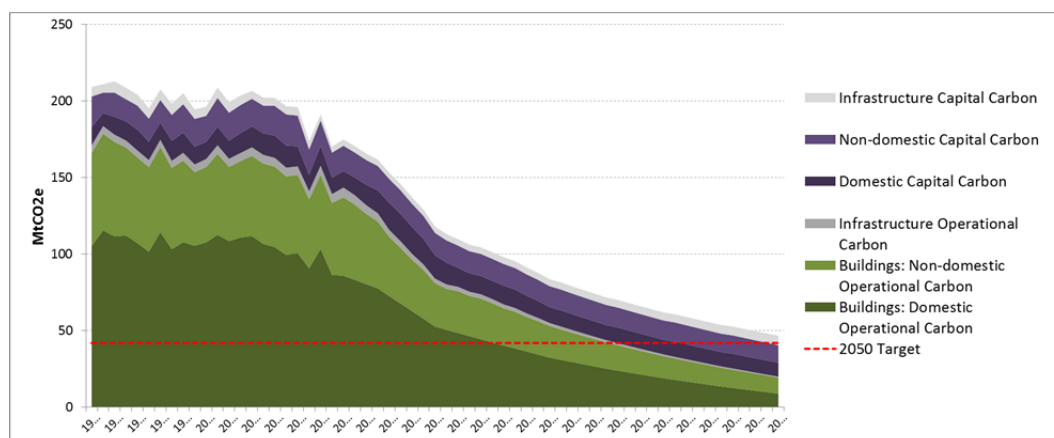


Figure 47: Scenario excluding CCS UK built environment results

6.4.5 Total emissions reduction in 2050

The 80% reduction scenario represents the low carbon trajectory if all solutions are implemented at maximum uptake (i.e. nearly 100%). The solutions in this scenario include some which are not economically viable and would require financial mechanisms, incentives or mandating to encourage/enable adoption.

It is cautioned that this scenario is just one possible scenario from a range of options that allows for delivery of an 80% carbon reduction. Whilst modelling analysis indicates that retrofit measures, fabric efficiency and other technological improvements should be maximised to their practical limits by 2050, the final contribution to emissions reductions must come from a switch in heat energy delivery. Heat delivery must move from fossil fuel-based standards to low-carbon alternatives. How these low-carbon alternatives develop in the coming years remains to be seen, and will depend on further technological innovation, costs, and a wholesale shift in the way the British public thinks about energy.

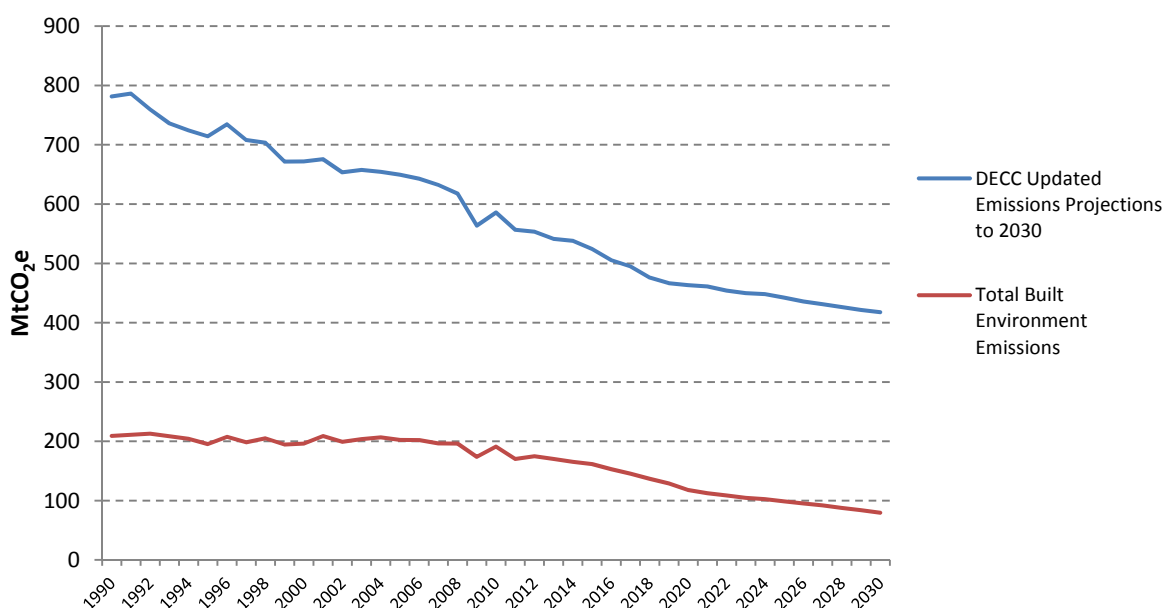


Figure 48: Total built environment carbon emissions (including capital carbon) as a portion of total UK GHG emissions for the 80% scenario.

7 Challenges and Opportunities

Summarised below are key opportunities and challenges in delivering the 80% carbon reduction target in the built environment.

7.1 Meeting the 80% carbon reduction target is challenging, but technically possible

- It is technically possible to deliver the government's target of an 80% reduction in carbon emissions in the built environment, as indicated in Figure 49; however, this would require maximum uptake of technically viable solutions in all sectors, including implementation of technologies that at present do not have a financial return on investment over their lifetime. Delivering this scenario is dependent on improving the economic viability of technical solutions and addressing market failures.

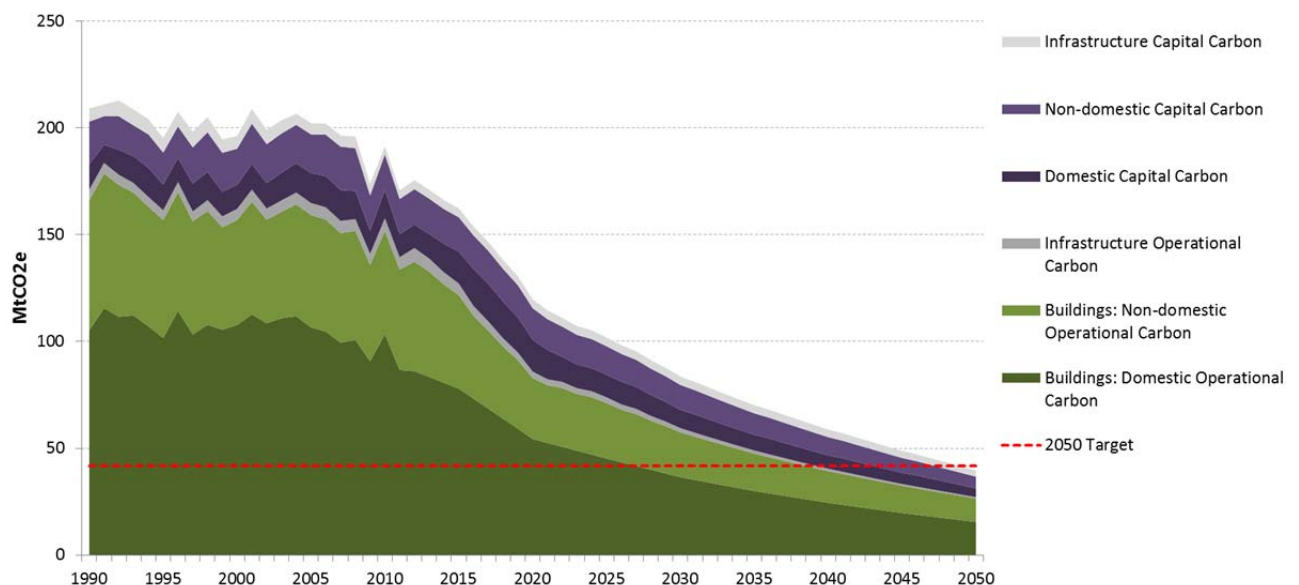


Figure 49: Built environment carbon emissions to 2050 under the 80% Scenario

- Even under the Central scenario, market failures would still need to be addressed as there is not a strong enough business case or incentive for the private sector to implement even those measures which could have a return on investment over their lifetime.
- Taking responsibility for carbon reduction at an industry level is essential to driving uptake and delivering results as quickly as possible. There are many sectors where no industry body “owns” the carbon and no plans have been developed to manage carbon reduction.
- There are strong opportunities to drive carbon reduction and promote ownership of carbon in specific buildings sectors

7.1.1 Domestic sector

- The most significant source of carbon emissions in the built environment is domestic direct emissions from space heating (e.g. oil and gas boilers), followed by non-domestic space heating (Figure 50). This is an area where improvements can be made through insulation, draught proofing and building control systems, but ultimately a change in fuel source is required to achieve an 80% emissions reduction.. The 80% scenario, indeed, assumes near full implementation of DECC's heat strategy, enabling substantial improvements to be made in carbon reduction.

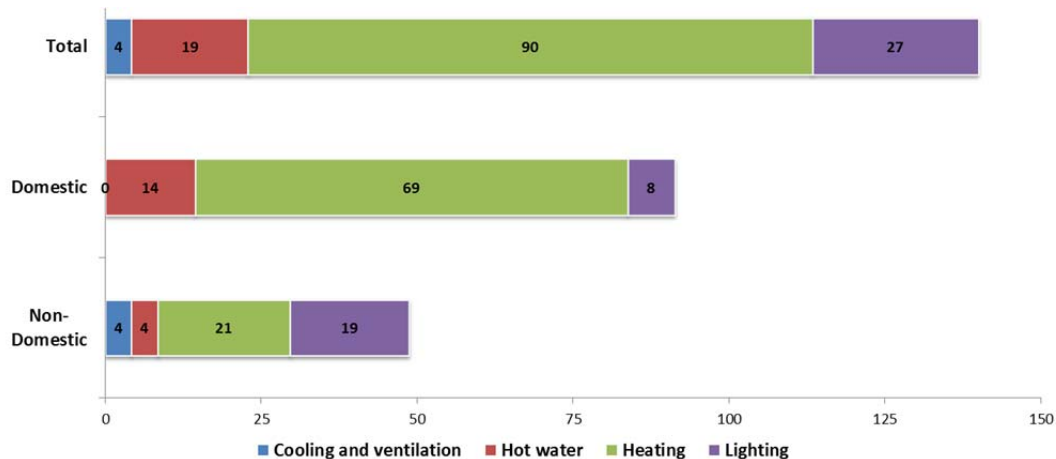


Figure 50: GHG emissions from regulated energy use in buildings (MtCO₂e)

- In the 80% reduction scenario, it is assumed that about 95% of easy to treat homes and 70% of hard to treat homes will be retrofitted with insulation, draught proofing and superglazing by 2050. This would require a substantial increase in the pace of retrofit, particularly in hard to treat domestic buildings. For example, as shown in Figure 51, with respect to cavity wall insulation, there remain about 1 million easy to treat homes, while 3.1m hard to treat properties still require measures (nearly 100% of the original hard to treat total). With respect to solid wall insulation, the potential is 7.7 million homes; to date, however, only 153,000 homes have been insulated. (Source: footnote 32)

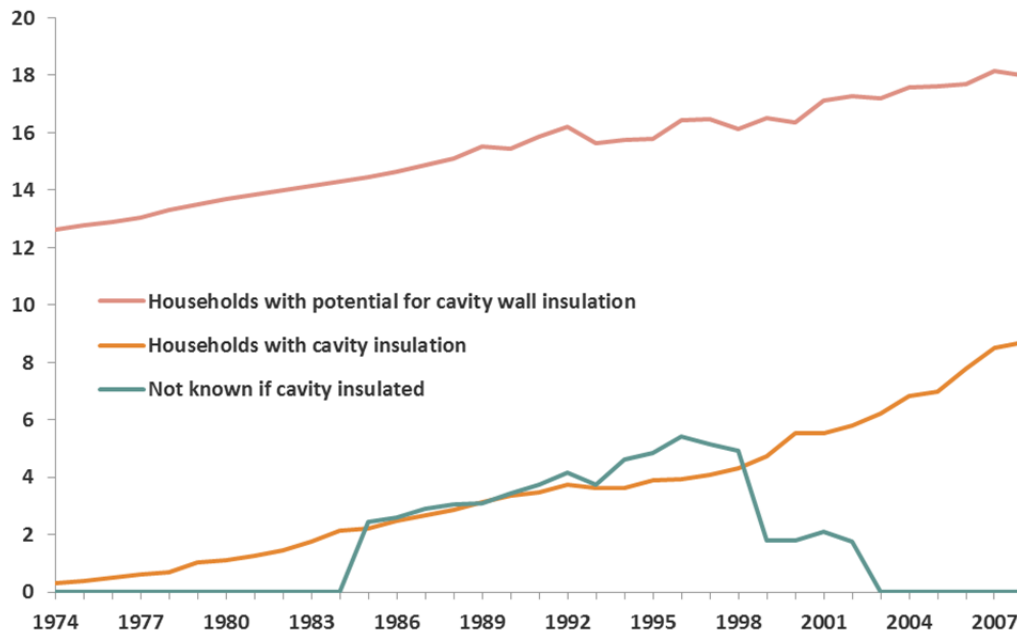


Figure 51: Cavity wall insulation (millions of homes). Source: DECC (2012) Great Britain's Housing Energy Fact File

- A programme of domestic retrofit can be staged to focus on easy to treat buildings first (see Figure 52). However, to achieve the high level of uptake needed to deliver the 80% reduction scenario, market mechanisms and regulation will need to be strengthened.

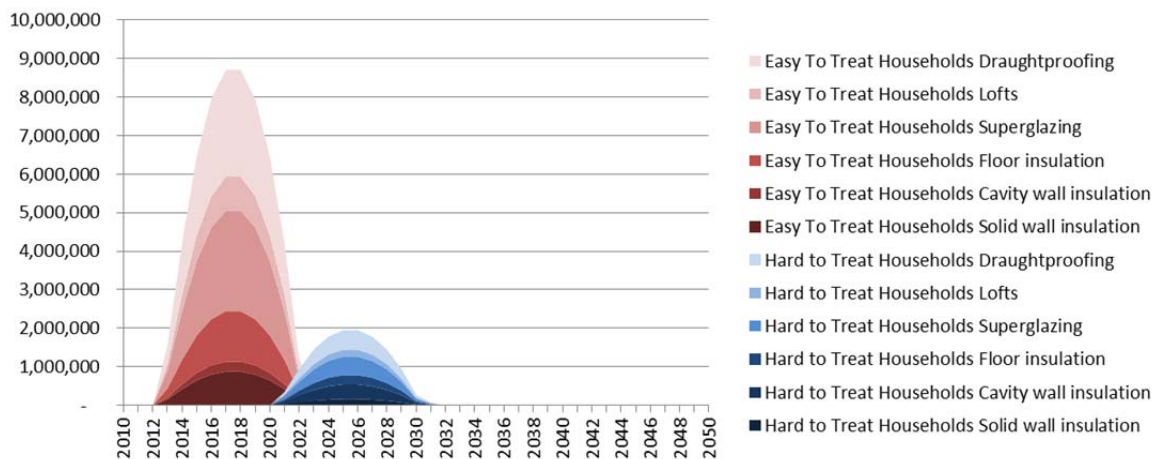


Figure 52: Annual Retrofit Measures Delivered in Domestic Sector (stacked)

- As indicated in Figure 53, ordering the nine defined⁵¹ non-domestic building types by most to least carbon emitted shows that the top three emit 50% of the non-domestic carbon and the top five emit 71%. The top five in order of largest to smallest emissions are retail, education, warehouses, hotels and catering and commercial offices. There is a need to encourage the industry representing each building sector to take ownership and drive carbon reduction. Already this is happening in higher education, where universities

⁵¹ i.e. the exact behavioural characteristics of the “other” category are not readily defined

are required to develop carbon management plans as a condition of gaining public funding.

7.1.2 Non-domestic sector

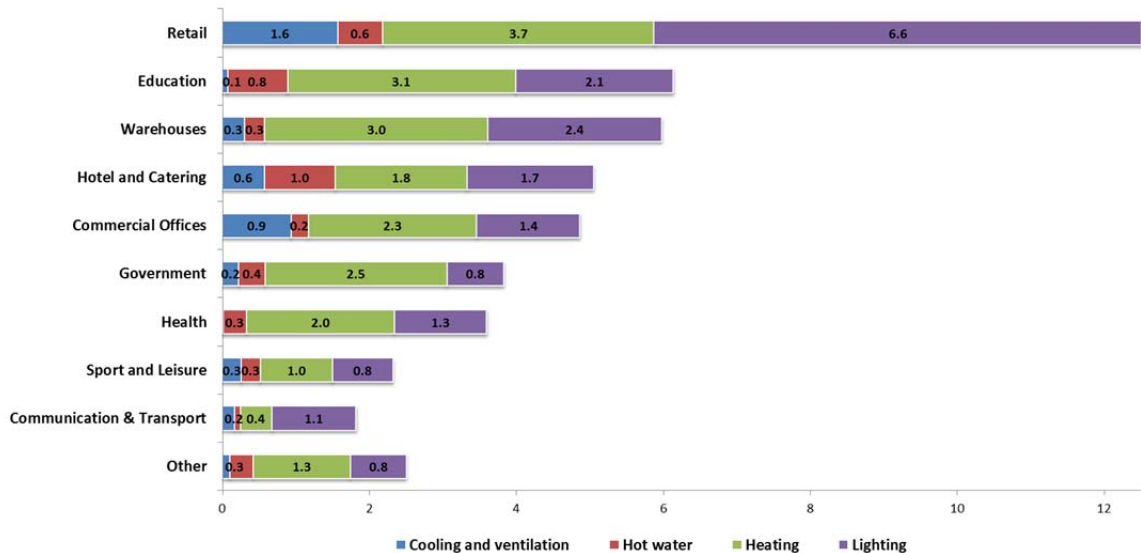


Figure 53: Non-Domestic Regulated Carbon Emissions (MtCO₂e)

- Lighting represents a significant source of emissions: it represents about 25% of energy use in 2010 and nearly 40% of carbon emissions within the non-domestic sector (Figure 53). In the retail sector, lighting is responsible for 53% of carbon emissions. There are significant opportunities to reduce emissions from lighting, particularly as much of the required technology already exists (e.g. LED lamps) and there can be good financial returns, but other barriers and misconceptions (e.g. about colour rendering) need to be overcome.
- Projections for emissions in the non-domestic sector are driven by the asset replacement cycle. This approach assumes technologies are replaced with higher performing, energy efficient alternatives in line with normal asset replacement cycles (eg, replacement of heating systems), thereby representing a smaller added cost. Future policy measures could be aligned with the asset replacement cycle. Potential measures suggested by stakeholders during our research included establishing minimum energy performance standards for technologies on the market; banning inefficient, outdated technology at the point of replacement; or providing incentives for choosing the highest performing technologies.
- The government has significant potential to drive carbon reduction in assets it owns, operates, builds and finances, in particular education, civil service and health buildings, which currently account for approximately 28% of operational emissions. Knowledge accumulated through large scale government retrofit programmes could help build capacity in the supply chain, as well as help create economies of scale for retrofit technologies and systems.

7.2 There are key issues that need to be monitored and addressed across the buildings sector to enable carbon reduction to be realised

- Reducing emissions from buildings is highly dependent on the pace of decarbonisation of the grid. Key decisions about what low carbon technologies will be needed in the future and the timing of when they need to be introduced need to be made in consideration of the pathway towards decarbonisation. The impact of no grid decarbonisation on the Scenario 3 (80% reduction scenario)⁵².

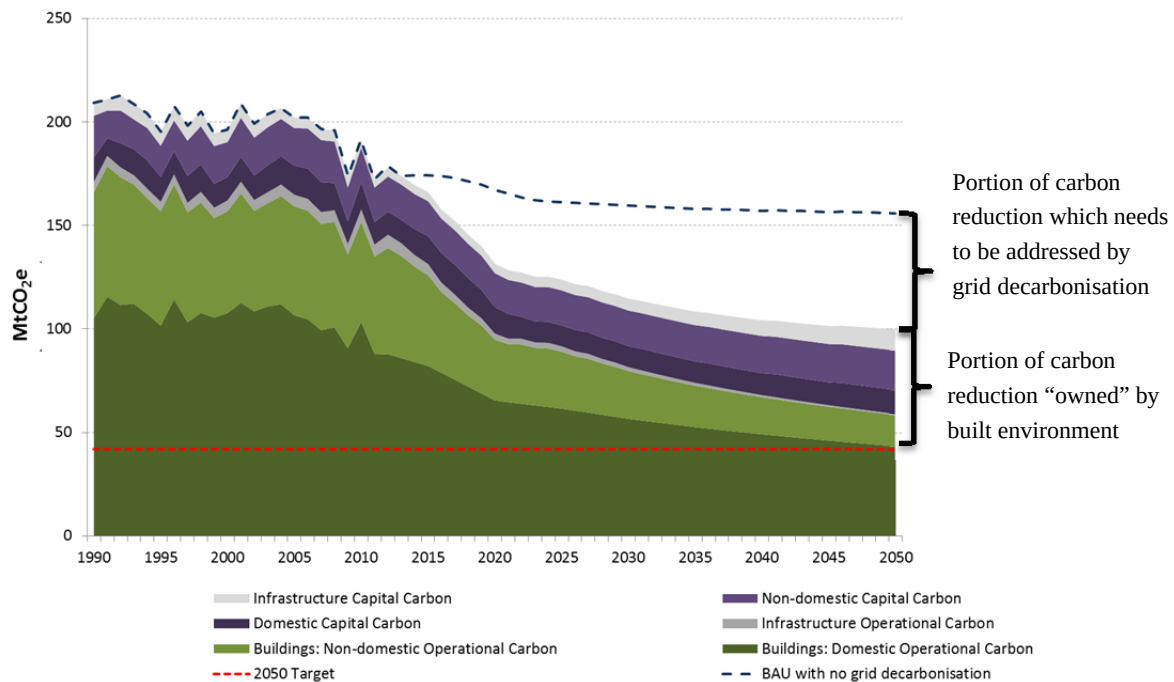


Figure 54: Impact of no grid decarbonisation on Scenario 3 (80% reduction)

- The built environment also has a role to play in enabling decarbonisation – if energy load to the grid and power demand can be reduced, the proportion which must be met through renewable sources becomes more manageable. For example, in the 80% reduction scenario, energy use in the domestic sector is reduced by around 35% between 2010 and 2030 versus the Business as Usual Scenario. Greater analysis is needed of this interplay and how energy demand reduction can play a role in supporting grid decarbonisation.
- Shifting to low carbon heat sources is essential to achieving an 80% carbon reduction. Even if the electricity grid is decarbonised, there remains the fundamental challenge that heat and hot water in the UK are supplied by fossil fuels. This is the primary reason why the BAU scenario only achieves a 52% reduction in carbon emissions, even under full grid decarbonisation.

⁵² It should be noted, the 80% scenario involves a technology shift that takes into account grid decarbonisation; if the grid does not decarbonise, the scenario would have to be structured differently.

- The performance gap (the gap in building performance between design and actual use) is a major issue that needs to be addressed, both for new build and retrofit. The model conservatively predicts the gap is around 30-35% at present, but there is no solid data on what the gap is between actual vs designed performance. This gap in effect means the benefit of all energy conservation measures will be reduced by this amount until the gap can be closed. Addressing this gap can reduce emission “leakage”, reduce the carbon rebound effect, improve the returns from retrofit initiatives, reduce risk and give greater confidence to investors/owners. Faster reduction would also enable cumulative emissions of the built environment to be reduced.
- Included in the performance gap are behavioural dimensions that can have a significant positive – and negative – impact on carbon emissions. For example, mean indoor temperatures have been rising steadily since the 1970s (See Figure 55); if this trend continues, it will be even more difficult to deliver the 80% carbon reduction. The Business as Usual Scenario assumes a continued increase in mean temperature from 17.5 to 19°C, while the 80% scenario assumes reversal of this trend and reduction in mean building temperature from 18 to 17.5°C. The national promotion and roll out of smart meters could help to create more awareness and reinforce energy conservation in the domestic sector.

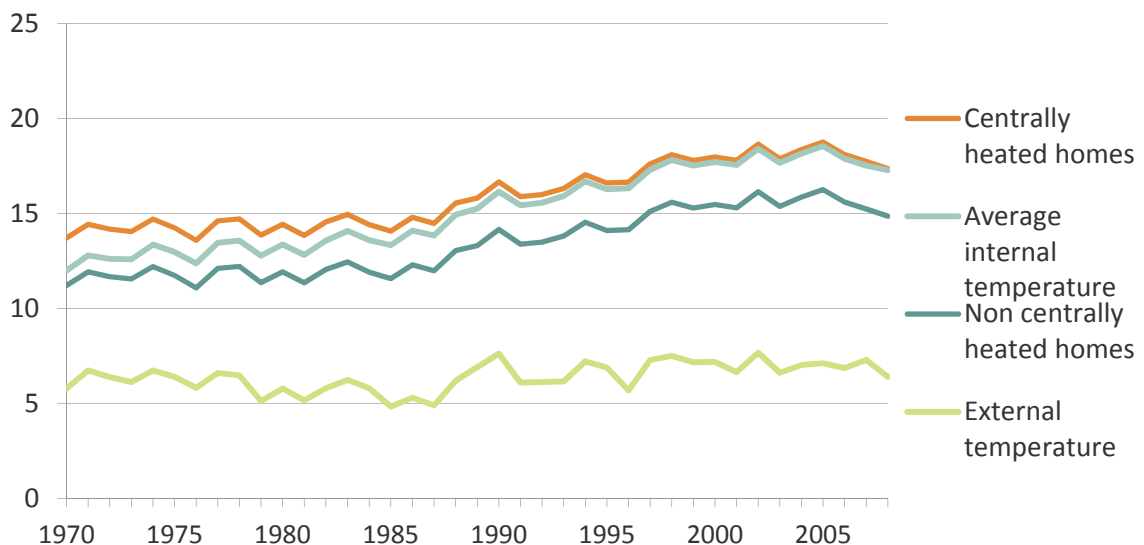


Figure 55: Average winter internal and external temperatures (°C). Source: DECC (2012) Great Britain's Housing Energy Fact File

- Overall the analysis undertaken to develop the Routemap shows that despite numerous studies and research, there is still insufficient bottom-up data on building energy use broken down by different building types. Understanding building performance at a detailed level is essential to promoting greater understanding of the scale of the challenge and developing low carbon solutions across the sector. Developing such an information database and providing open access to it could enable government, research institutes, industry associations and others to evaluate opportunities and track progress.

7.3 Capital carbon must start to be addressed in tandem with operational carbon

- The model projects that in 2050, capital carbon will represent nearly 40% of the built environment's emissions versus 18% in 2010.
- There is a relationship between capital carbon and achievement of operational carbon reduction. The projected growth in infrastructure spending has a significant impact on capital carbon and offsets many of the gains made in reducing capital carbon intensity; nonetheless, investment in infrastructure (such as rail electrification) is expected to help to reduce the UK's overall carbon footprint. This link between capital carbon and emissions from use of infrastructure is significant, but has not been directly evaluated as it lies outside the scope of this project.

Growth in demand for new building stock and investment in refurbishment together with infrastructure development have a significant impact on capital carbon. Figure 56 shows capital carbon in the 80% scenario, while Figure 57 shows the impact of rapid retrofit (if all other factors remain equal to 80% scenario, but domestic refurbishment is carried out over 10 years rather than 30, and there is more rapid asset replacement and retrofit across the non-domestic sector). As shown in the figures, significant growth in retrofit at early stages has the potential to cause large increases in capital carbon, unless measures to reduce capital carbon intensity have been implemented.

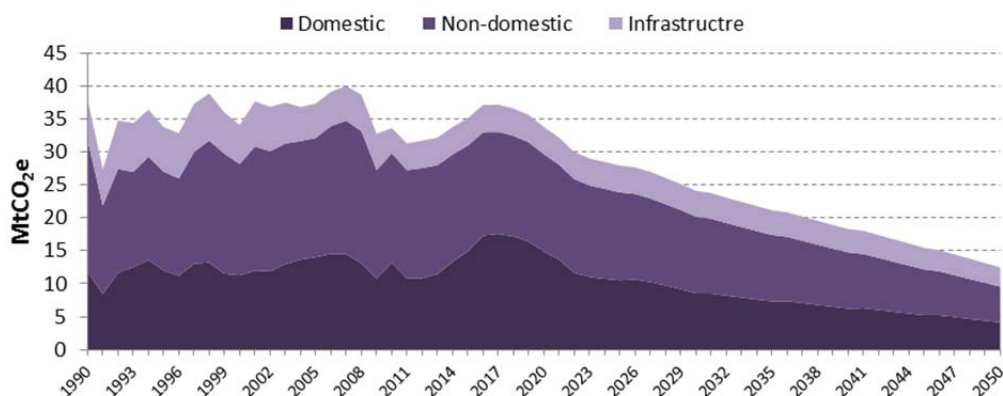


Figure 56: Capital carbon emissions (MtCO₂e) in the 80% Scenario

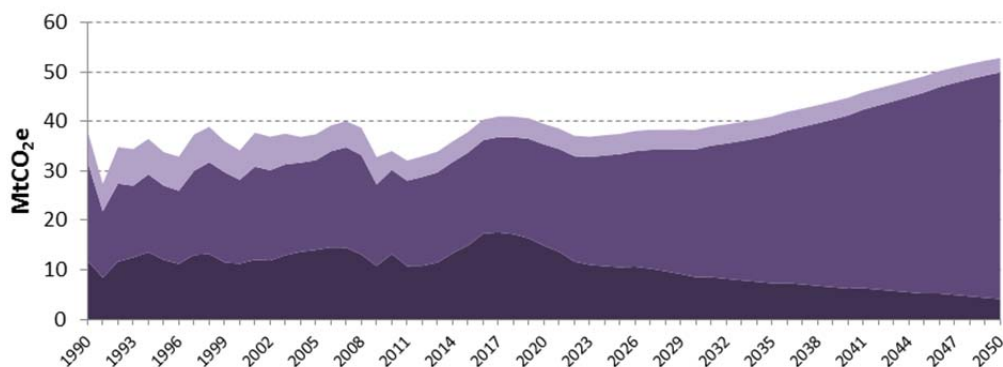


Figure 57: Capital carbon under rapid retrofit

- Improvement will be needed in the efficiency of process systems for materials manufacture. Step change manufacture technology will be required to deliver the necessary gains.
- The findings show that to meet 80% reduction targets there will be a reliance on biofuels (for transportation) and carbon capture and storage for energy carbon intensive industries (i.e. steel and cement). The questions of if and when these technologies can be deployed require resolution.
- Technology change need not be the only solution and there is opportunity in fundamental change in supply side business models (materials/steel and systems/façade).
- The material life-cycle loop must be closed with the establishment of end-of-life solutions. This could be through providing buildings and infrastructure with features such as appropriate services life, adaptability and carbon efficient recycling. The opportunities for reuse are many for example with high-rise structural materials and foundations. New systems which generate change, for example end-of-life obligations for asset creators may also be required to effect change.
- Innovation in materials technology can offer solutions in a number of ways including improved efficiency through the delivery of the same utility, with reduced carbon, or in areas such as carbon sequestration.
- Solutions exist with buying local/national, and/or being selective about where materials are sourced from. As the carbon agenda matures the issue of carbon leakage may be relevant. The capital carbon model as it standards is boundary free and therefore includes all carbon regardless of where it arises. However, formal national carbon accounting does not measure in this way, which might lead to constraints on national industry. The opportunity is that as the world shifts to recognise full Scope III emissions measurement UK industry could be advantaged if it can offer low carbon material solutions.
- There may be a role for meaningful penalty/incentive schemes to limit GHG emissions during manufacture, which is recognised regardless of where products are supplied from.
- Standards for carbon measurement and reporting at all scales (product, asset, organisation, region, etc) are required. These will become the backbone for measurement, benchmarking, target setting and improvement.
- Carbon performance data on materials is required through Environmental Product Declarations, together with carbon databases, building and infrastructure assessment tools, and design guidance to deliver low carbon solutions. A campaign for the development of these together with training to cultivate the necessary skills and knowledge in the industries professional base.

7.4 The drive to 80% carbon reduction represents an economic opportunity

- Delivering the 80% carbon reduction will generate significant business opportunities, in particular for SMEs involved in domestic retrofit. By 2030 in the 80% carbon reduction scenario, it is estimated annual spending on domestic retrofit alone could reach £4-4.5 billion. A study by Verco and

Cambridge Economics found that treating the UK's 9.1 million fuel poor homes alone could create 129,000 jobs per year⁵³.

- By directing funding towards research, development and demonstration in the built environment, and undertaking large scale retrofit over the next 20 years, the UK could position itself as a real leader and innovator in the low carbon economy.
- As the pace of grid decarbonisation becomes more clear, R&D and skills development efforts could focus on what low carbon technologies might be needed in the future, in particular relating to the future heat strategy for the UK.

7.5 Beyond the Routemap - Key Messages to the GCB

During the course of the development of the Routemap, stakeholders identified areas for action by Government that go above and beyond the scope of the Arup's brief for the Routemap project. However, these actions address fundamental dynamics and policies on carbon reduction and are important to record. They include:

- Stakeholders felt that government policies and regulations are needed to create and drive markets; otherwise the 80% reduction target cannot be achieved. They agreed that at a certain point, government will need to either make certain low carbon solutions mandatory and/or provide a strong economic incentive. They also noted carbon reduction policies can also have positive outcomes –they can help to build new markets, strengthen the supply chain and spur innovation.
- Stakeholders noted that energy prices are considered to be too low to induce action and do not cover the costs for negative externalities like carbon. Unless this changes, stakeholders felt that policies requiring mandatory action or providing strong financial incentives are needed to address these fundamental market failures and ensure good progress can be made on reaching the 80% carbon reduction target. Similarly, stakeholders noted the importance of defining different scenarios for future electricity prices so that industry can plan and respond appropriately.
- Stakeholders emphasised the need to attach value to energy efficiency. Some mentioned the idea of 'negawatt' accounting as a means to account for energy efficiency savings should be explored as should establishing policies that place a value on negawatts. The Government's recent consultation on electricity demand reduction should provide some clarity on this issue in the future.
- Stakeholders welcomed the idea of introducing a clear target and timetable for grid decarbonisation and noted this could facilitate long term planning and investment decision-making, and enable skills development to focus on the low carbon technologies needed in the future.
- Stakeholders felt that overall, policies to drive carbon reduction in the built environment need to be clear, consistent, stable and targeted; in addition,

⁵³ Jobs, growth and warmer homes: Evaluating the Economic Stimulus of Investing in Energy Efficiency Measures in Fuel Poor Homes, Verco and Cambridge Econometrics, 2012

progress needs to be monitored overtime to enable policies to be strengthened accordingly.

- The drive to reduce carbon is also a significant opportunity for innovation and development of a strong UK supply chain. Stakeholders highlighted the need for government, working in collaboration with research bodies and industry associations to provide targeted funding for research, development and demonstration projects as well as training, education, and knowledge sharing.

Appendix A

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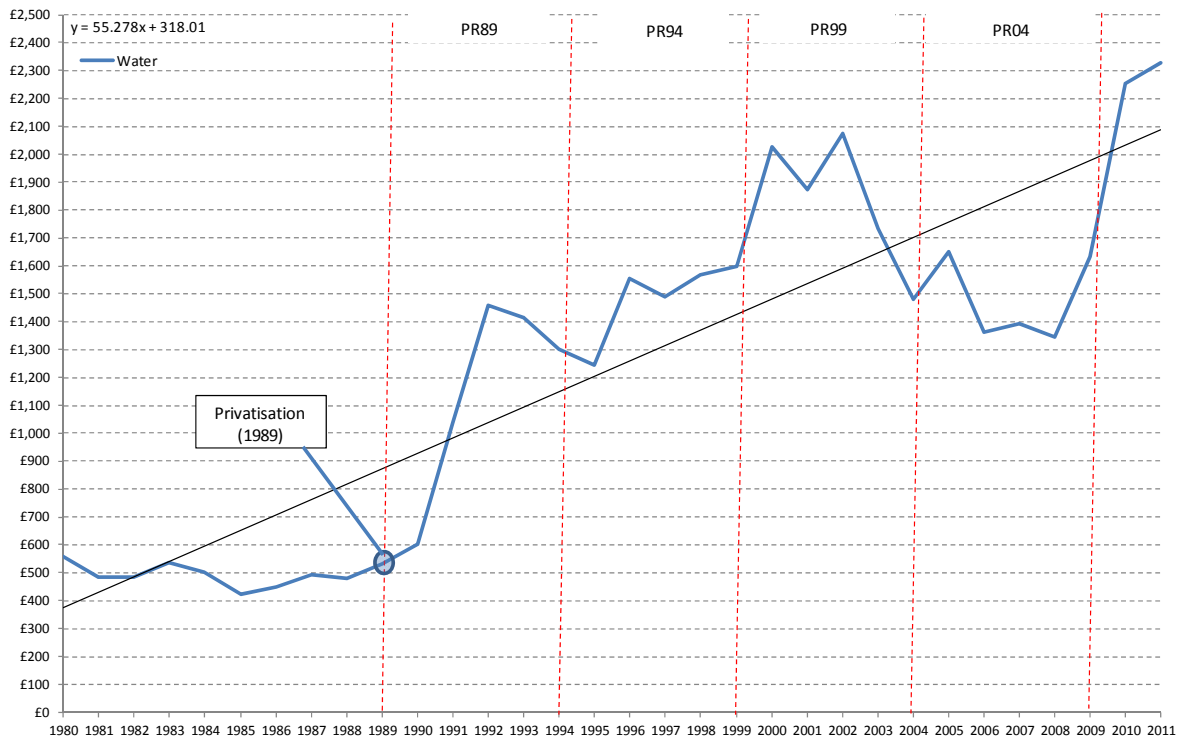
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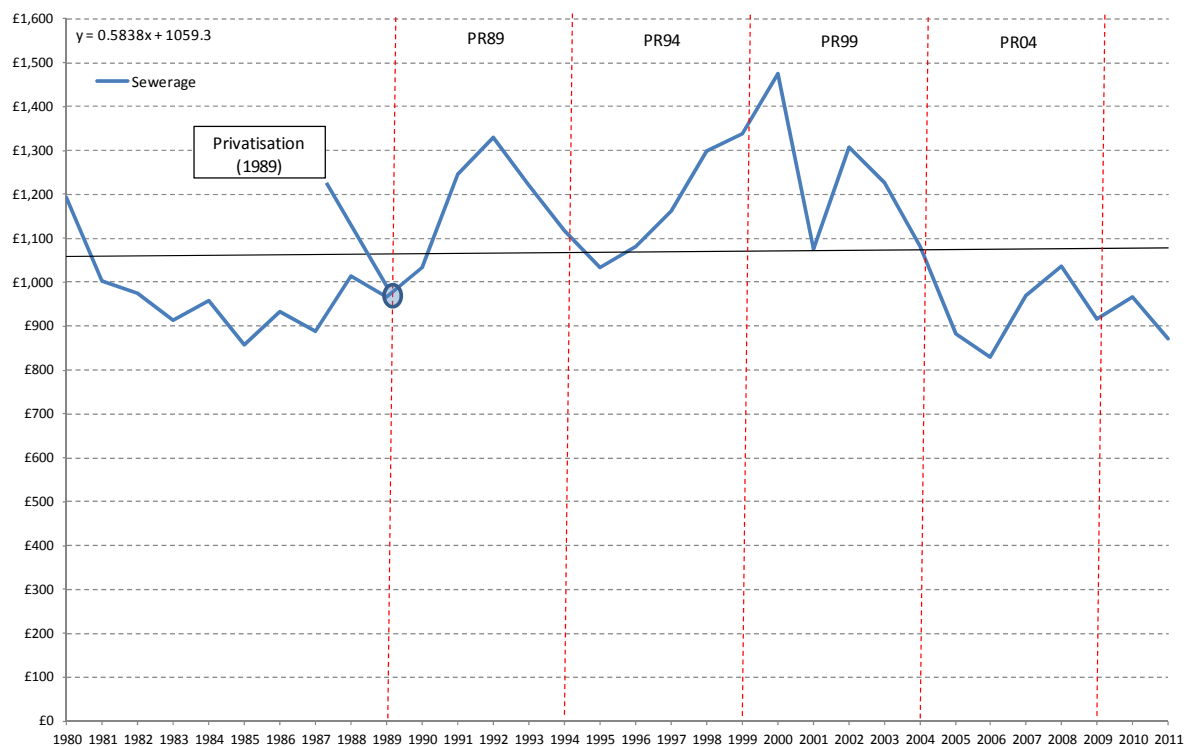
Appendix B

Infrastructure Spending Projection Graphs

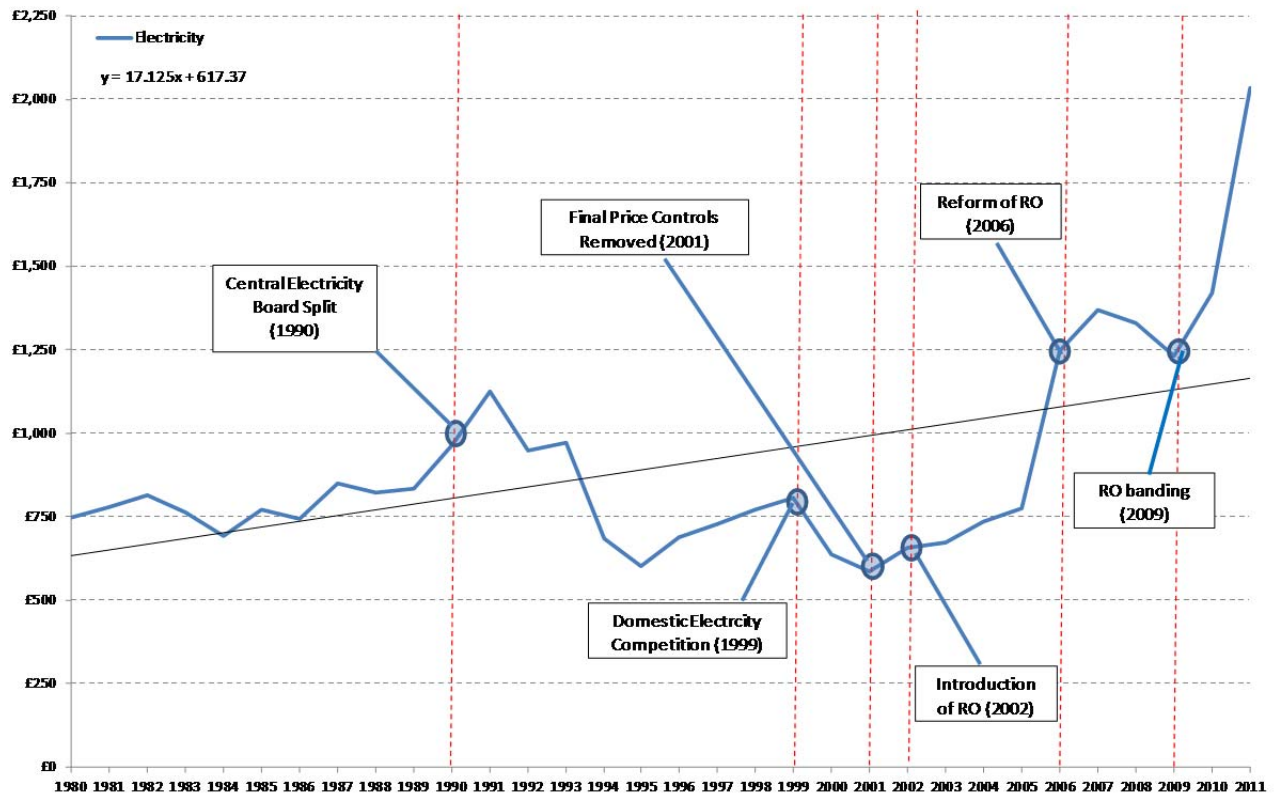
B1 Water Infrastructure



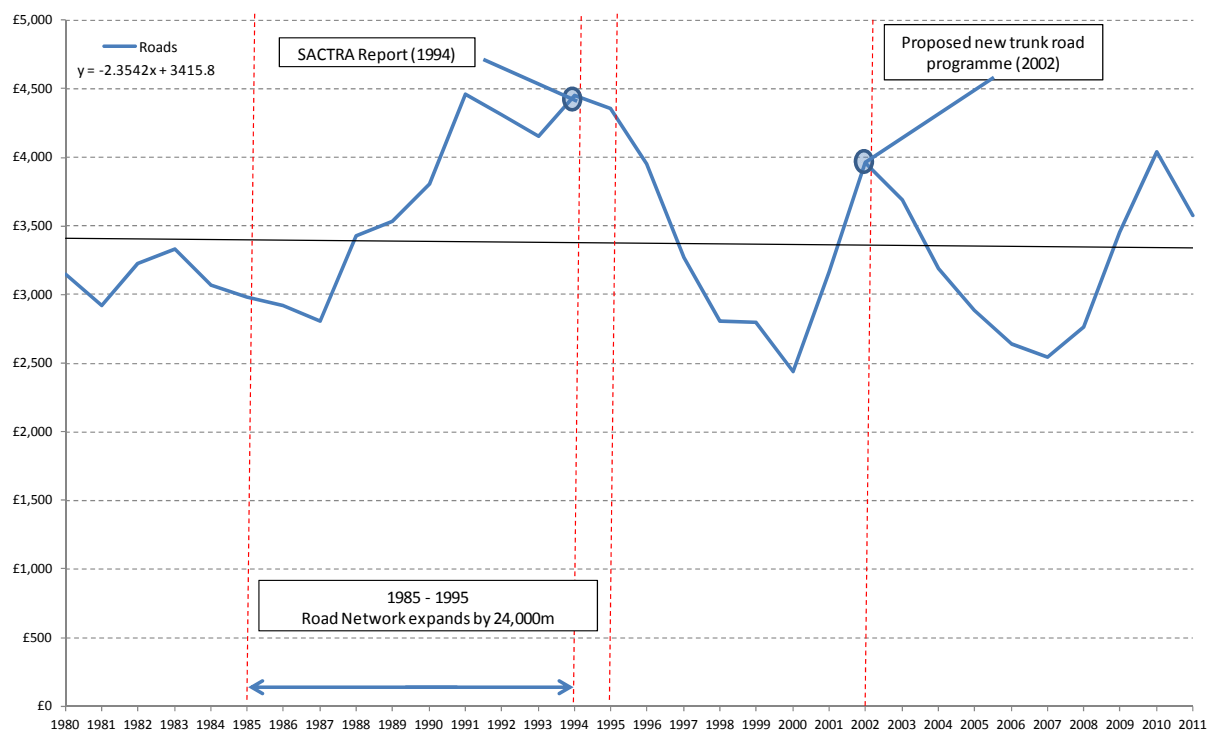
B2 Sewerage Infrastructure



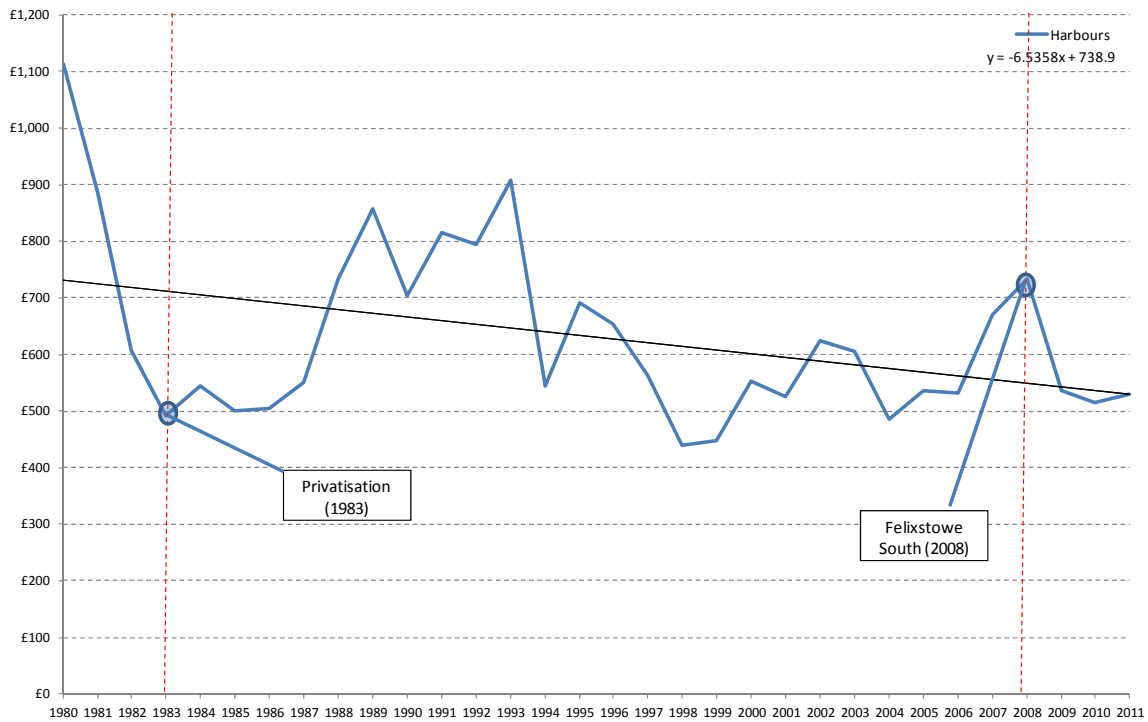
B3 Electricity Infrastructure



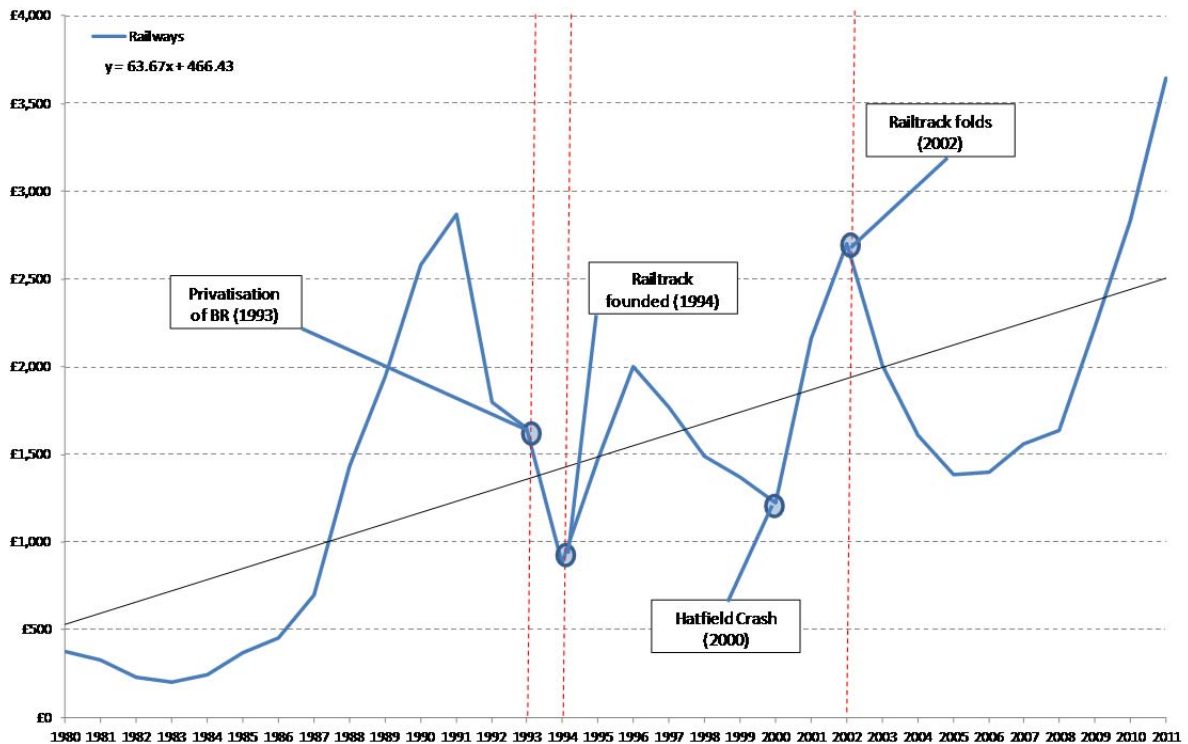
B4 Road Infrastructure



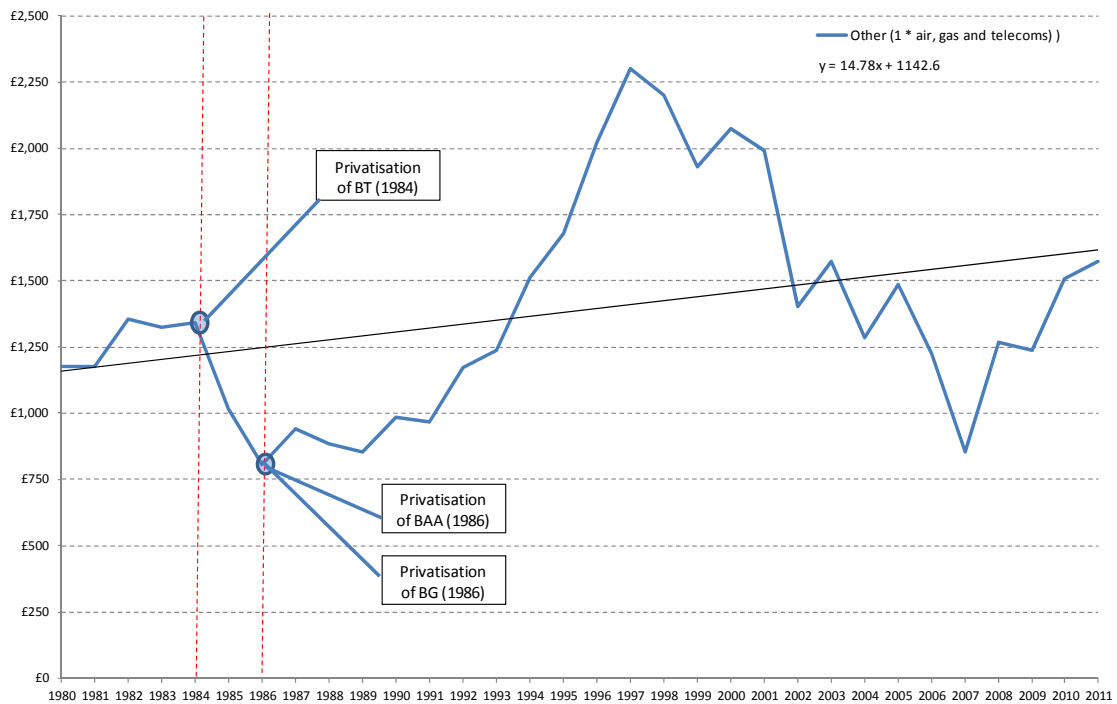
B5 Harbour Infrastructure



B6 Railway Infrastructure



B7 Other Infrastructure (Gas, Air, Communications)



Appendix C

Actions Proposed by Stakeholders to Drive Carbon Reduction

Workshops were held with stakeholders during the course of developing the Routemap. This section provides a list of actions proposed by stakeholders that could help to:

- drive demand for retrofit and development of low carbon buildings
- ensure there is capacity to deliver low carbon buildings
- encourage and enable low carbon infrastructure projects across the UK.

C1 Actions to Drive Demand for Retrofit and Low Carbon Buildings

C1.1 Actions across all building types

- Establish a mechanism to capture energy use data and benchmarks on building energy performance across the UK
- Roll out mandatory energy performance disclosure of buildings with a “default” rating if an EPC or DEC has not been established by the building owner
- Establish protocols for measurement and verification of performance of energy efficient technologies in buildings
- Establish a specialised body to collate and publicise reliable operational data on retrofit technologies and performance based on criteria specific to different types of domestic and non-domestic buildings
- Implement bans on inefficient lighting technologies
- Roll out mandatory smart metering and submetering in multi-let properties
- Support and promote large scale demonstration projects that track energy and carbon performance on a before and after basis
- Support and promote research on the performance gap between designed vs actual energy use in buildings
- Identify, promote and support the most promising technologies for building retrofit
- Focus training and skills development on most promising technologies for building retrofit
- Undertake and promote research on the link between energy/carbon performance and value targeted at different types of asset owners/occupiers
- Increase support for research and development in energy efficient building technologies
- Identify, promote and support the most promising technologies for building retrofit

C1.2 Actions across domestic buildings

- Ramp up education and promotional programme for consumers – pre and post Green Deal

- Provide access to low cost financing sources for domestic retrofit and guidance to home owners on financing sources (such as using existing mortgage providers)
- Undertake large scale Green Deal demonstration programmes to create momentum for uptake
- Develop programmes for local authorities to aggregate households interested in Green Deal to enhance purchasing power
- Introduction of stamp duty based on building EPC performance
- Encourage banks to consider energy performance in lending rates or loan to value ratios (eg, green mortgages) and provide financing for domestic retrofit
- Provide guidance to local authorities on how to create large scale domestic retrofit programmes
- Support and promote large scale demonstration projects that track energy and carbon performance on a before and after basis

C1.3 Actions across non-domestic buildings

- Require all new buildings > 500 m² to display a DEC within two years of occupation.
- Allow either a DEC or an EPC to be displayed in a building > 500 m² frequently visited by the public to satisfy Article 13.2 of the EPBD recast, and allow either to be used on its sale or let
- Develop and promote guidance material on how to implement Green Deal for commercial properties
- Index business rate multipliers based on energy use
- Encourage large tenants to establish minimum energy performance standards for their real estate
- Encourage institutional investors to establish minimum energy performance levels for investments in real estate assets
- Encourage industry to commit to adopting green leases or developing business models that better align incentives for carbon reduction across property developers, owners, occupiers and maintenance teams
- Establishment of zero carbon retail development pilot schemes as demonstration projects to enhance visibility of technology solutions
- Encourage industry to adopt a lifecycle approach to retail design and commercial arrangements that align incentives for carbon reduction across developers, owners and retail tenants
- Undertake demonstration programmes and develop guidance documents on low energy lighting and use of natural daylight in retail
- Establish standards for minimum natural day lighting levels for certain warehouse types
- Introduce compulsory measurement and reporting on warehouse energy consumption
- Introduce minimum energy performance standard for existing warehouses
- Introduce compulsory measurement and reporting on venues energy consumption
- Introduce minimum energy performance standard for existing venues

- Promote knowledge sharing and best practice case studies for successful sporting venues retrofit
- Sporting federation to introduce mandatory performance standards for participants in each sporting / leisure field
- Incentivise large hotels to invest in CHP or connect to district heating or renewable decentralised energy systems.
- Target chain operators with large portfolios to use their buying power to procure more efficient heating systems.
- Run industry education programs for asset managers on affordable low energy technology alternatives.
- Introduce regulation requiring measurement, monitoring / commissioning and benchmarking of energy consumption in hotels on a property by property basis.
- Identify taxation incentives to encourage uptake of retrofit
- Promote adoption of high green standards by large tenants and developers
- Implementation of a 'code for sustainable schools'
- Pilot retrofit of large hospital and disseminate findings
- Research how to assess opportunities to undertake retrofit in health sector and potential to modify existing codes to facilitate retrofit
- Provide more clarity on the future impact of Part L 2013 for the sector
- Establish a target for retrofit of all central government stock and encourage local authorities to do the same
- Undertake retrofit of a large, prominent government building (eg, House of Parliament)
- Introduction of a national compulsory programme of sub metering introduction
- Assess potential for public sector buildings to become anchor-loads for community heat networks
- Government commitment to large scale deployment of promising technologies to encourage investment by the supply chain.
- Provide guidance on facilitate the introduction of revolving funds to invest in retrofit within government estate
- Promote large scale pooling of projects for energy performance contracts that target deep energy efficiency retrofit

C2 Actions to Ensure Capacity to Deliver

C2.1 Procurement, business models to enable innovative retrofit

Short term

- Integrate retrofit measures as part of asset management plans
- Incentivise manufacturers to reduce CO² intensity of concrete, steel, plaster and timber
- Provide SME's with the ability to do guarantee backed retrofit
- Promote usage of local SME's
- Business model for renting plant based on plant performance

- Develop warranties and professional indemnity solutions which enable innovative solutions to enter the market quicker
- Develop a standard form for energy performance contracting with an arbitration process for when things don't perform
- Measure productivity, health and well-being impacts of buildings and not just cost analysis

C2.2 Industry training, skills and knowledge

Short term

- Promote knowledge sharing and best practice case studies, and ensure industry wide familiarity with research results
- Training/skills on selling retrofits to building owners before they're compelled to do it
- Training in deep refurbishment methods (Solid wall insulation, air tightness and systems thinking)
- Establish accredited and regulated Green Deal assessors
- Focus training and skills development on most promising technologies for building retrofit
- Existing Homes Hub to develop standardised solutions for retrofit
- Definition of standard design details available to whole industry
- Process efficiency in delivery
- Demand side management – industry needs to speak with a single voice
- Creation of multi-disciplinary groups with representatives from professional institutions, government and universities, to break industry's silos

Medium term

- Upskill industry on capabilities of BIM/ICT to deliver low energy/resource efficient construction
- Cross skilling of labour to deliver holistic solutions
- Industry-wide best practice sharing for asset management as well as supply chain management
- Soft landing initiative principles as a manual for end users to optimise performance of buildings
- Demand feedback from completed projects for sharing with industry
- Bring long term planning into the current short term/compliance driven industry

C2.3 Metrics and governance

Short term

- Incentives for energy efficiency rather than just generation
- Legal requirement for thermal surveys
- Better onsite quality assurance (as large number of new build properties don't meet building regulations in practice)
- Test building performance at handover (requires development of effective measurement protocols)

- Protocols for measurement and verification of energy performance in buildings
- Develop clear shared metrics for building performance
- Establish a specialised body to gather and publicise reliable operational data of technologies
- Establish standards for minimum day lighting levels
- Mechanism to capture data and benchmarks on building energy performance across the industry
- Legislate to require best available technology, e.g. all windows being triple glazed to Scandinavian standards
- Revisions to building regulations regarding gas fired boilers
- Minimum energy performance standards to consider operational energy rather than just EPC rating
- Specification of base load onsite micro-generation as a retrofit standard and link to green deal cash

Medium term

- Legal requirement for POE (covering energy gap)
- Implementation of methods of monitoring construction waste
- Refine DEC method with legal requirement for all non-domestic building stock
- Understand and plan for low carbon urbanism
- Legislate for minimum building occupancy
- Regulate for Passivhaus + Standards
- Revision of EU directives on competition regarding material procurement

Long term

- Personal carbon quotas to drive demand

C2.4 Reaching out to stakeholders

Short term

- Bring lenders, mortgage providers, estate agents and insurers into the solution
- Provision of training to local authorities and housing associations across all levels
- Guidance to portfolio owners: funding models for retrofit through energy performance contractors
- Encourage deployment of CHP schemes where feasible

Medium term

- Industry education programs for asset managers on affordable low energy technology
- Energy education throughout schools
- Understand what is exciting to a consumer about a 2050 retrofit and how solutions should be developed accordingly

C2.5 Challenges for the design community

Short term

- Understand the gap between design and actual performance
- Change to an evidence based approach to design
- Measure productivity and health and well-being of buildings, not just cost analysis
- Visible, intuitive, useful household controls to reduce energy consumption of regulated and unregulated loads.
- Produce generic details for retrofit insulation for solid walls
- Deployment of local controls on heating
- Promote low energy lighting replacement of tungsten lighting systems

Medium term

- Adopt wide scale use of heat storage technologies
- Deployment of fuel cell technology in domestic sector
- Deployment of advanced insulation systems
- Designers should demand good information on performance
- Design to avoid overheating of highly insulated buildings
- Adoption of commissioning plans based on unforeseen consequences (eg poor IAQ, clogged filters etc)
- Integrate methane generation from farm waste and sewerage plants to be used as energy source
- Centralised asset management tool for campuses/ portfolios
- Back cast from a 2050 building into a series of retrofits that get the 2010 building to the 2050 building

C2.6 Research and product development

Short term

- Research on the performance gap between designed and actual energy use in buildings
- Large scale demonstration projects: energy and carbon performance
- Research into impact of occupant behaviour on building performance
- Re-initiate research into breathable traditional buildings, and collect reliable data
- Develop heat pumps with higher coefficient of performance
- Develop a clear understanding of new technologies and their application
- Establish relationship between embodied carbon and thermal mass with that of operational energy

Medium term

- Achieve building based energy storage
- Street scale energy generation, storage and load sharing
- Develop heat exchange technology to heat water using comfort cooling waste assuming 23% increase in average temperature
- Alternative asphalt materials with lower carbon intensity

Long term

- Achieve building based carbon capture and storage

C3 Actions for Low Carbon Infrastructure

C3.1 Measurement

- Ensuring replacement schemes are correctly designed with optimum spacing (light & controls)
- Lifetime costing
- GHG emissions from waste streaming
- Accounting for embodied carbon in vehicles themselves
- Benchmarking capital carbon: carbon measurement standards

C3.2 Targets & Standards

- Modification of standards for materials (with lighter materials being incentivised)
- Implementation of mandatory CEEQUAL type scheme
- Measure and reporting mechanisms for carbon footprint of products using TC350 standards methodology
- Onsite measurement, monitoring and targeting (difficulty with targeting is dependent on work mix however)
- Introduce incentive measures that sit outside the Ofwat regulations that encourage reduced energy use by water authorities
- Encourage national construction waste benchmarking following on from BRE initiative
- Introduce requirements for planning of new systems to be designed for use, not current standards
- Mandate minimum recycled content in specific construction products

C3.3 Regulation

- Regulators to encourage innovation by clarity of objectives
- Establishment of mandatory measurement, reporting and targets for capital carbon across sectors
- Legislation to mandate fuel efficient plants
- Incentivisation of further deployment of fuel efficient and renewable fuel use in the construction sector
- Land bank renewable energy potential: with added guidance from regulator as issue is not a technological one
- Address carbon in MP investment cycles (impact recognised as negative at 5 year cycles)
- Capital loans and grants to fund new technologies in waste sector

- Legislation to align storm water retention and management with storm planning and prediction (enabling reduced pumping loads during flood)
- Simplification of the resource efficiency support to CD&E sector
- regulators to have a partial responsibility for lifetime capcarb and opcarb
- Ban on use of construction products which cannot be reused/recycled
- Mandate whole life carbon selection/appraisal for new waste infrastructure planning/design and delivery
- Establishment of mandatory measurement of energy consumption and carbon footprint
- Carbon Capture and Storage deployment
- Implementation of Low carbon efficiency scheme for products and materials similar to white goods for energy with ratings
- Mandate waste hierarchy for resources & materials

C3.4 Procurement

- Operators: to set carbon targets at schemes level to influence designers in design phase
- Off-site construction driven by client and designer
- enabling of contractor to suggest alternative methods & materials use in contractual arrangement
- Incorporate lower energy consumption technologies (pumping & aeration) in asset management upgrade plans (with focus on old)
- Procure for low carbon (with focus on whole life assessment)
- Movement minimisation (incentivisation of procurement of labour and materials made from nearby suppliers)
- Client led waste specification (zero landfill specification)
- Integration of carbon performance in government client procurement for waste contracts
- Implementation and harmonisation of performance based materials specification (single specification across local authorities for similar materials)

C3.5 Design

- 'Designing out waste' campaign: awareness campaign for designers of Capital vs Whole life carbon
- Official recognition of key role of design to deliver low carbon infrastructure
- Designers to establish baselines and benchmarks to measure embodied and operational carbon
- Design and specify to enable procurement of low carbon products
- Enhanced use of daylight to trim energy use associated to baseload lighting
- Lifetime optimisation (design for intended life) with inclusion of lifetime costings
- Flexible design (informing the design process)
- Deploy materials inventory in infrastructure
- Deployment of low carbon materials (zero carbon cements and concretes) with mandatory minimum use on each project

- Use of a systems based approach to allow multi-infrastructure use of same corridors (eg rail, water, ICT)
- Modal Shift of materials (planning by clients & contractors)

C3.6 Materials/ supply chain

- Materials transportation in T&C for lower carbon intensity
- Quantification of emissions associated with chemicals used in water treatment, with mandatory data publication
- Deployment of closing loop technologies (biogas digesters)
- Deployment of leakage reducing technologies
- Mining of materials from disposal sites (process reversing)
- Deploy a scheme of materials renting to push back end of life

C3.7 Site activities

- Increase precision of future waste estimates associated with construction process
- Off-site buildings
- Energy efficient site accommodation measures to be client driven (with enhanced use of existing permanent accommodations)
- Onsite measurement, monitoring and targeting (difficulty with targeting is dependent on work mix however)
- Innovate in electrification of CD&E machinery
- Early connection of site to the grid
- Logistics consolidation
- Fuel efficient vehicles
- Reduction of waste transportation
- National Ebay for reuse of materials (end of life of construction) to avoid waste treatment and disposal

C3.8 Operations

- Improved measure & understanding of N₂O & CH₄ in water and wastewater treatment
- Transport Policy: organisational travel plans indexed on carbon use, not cost
- Mandatory equipping of operational property with heating controls and insulation
- Use of demand management to reduce size of infrastructure new build requirements
- Incentivise change in behavioural patterns of plant operatives
- Encourage and incentivise modal shift in people within behavioural economics approach
- Planning for segregation of water types in future infrastructure upgrades
- Enhanced use of smart ICT & technologies (intelligent charging, use of batteries, review of shut down times)
- Decentralised generation of energy (small scale pv and wind)

C3.9 Knowledge & Skills

- Raise awareness and promote efficient driving
- Foster low carbon skills
- Designer education in carbon awareness

C3.10 Lighting & Controls

- Introduction of in situ renewable powered lighting & controls
- Introduction of central management systems to allow remote monitoring and analysis of lighting & controls performance
- Dimming of current average lighting levels
- Roll out of AMRs for all lighting systems across the UK
- LED light/ signals replacement
- Ensure replacement schedules include reduced poles and luminaries based on latest lighting technologies
- Removal of dot matrix