Net Zero Whole Life Carbon Roadmap

Technical Report

November 2021

UK GBC
WORLD GREEN BUILDING COUNCIL
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Laudes Foundation
IKEA Foundation

Contents

The Net Zero Whole Life Carbon Roadmap project aims to build a common vision and agreed actions for achieving net zero carbon in the construction, operation, and demolition of buildings and infrastructure in the UK. The main elements include a carbon footprint for the UK built environment and a Net Zero Carbon trajectory to 2050, as well as policy recommendations and industry action plans to deliver the 2050 scenario. These outputs are published in an initial series of four reports:

A Pathway for the UK Built Environment – aimed at stakeholders from across the built environment value chain who want an overview of the Roadmap findings and its implications for the sector. The report provides context for why the Roadmap exercise is critical to delivering the UK net zero goal, while also detailing the necessary technological shifts, policies and industry actions that can help deliver decarbonisation.

Technical Report – provides detail on the project structure, the process for data collection, the key features of the calculation methodology and concludes with a description of the net zero scenario definition and results

Summary for Policy-Makers – aimed at Central Government, Local Authorities, and anyone interested in built environment policies. The Summary provides an overview of the relevant Roadmap findings and policy recommendations for Central Government to deliver a net zero built environment by 2050.

Stakeholder Action Plans – these set out specific recommended actions for 14 key industry stakeholders so that they may play their part in achieving the Roadmap.

UKGBC is one of several European GBCs developing national Whole Life Carbon Roadmaps under the WorldGBC #BuildingLife project, funded by Laudes and the Ikea Foundation. In the runup to COP26, WorldGBC has convened ten European Green Building Councils to galvanise climate action in the built environment through national and regional decarbonisation roadmaps. The Green Building Councils spearheading the project are Croatia, Finland, France, Germany, Ireland, Italy, the Netherlands, Poland, Spain and the UK. BuildingLife is accelerating ambitions in the building sector by creating the first region-wide response to the vision of a net-zero whole-life carbon built environment as set out in WorldGBC's 2019 report.

WORLD GREEN BUILDING COUNCIL #BUILDINGLIFE Laudes Foundation IKEA Foundation

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1. Introduction

In December 2020 the UK Green Building Council (UKGBC) announced the launch of the Net Zero Whole Life Carbon Roadmap project for the UK built environment. The Net Zero Whole Life Carbon Roadmap (hereafter known as The Roadmap) aims to build a common vision and agreed actions for achieving net zero carbon in the construction, operation and demolition of buildings and infrastructure in the UK. The main elements include a carbon footprint for the UK built environment and a Net Zero Carbon trajectory to 2050, as well as policy recommendations and industry action plans to deliver the 2050 scenario.

UKGBC is one of several European GBCs developing national Roadmaps under the WorldGBC #BuildingLife project[1]. In the runup to COP26, WorldGBC has convened ten European Green Building Councils to galvanise climate action in the built environment through national and regional decarbonisation roadmaps. The Green Building Councils spearheading the project are Croatia, Finland, France, Germany, Ireland, Italy, the Netherlands, Poland, Spain and the UK. BuildingLife is accelerating ambitions in the building sector by creating the first region-wide response to the vision of a net-zero whole-life carbon built environment as set out in WorldGBC's 2019 report.

The UK already has a legal commitment to achieve net zero by 2050, with pathways and recommendations for how this could be achieved set out by the Climate Change Committee (CCC) through their UK Carbon Budget analysis and reports. The Roadmap highlights and provides focus to the emissions footprint specific to the UK built environment and presents a view of the specific actions and steps needed throughout the sector in order to reduce emissions, through the lens of whole-life carbon.

1.1. Roadmap Project Outputs

The Net Zero Whole Life Carbon Roadmap project outputs are published in an initial series of four reports:

1. **A Pathway for the UK Built Environment** – aimed at stakeholders from across the built environment value chain who want an overview of the Roadmap findings and its implications for the sector. The report provides context for why the Roadmap exercise is critical to delivering the UK net zero goal, while also detailing the necessary technological shifts, policies and industry actions that can help deliver decarbonisation.

2. **Technical Report** – provides detail on the project structure, the process for data collection, the key features of the calculation methodology and concludes with a description of the net zero scenario definition and results

3. **Summary for Policy-Makers** – aimed at Central Government, Local Authorities, and anyone interested in built environment policies. The Summary provides an overview of the relevant Roadmap findings and policy recommendations for Central Government to deliver a net zero built environment by 2050.

4. **Stakeholder Action Plans** – these set out specific recommended actions for 14 key industry stakeholders so that they may play their part in achieving the Roadmap.

1.2. About This Report

This technical report provides detail of the project structure, the process for data collection, the key features of the calculation methodology and concludes with a description of the net zero scenario definition and results.

This report includes the following sections:

- **Section 2: Project Overview:** An introduction to The Roadmap project and process
- **Section 3: Methodology:** The scope, definition and principles underpinning The Roadmap
- **Section 4: Net Zero Scenario – Definition:** An overview of the references and inputs used
- **Section 5: Net Zero Scenario – Results:** A presentation of the trajectory to 2050
- **Section 6: Net Zero Scenario – Sensitivities:** The results of a set of key sensitivities
- **Section 7: Summary:** Final conclusions

2. Project Overview

2.1. Purpose of the Roadmap

The aim of The Roadmap project is to develop a roadmap of actions and secure the support of relevant market actors in delivering the decarbonisation of the total impact (whole life cycle) of the built environment in the UK, as supported by the following objectives:

- Build consensus on a pathway to a net zero carbon built environment among businesses and industry bodies.
- Identify key interventions required and any critical interdependencies.
- Develop sectoral carbon targets.
- Set out actions, owners and processes to achieve these targets.
- Identify a range of policy recommendations to support, incentivise and where necessary regulate carbon reduction measures.
- Encourage and enable greater consistency between sector-based action plans that are published or in development.

2.2. Project Team

A key aspect of the project approach was that The Roadmap would be co-created with industry. To facilitate this engagement, UKGBC appointed Arup and Dr Jannik Giesekam (CREDS) to deliver the WLC analysis as technical partners and convened a project Steering Group, and four Task Groups, which focused on New Build, Domestic Retrofit, Non-Domestic Retrofit, and Infrastructure. All the groups comprised representatives from commercial organisations, professional institutions, and other key sector bodies. The full list of representatives is available at the back of this report.

The Task Groups developed the carbon trajectory, and policy and industry proposals, through a series of workshops, working collaboratively with project technical partners. A formal industry consultation was undertaken on the draft proposals, alongside dialogue and engagement with government, local authorities, key industry stakeholders and the Climate Change Committee (CCC).

2.3. Approach

The Roadmap modelling methodology builds on the work of the Green Construction Board's 2013 Low Carbon Routemap for the Built Environment[2]. The 2013 Routemap analysis model[3] has been updated to capture both historic emission data for the period 2013 – 2020 and incorporate key changes during this period (i.e. grid carbon factors). Details on these methodology updates are provided in Section 3.

The net zero scenario was defined by the four project Task Groups through a series of workshops. In between workshops, Task Group members undertook research, collected data for each component of the scenario and assessed the data quality and coverage. The industry-wide Steering Group provided strategic input throughout the process and acted as a reviewing body for the Task Group outputs.

The project team modelled the net zero scenario and produced interim outputs. These were published, alongside a summary of the net zero scenario inputs, for consultation in August 2021. Consultation responses were used to refine the net zero scenario, before the final net zero scenario modelling was completed in October 2021.

It should be noted that the net zero scenario development and modelling was undertaken in advance of the UK Government strategies launched on 19 October 2021 which included the Net Zero Strategy and the Heat and Buildings Strategy. The timing has not allowed any detailed comparison or analysis in relation to these strategies.

3. Methodology

3.1. A Carbon Budget for the Built Environment

Since the publication of the Green Construction Board's Low Carbon Routemap in 2013, a new context has emerged for rapidly and aggressively reducing carbon emissions in the UK. Declarations of climate emergencies by Central and Local Governments, ambitious target setting and increasing consensus around limiting warming to 1.5° frame a challenge of unprecedented scale for the built environment.

The CCC recommends emission reduction targets aligned with the UK's 2050 net zero goal, as defined by the 2015 Paris Agreement. In 2020, the CCC proposed a legally binding emission target for the period of 2033-37, known as the "Sixth Carbon Budget," which commits the UK to lowering its emissions to 78% below a 1990 baseline by 2037. As of April 2021, the UK has adopted the CCC's recommendation as a legally binding target.

Emissions attributable to the UK built environment cut across several of the CCC emissions categories, and the Sixth Carbon Budget therefore does not provide a clearly defined quantum of emissions for the built environment that align with the UK's overarching carbon budget.

One of the objectives of this project is to identify and set out an emissions budget to 2050 for the built environment, consistent with the wider UK carbon budget, with a suitable system boundary. Emissions have been broken-down by sub-sectors and emissions categories relevant to the built environment to enable specific actions to be determined for responsible stakeholders.

The benefit of identifying carbon budgets is that they provide a ceiling for allowable emissions, whilst enabling choices within that budget around how emissions are allocated between sub-categories and different carbon emitting activities. Value judgements may be made around competing priorities and preferred pathways based on economic or technical considerations.

Determining and agreeing an overarching carbon budget for the built environment will provide a top-down dataset from which to establish asset and project level targets.

3.2. Net Zero 2050 Target

The CCC 6th Carbon budget sets out a balanced pathway for carbon reduction towards Net Zero across all sectors. Some sectors, such as Buildings, are projected to decarbonise completely, whereas other sectors, such as Manufacturing and Construction (which includes embodied carbon emissions from buildings), are not projected to reach full decarbonisation, and are left with a degree of residual emissions.

Total residual emissions across all UK sectors are then proposed to be offset via both nature-based removals (i.e. land-use change, increased forestation, peatland restoration), and engineered greenhouse gas removals (i.e. Bioenergy with carbon capture and storage (BECCS), Direct Air Capture of CO_2 with storage (DACCS) across multiple sectors, and increased use of timber in construction) to permanently remove carbon from the atmosphere and achieve the UK's Net Zero target by 2050.

To align with the UK's Net Zero 2050 target, the Built Environment is therefore required to deliver the full decarbonisation of direct emissions from buildings (energy usage).

Any residual emissions related to the Built Environment must be limited to embodied carbon (manufacturing and construction), and will need to sit within the available total UK removals budget as defined by CCC, and not exceed the sector proportion of UK-wide natural and engineered carbon removals.

The UK Built Environment Net Zero target therefore takes the form of a sector emissions budget, which aligns with the UK's Net Zero 2050 strategy, and identifies lowest possible residual emissions.

3.3. Scope of UK Built Environment Emissions

Within its analysis and reporting, the CCC splits UK emissions into sectors, with associated mitigation measures and recommended actions per sector. Emissions related to the UK built environment cut across several of these CCC sectors, most obviously Buildings, but also elements of Manufacturing and Construction, Waste, Surface Transport, F-Gases and others. Furthermore, although a proportion of embodied carbon emissions from construction are captured within UK Manufacturing and Construction, a significant proportion (30-40%) relate to extraterritorial emissions, i.e. construction materials and products produced overseas and imported to the UK. Therefore, to accurately determine a carbon footprint for the UK built environment and identify relevant actions, an appropriate system boundary and sub-sector categories are required.

The built environment encompasses all elements of man-made infrastructure and buildings. If the construction, operation and use of all these elements are included within the system boundary, such as the supply and distribution of fuel and power, and all vehicle usage on our transport networks, the resultant quantum of emissions is nearly 70% of the UK emissions total based on 2018 data.

A significant proportion of this is from the transport (vehicle usage), and energy (supply) sectors, and decarbonising these sectors is clearly critical in the context of the UK's Net Zero 2050 commitment. They are also integral parts of the wider built environment, and ultimately a systems viewpoint is required to evaluate the wider interconnected carbon impacts and reduction opportunities. However, to provide adequate focus to the industry within the constraints of this project, the system boundary includes all embodied and operational carbon in buildings and infrastructure, and excludes emissions related to surface transport and energy distribution.

The following scope of emissions and sub-categories have been determined to represent the UK built environment in this project*.

Table 1: Emissions Scope for the UK built environment as defined for the Roadmap

	Embodied Carbon	Operational Carbon (Regulated)	Operational Carbon (Unregulated)	F-Gas
Domestic Buildings	Embodied carbon from Construction, Maintenance & Demolition. Both domestic and consumption (imported) emissions.	Carbon from regulated energy uses: • Heating • Cooling • Ventilation & Pumps • Lighting • Hot Water	Carbon from unregulated energy uses: • Cooking • Appliances • Lifts • Small power / plug loads • IT / servers	F-Gas leakage from refrigeration, heat pumps and air conditioning plant within buildings
Non-Domestic Buildings				
Infrastructure		Carbon from the operation of infrastructure: • Street & public realm lighting • Communication networks • Water supply & treatment • Waste treatment	Not in scope (i.e. "User Carbon")	Not in scope

* There exist differences in terminology and categorisation of GHG emissions between the buildings and infrastructure sectors in the construction industry. This project does not take a view on the merits of the different terminology, but simply aims for clarity on what is described by the language used.

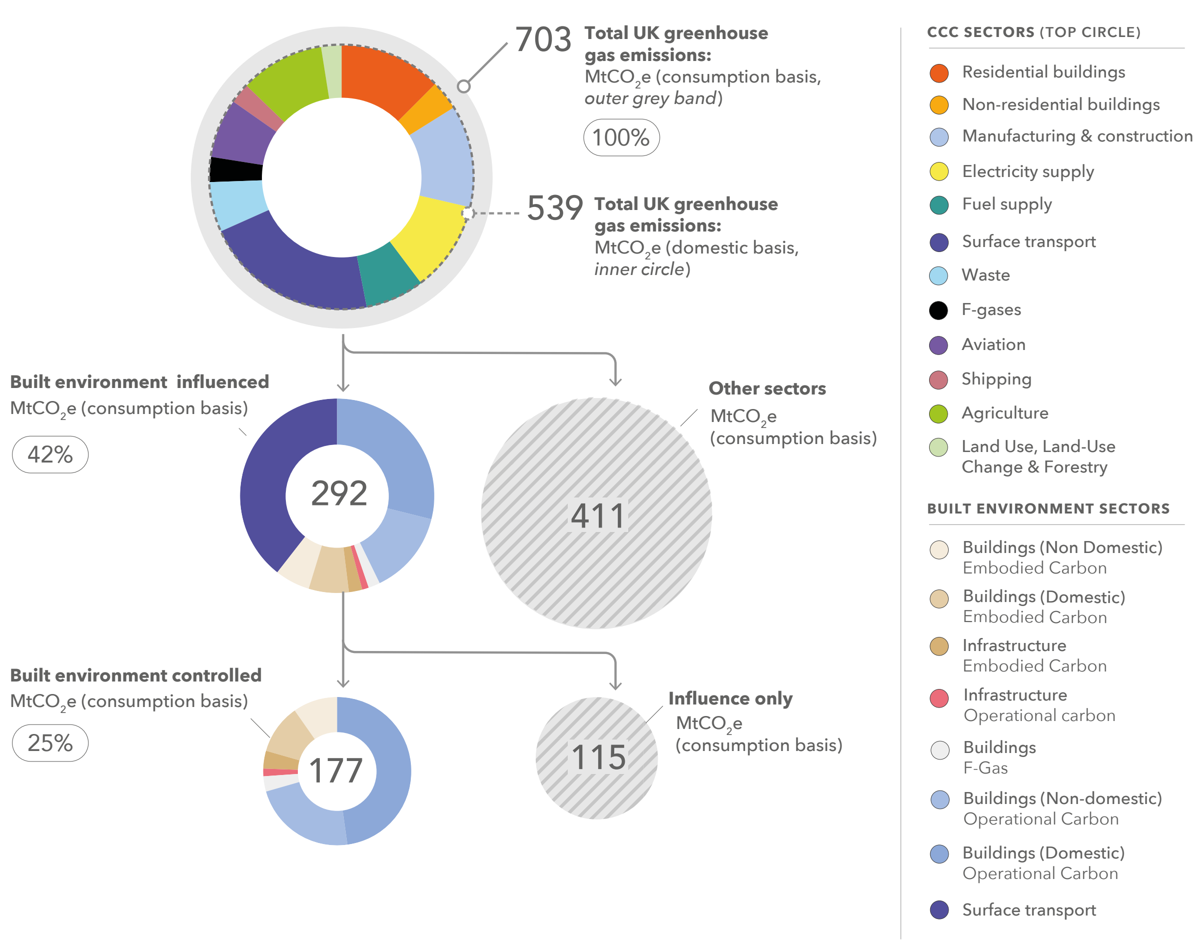

Figure 1: UK greenhouse gas emissions 2018 (MtCO$_2$e) showing influence and control of the built environment. Grey bubble represents consumption-based emissions (i.e. including imports and excluding exports).

3.4. Roadmap Scenarios

Once boundary conditions have been established, a carbon budget for the built environment can be estimated based on projections of the pace and scale of carbon reduction interventions over time. The projected emissions form the pathway, or emission trajectory, with the interventions forming the projected scenario. Policy can then be identified to support and drive the interventions, via regulation, economic or fiscal incentivisation or other market drivers.

The Roadmap contains two scenarios: a Reference Scenario, and a Net Zero Scenario.

3.4.1. Reference Scenario

The reference (or business as usual) scenario is modelled based on the BEIS energy and emissions projections research and represents a forward "business as usual" scenario based on existing government policy outlook.

Each year BEIS publishes Energy and Emissions Projections (EEPs), analysing and projecting future energy use and greenhouse gas emissions in the UK. These projections allow BEIS to monitor progress towards meeting the UK's carbon budgets and are used to inform energy policy and associated government analysis.

The projections are based on assumptions of future economic growth, fossil fuel prices, electricity generation costs and UK population. They also give an indication of the impact of the uncertainty around some of these input assumptions. Each set of projections takes account of climate change policies where funding has been agreed and where decisions on policy design are sufficiently advanced to allow robust estimates of policy impacts to be made.

The roadmap trajectory modelling takes a simplified approach whereby the future emissions profile (curve shape) presented in the selected BEIS scenario is applied from the baseline year of built environment emissions. As the BEIS data only projects to 2040, the scenario utilises the profile data to 2040 and extrapolates this to 2050[4]. This is therefore a forward "business as usual" scenario based on government policy outlook.

3.4.2. Net Zero Scenario

For the net zero scenario, the pace and scale of carbon reduction measures applied have reference to the CCC's pathways analysis, but were primarily determined by the Task Groups and Steering Group, reflecting the latest industry thinking, research and publications.

3.4.3. Guiding Principles for the Net Zero Scenario

An overarching principle of The Roadmap project is that the UK built environment will seek to progress towards zero emissions (including capital and operational emissions). Project team members thus considered which measures, interventions and solutions should be implemented in the drive towards net zero and in the context of the climate emergency, paying consideration to the following:

- Technical feasibility: Solutions and measures reflect what is currently considered to be technically feasible over the period to 2050. Technical feasibility of implementation is referenced through technical studies and background evidence, with the quality, transparency, objectivity, scalability and applicability of different resources considered throughout the process.
- Economic viability: The scenario includes measures which may not be currently viewed as economically viable, or do not have a positive return on investment (i.e. large scale retrofit of hard to treat domestic properties) and which would therefore require financial mechanisms, incentives or regulation to encourage or mandate adoption.
- Market viability: Measures proposed for implementation in the short and medium-term are cognizant of current market position and enabling actions required, i.e. unrealistic step changes should be avoided. Measures proposed further into the future are likely to increasingly rely on positive progressions in policy and market landscapes.

The project team also assumed the following direction of travel over the 30-year period from 2020-2050 for the net zero scenario, policy recommendations and stakeholder action plan:

- An overarching shift in national and local policy landscape towards net zero as part of a green recovery strategy.
- Increasing urgency for the implementation of net zero solutions, including fundamental changes in approach where necessary.
- Strong drivers toward net zero from both the investment community and occupiers.
- A responsibility, ownership and drive from within the construction industry and supply chains to accelerate change.
- Increasing consumer and societal pressure and appetite for climate action, and higher acceptance of disruption.

The Roadmap does not attempt to quantify, model or predict specific impacts related to the COVID-19 pandemic within the built environment, albeit some recent trends are captured within the projected growth rates for certain building sectors.

3.4.4. CCC Comparison

To provide a further point of reference, the net zero scenario was compared against the 'balanced pathway' published by the CCC in the Sixth Carbon Budget report.

The key difference is the boundary of the emissions assessment. The Roadmap net zero scenario is calculated on a consumption basis (including emissions from imported materials), thereby accounting for all emissions for which the built environment is responsible. The CCC balanced pathway (as well as the UK net zero target) is based on territorial emissions, i.e. only those emissions arising within the geography of the UK.

The comparison of the two sets of results was established through dialogue with the CCC and its published work. The comparison maps the national emissions budgets established by the CCC, then compares The Roadmap net zero scenario to the sectoral emissions from the CCC balanced pathway that match the built environment definition of this project. Note that this comparison necessarily omits consideration of extraterritorial emissions associated with imported construction materials.

3.5. Modelling Methodology

The objective of The Roadmap model is to provide a calculation platform to develop an emissions profile setting out the pace and scale of actions that support net zero by 2050. This involved two key steps:

1. Updating the 2013 Low Carbon Routemap model for the UK built environment[3]; and
2. Creating and then applying a net zero scenario for the UK built environment to 2050.

Both these steps have been undertaken and supported through a detailed consultation and engagement exercise with the Task Groups.

3.5.1. Scope of the model

The scope of The Roadmap model includes new and existing buildings in both domestic and non-domestic sub-sectors, as well as infrastructure. For both buildings and infrastructure, the model assesses 'operational' and 'embodied' carbon emissions. It is a timeseries model, which reports historical emissions (from 1990 to the 2018, in this case) and then calculates projected emissions to 2050.

3.5.2. Modelling approach

Model Structure

The structure and calculation methodology of The Roadmap model is based on the 2013 Low Carbon Routemap project. The primary focus of this project was to bring historic input data up-to-date and to make minor modifications to allow the full range of interventions included in the net zero scenario definition. This included a few additional interventions that were not included in the 2013 Routemap project.

This methodology section is designed to be read together with the original 2013 Low Carbon Routemap model technical report[3], most of which remains relevant except where stated here.

The calculation flow of The Roadmap model is shown in Figure 2. The model comprises a number of calculation modules covering aspects such as historical emissions, embodied carbon, and the energy models for domestic and non-domestic buildings operational carbon. The calculation modules are driven by a wide range of input datasets, including long-running authoritative national sources, e.g. Digest of UK Energy Statistics (DUKES 2020). Future emissions depend on the various interventions in the model (e.g. changes in heating technologies mix, building fabric standards, etc). The data for these defining the timing and scale of action has been taken from a diverse mix of references.

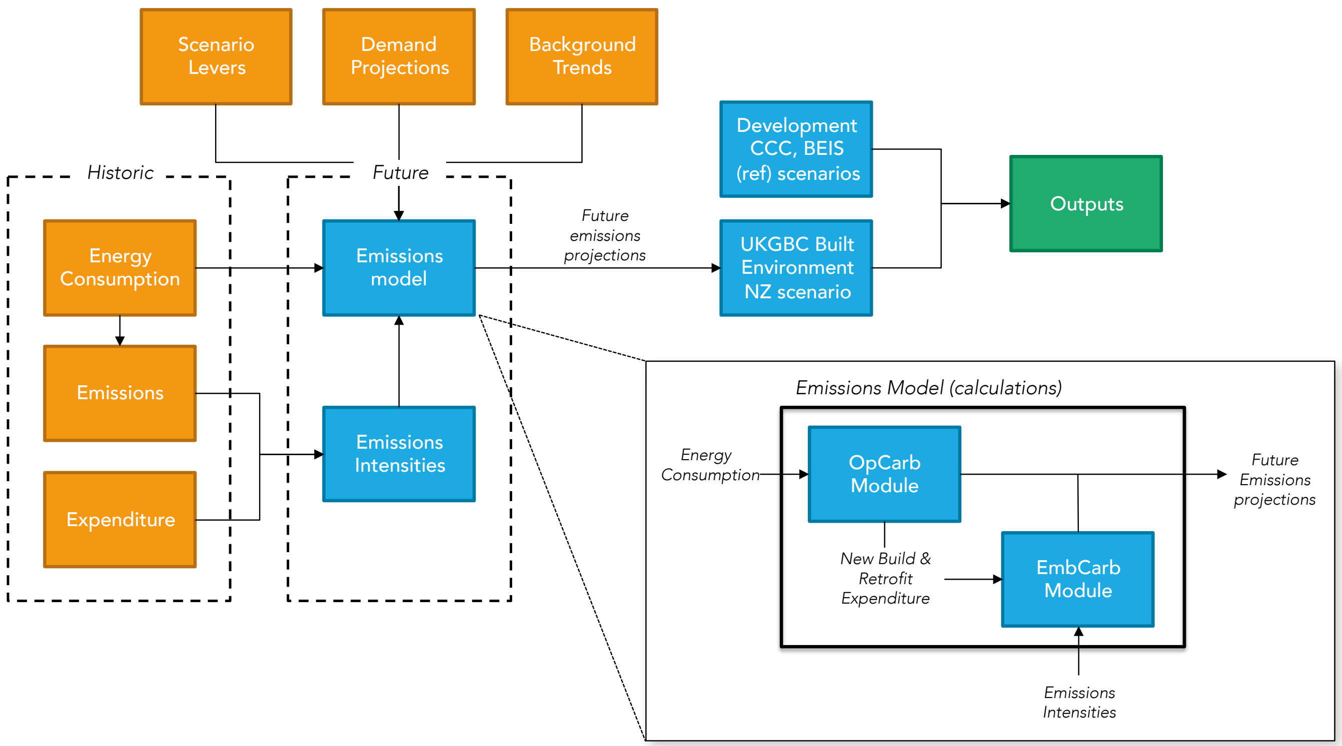

Figure 2: Roadmap modelling methodology

Many different input datasets are applied across the calculation modules. A summary of the most important highlight several key model features.

Operational Carbon

Historic operational carbon emissions are primarily calculated from data for UK energy consumption sourced from the Digest of UK Energy Statistics (DUKES) developed by BEIS/ONS. This energy data has been combined with GHG emissions factors to calculate the operational carbon contribution from various built environment sub-sectors.

For the modelling of future energy demand of domestic buildings, a hybrid approach is applied using a deconstructed version of the DECC 2050 Pathways Calculator. This has been modified with bespoke data for parameters such as electricity grid decarbonisation, heat delivery modes, and time-series space heating demand for both existing and new stock. For non-domestic buildings, a similar approach is applied, projecting sectoral energy demand based on future growth rates. Retrofit measures are introduced according to building and system lifecycles. The implied expenditure on new building and retrofit construction is estimated and imported into the embodied carbon model.

Embodied Carbon

The embodied carbon module draws upon updated estimates of construction output from the ONS, Defra's 2020 UK Statistics on Waste generation and treatment, and emissions data derived from external models (some of which have undergone substantial updates). The bulk of the consumption-based emissions data arises from a decomposition analysis of the UK multi-region input-output (UK MRIO) model that underpins the UK's consumption-based emissions accounts, published annually by Defra as the 'UK's Carbon Footprint'[5]. This analysis has been updated to include the 2021 version of the UKMRIO model, incorporating data up to 2018 at a greater economic sector disaggregation (126 economic sectors) than used in the 2013 Low Carbon Routemap, providing additional granularity. Additional contextual information on infrastructure emissions were also incorporated from the ICE's 2020 update of the Infrastructure Carbon Review.

4. Net Zero Scenario – Definition

4.1. Overview

This section contains a detailed description of the net zero scenario by presenting the main input parameters and providing an explanation of the underlying assumptions and reference data.

In addition, this section also indicates important points where the model methodology differs from the 2013 Routemap project. The 2013 Routemap report remains an important reference document and it should be consulted alongside this section for a complete explanation of the model methodology.

4.2. Scenario Definition – Background Trends

4.2.1. Grid Electricity Decarbonisation

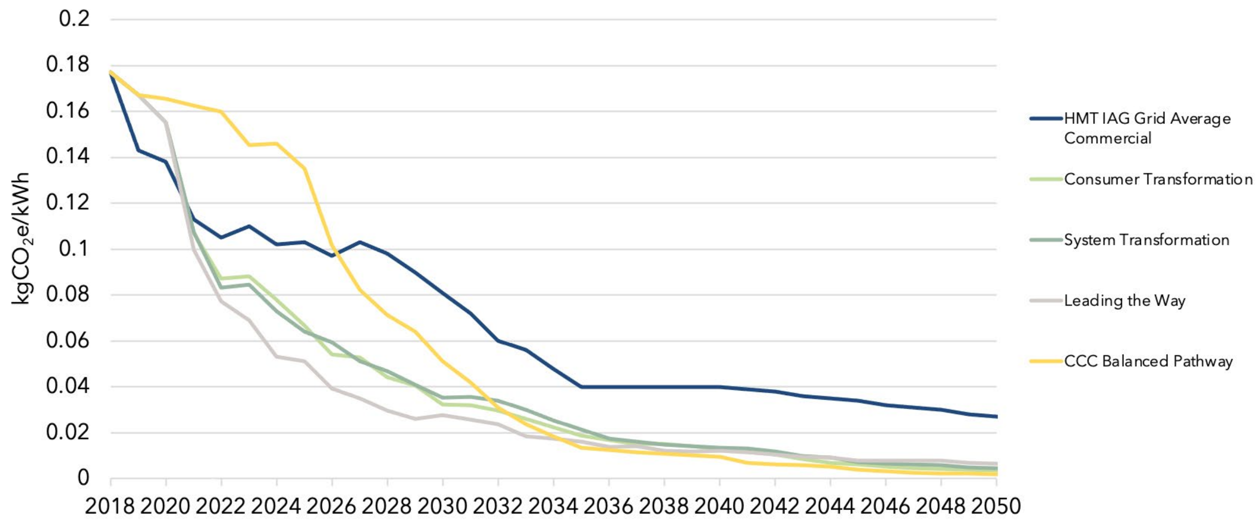

Figure 3: Grid electricity carbon factors

There are several UK grid carbon factor projections available. Figure 3 shows carbon factors from HM Treasury Green Book (grid average commercial projections)[6], alongside National Grid Future Energy Scenarios (FES) 2021[7]. The other projection uses the CCC Balanced Pathway data for the energy sector to calculate the implied carbon factors.

It should be noted that any benefits of Carbon Capture and Storage (CCS) or other carbon removals technologies are stripped out of all grid decarbonisation projections, in line with the overall approach of enabling comparison of final residual emissions with CCC projections for total removals potential by 2050 (and also to avoid the situation whereby negative grid carbon factors distort embodied carbon results).

The FES 'Consumer Transformation' projection was used for the main analysis, since the assumptions for grid energy mix aligned most closely with the UKGBC net zero scenario.

4.3. Scenario Definition – Domestic Buildings

4.3.1. Growth Rates for New Dwellings

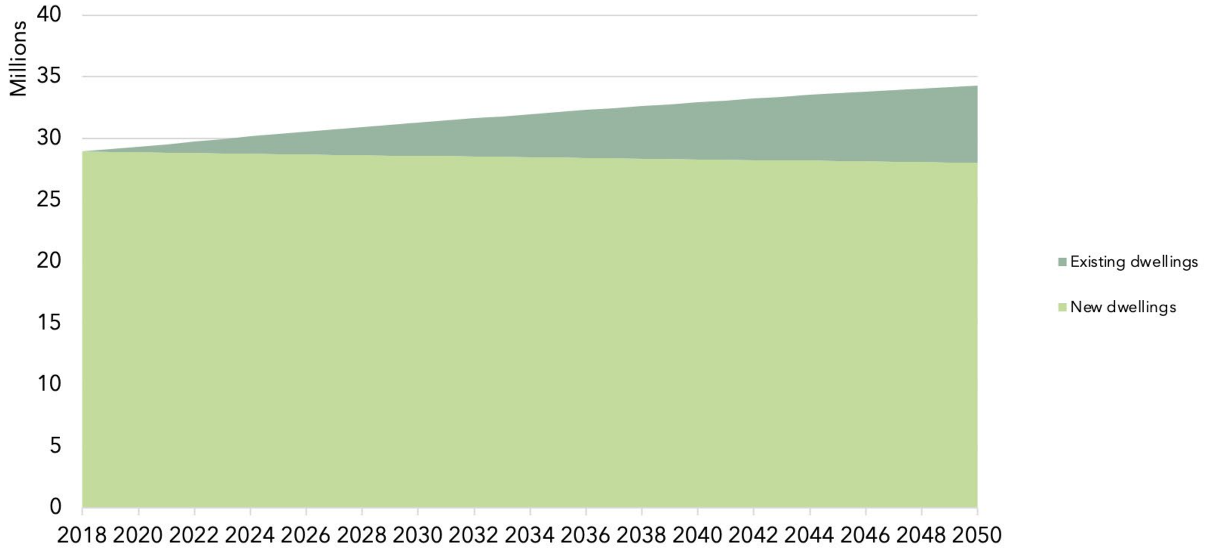

Figure 4: New homes growth rate

Growth rates for the residential sector, i.e. new dwellings, are based on Office of National Statistics (ONS) UK household estimates and projections for 2018 to 2039.[8] These are then linearly forecast through to 2050.

4.3.2. Heating Technology Mix in Existing Dwellings

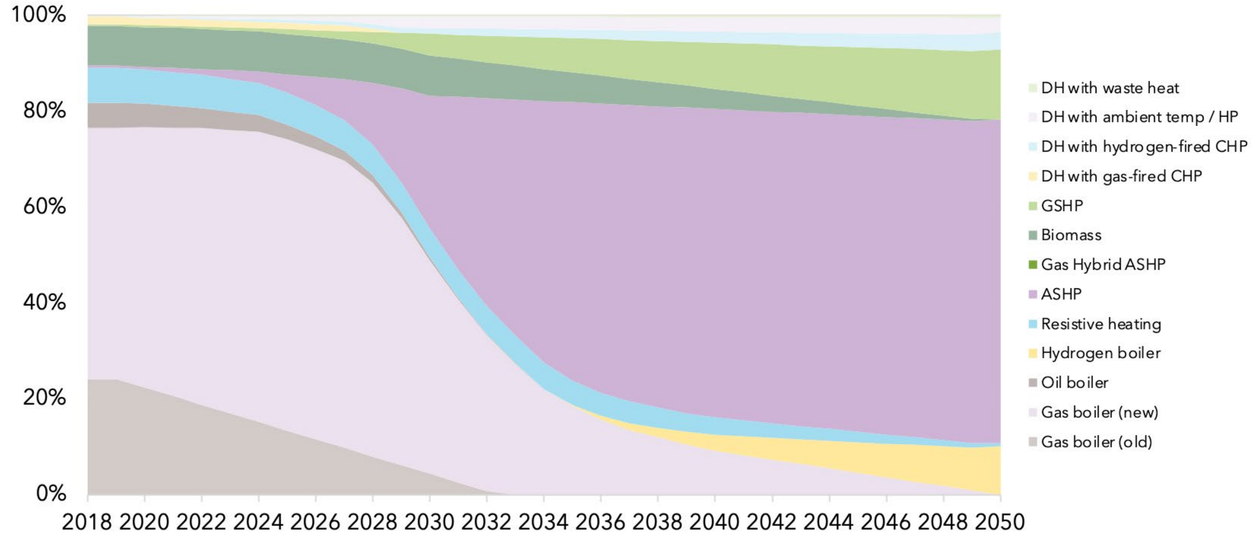

Figure 5: Heating technology mix in existing dwellings

The 2018-2020 heating mix for existing dwellings is based on the Energy Consumption UK data published by BEIS[9] and the National Grid ESO Future Energy Scenario (FES) 2020[10].

For the 2050 end point, hydrogen is assumed to align with the CCC Sixth Carbon Budget Balanced Scenario with hydrogen accounting for c.12% of the heating mix[11]. The split between hydrogen boilers and district heat with hydrogen was based on the assumption that 12% of suburban areas are reasonably close to hydrogen production and storage facilities, and the density should still be high enough to support the value proposition (using MHCLG English Housing Survey figures to establish split between hydrogen boilers and district heating with hydrogen), based on proportion of houses that are classified as suburban[12]. The total number of houses on DH was also based on FES 2020 numbers.

Biomass in the current mix is assumed to continue for the first decade, then transition to other technologies.

Other key assumptions agreed included no gas boilers existing in the mix in 2050, and almost no resistive heating or storage heaters in existing dwellings as these are replaced by heat pumps, due to higher efficiency made possible by increasing thermal efficiency standards. The scenario is linked to a transformative domestic retrofit programme, with heat-pump roll-out aligned with the domestic retrofit profile, on the basis that heat pumps will be installed as part of wider retrofit measures.

4.3.3. Heating Technology Mix in New Dwellings

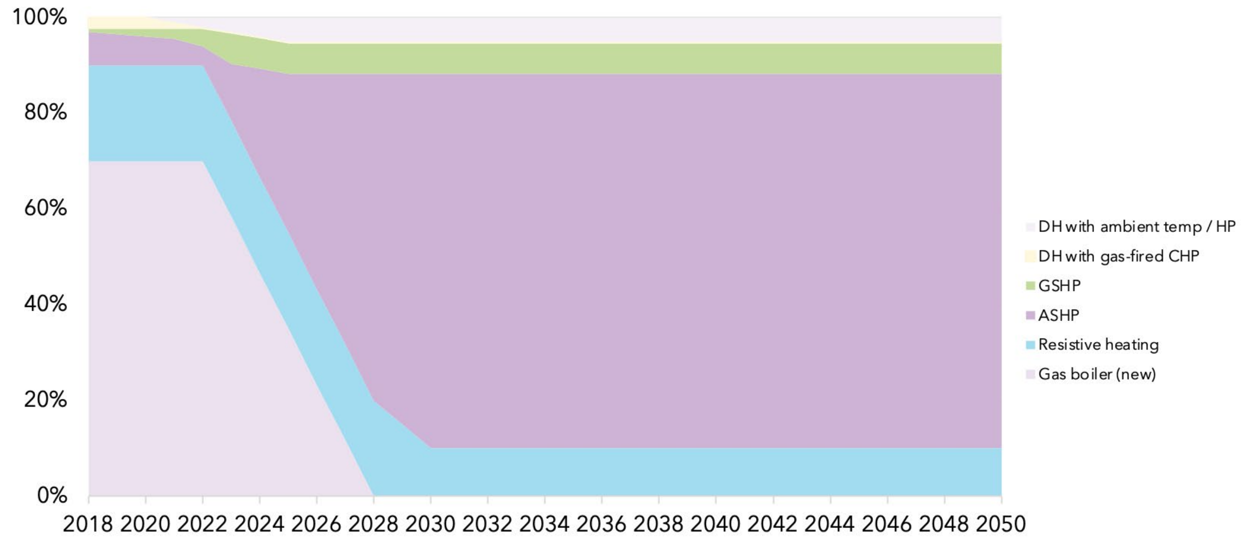

Figure 6: Heating technology mix – new dwellings

The basis for heating technologies in new dwellings assumes that the rate of current boiler installations continues until 2022, then decreases until Future Dwellings Standard ceases further boiler installations in new houses with the full effect not realised until 3 years after the new legislation in 2025. The current boiler rollout in new houses is derived from annual changes in domestic gas meters from BEIS Postcode level domestic gas and electricity consumption[13]. Once gas boilers are phased out, 75% of new dwellings benefit from heat pumps for space heating and hot water. The proportion of GSHP installations is assumed to be lower in new dwellings than in the existing stock. Initially, 20% of new dwellings are assumed to feature electric resistive heating, either due to very low heat demands due to size and heat loss characteristics (i.e. apartments), and installation challenges in some situations. This reduces to 10% on the assumption that air-to-air heat pumps become more competitive over time.

4.3.4. Domestic Heating Technology Efficiencies

Table 2: Heating technology efficiencies (current and future)

Technology	Heating efficiency		Electrical efficiency	
	2018	2050	2018	2050
Gas boiler (old)	82%	82%	–	–
Gas boiler (new)	86%	95%	–	–
Oil boiler	65%	65%	–	–
Hydrogen boiler	86%	95%	–	–
Resistive heating	95%	95%	–	–
ASHP – Heating	300%	420%	–	–
ASHP – DHW	250%	350%	–	–
Gas Hybrid ASHP – Gas	86%	95%	–	–
Gas Hybrid ASHP – Electricity	313%	429%	–	–
Hydrogen Hybrid ASHP – Gas	86%	95%	–	–
Hydrogen Hybrid ASHP – Electricity	313%	429%	–	–
GSHP	325%	450%	–	–
DH with gas-fired CHP	36%	36%	35%	35%
DH with hydrogen-fired CHP	36%	36%	35%	35%
DH with ambient temperature heat pump	276%	383%	–	–
DH with waste heat	36%	36%	–	–

Efficiencies are applied within the model to the various heating technologies deployed. Efficiency data has been derived from a variety of sources, including:

- National Grid FES
- SEDBUK ratings for gas boilers
- English and Scottish housing surveys for boiler populations – numbers of old and new boilers
- Scottish household surveys from the Scottish Government and the English Housing Survey from Ministry of Housing, Communities & Local Government (MHCLG)

In some cases, there is an expected efficiency improvement through to 205, while in other cases, the technology has an efficiency ceiling and no further improvements are expected. Heating efficiencies for old gas boilers are based on non-condensing boiler averages from MHCLG English Housing Survey averages, with no improvement factor to 2050 on the basis there will be no new installations of this technology type. Hydrogen boiler efficiencies are based on gas boilers.

Following the CIBSE code of practice[14], 15% district heating losses have been assumed and built into the reported heating efficiency values for district heating systems.

4.3.5. Proportion of Existing Housing Stock Retrofitted

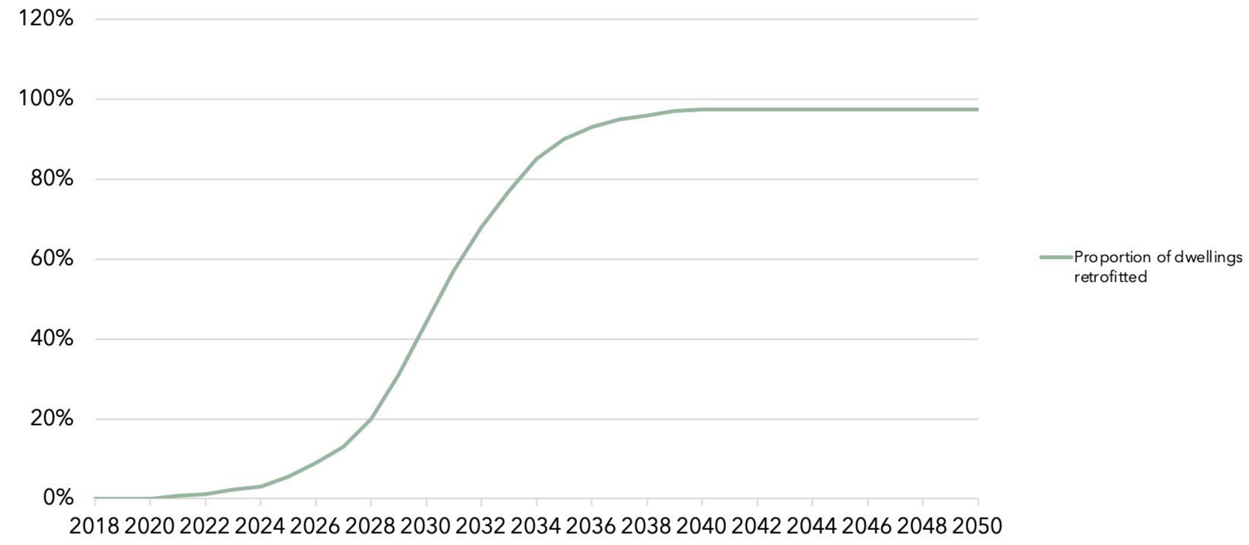

Figure 7: Existing dwellings national retrofit strategy

The retrofit trajectory for existing domestic stock is based on the proposals set out in the Construction Leadership Council's National Retrofit Strategy[15] (NRS). The NRS sets out a 20-year transformative plan for the energy efficiency retrofit of 97% of UK homes by 2040. The goal is to tackle the challenge systematically and pragmatically, establishing firm foundations for scaling up to meet the volume of work needed, whilst highlighting the resulting economic, social and environmental benefits.

The NRS retrofit roll-out profile is based on a slow start to focus on education of householders and upskilling of the wider industry, plus an intensive training programme for new entrants to the industry to build capacity. This is followed by a 'quick' middle period based on a mature supply chain eco-system and strong customer protections. Finally, there is a ramp down of pace toward the end to deal with very-hard-to treat properties, and a signalled ramp down helps the skilled workforce to shift to other sectors without a sudden shock.

The deployment profile applies to the whole UK housing stock. The trajectory is linked to the data-points set out in the NRS for number of houses retrofitted by 2021, 2024, 2030 and 2040, with interpolation between these to match the S-curve roll-out profile.

Estimated costs per dwelling are used to derive the embodied carbon impact of the programme. Cost estimates have been aligned with the CLC NRS value of £18,000 per dwelling.

4.3.6. Space Heating Demand

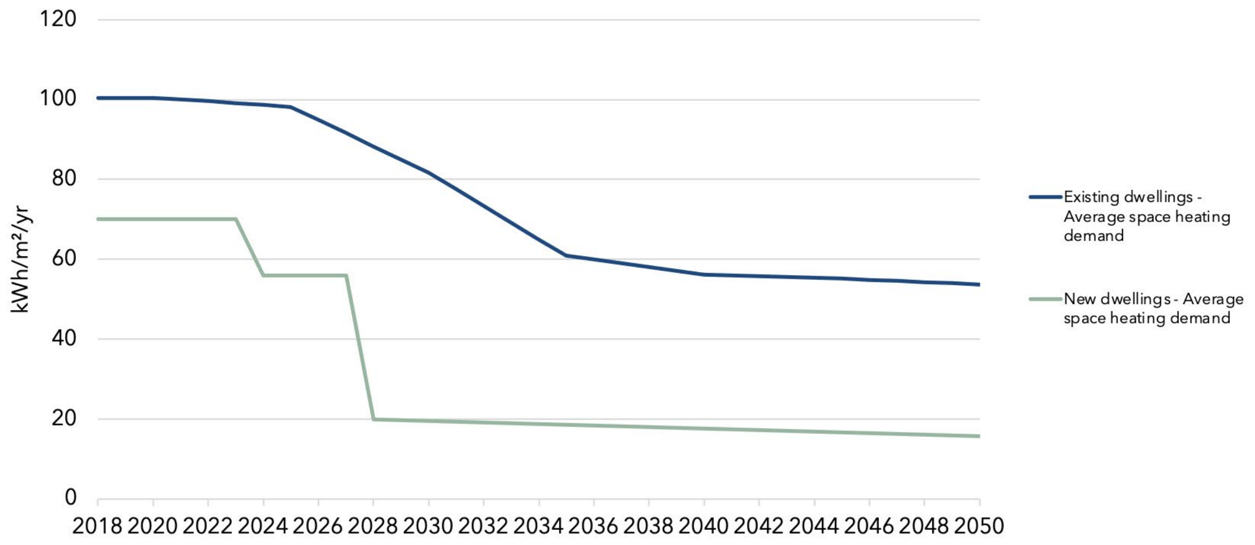

Figure 8: Average space heating demand

Energy efficiency measures and building fabric standards are expressed as a resultant space heating demand figure (kWh/m²/yr).

For existing dwellings, the stock average space heating demand was calculated using the total space heating energy demand reported in the ECUK and DUKES data for 2018, the total housing stock and the average existing dwelling floor area[16]. This is an aggregated value and includes the combined effects of under-utilisation and under-heating (influenced by consumer energy costs and fuel poverty).

It was assumed that the retrofit roll-out delivers an average design figure of 50 kWh/m²/yr, aligning with the CLC NRS, the AECB retrofit standard target[17] and the LETI retrofit guide[18]. This figure represents an average figure representative of all dwellings and does not differentiate between easy-to-treat and hard-to-treat typologies. A performance gap uplift of 20% is applied initially, reducing linearly to 5% by 2050.

For new dwellings, space heating demand projections are based on the following rationale. Following new regulation, a 3-year lag period has been included to allow for transitional arrangements.

- From 2018: 70 kWh/m²/yr = current new-build dwelling average, based on EPB Statistics for 2020[19], with a 33% performance gap uplift.
- From 2024: 56 kWh/m²/yr = 20% reduction through 2021 Building Regulations Part L (FEES impact).
- From 2028: 15 kWh/m²/yr = through Future Homes Standard uplift, aligning with CCC assumptions (20-15 kWh/m²/yr from 2025 onwards). In 2028, an additional 33% performance gap uplift is applied. This reduces linearly to 5% uplift in 2050.

Figure 8 shows the resultant space heating demands for new dwellings installed in each year and the stock average value for all existing buildings in each year.

The performance gap factors are applied to the space heating demand to reflect the reality that design intent is not always fully realised by performance in practice. The uplift factors assumed here are drawn from the data shown in Figure 9. Assumptions for current performance of the retrofit measures in 2018-2020 were based on a review of numerous studies on the performance gap as well as data from heat flux texts in UK dwellings. It was assumed that by 2050, a clear focus on skills, quality and continuous improvement within the NRS would result in performance gaps reducing to a similar level as Passivhaus outcomes (< 5% uplift).

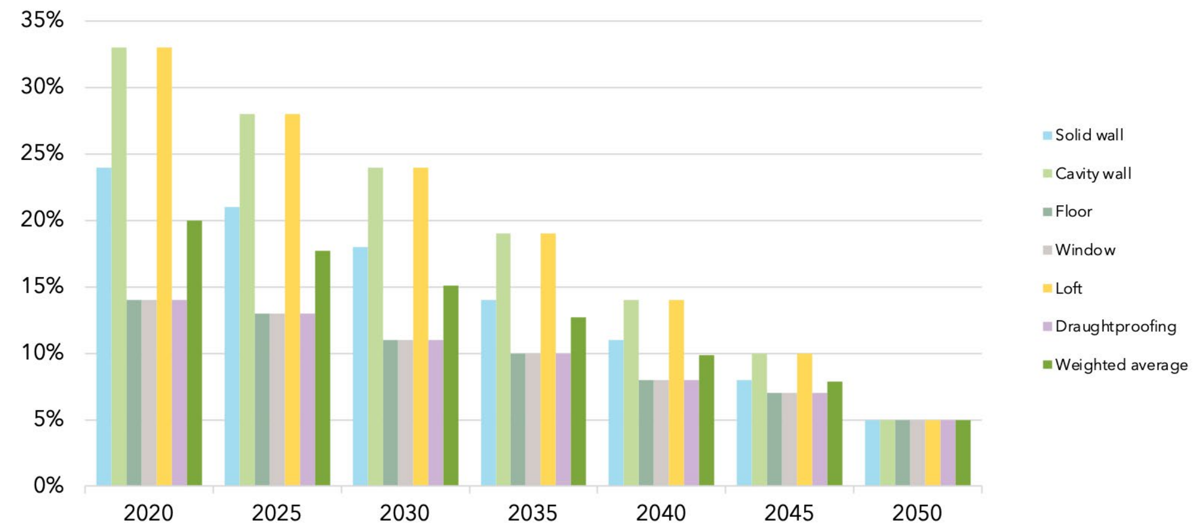

Figure 9: Performance gap factors for retrofit measures in existing homes

The performance gap review assessed the sources listed in reference 23[20].

4.3.7. Behaviour Change – Mean Internal Temperature

The latest statistics show 13.4% of homes are in fuel poverty[21] and it is assumed those homes are, on average, set to 14°C compared with an average of 19°C (the lower temperature being the threshold at which significant health issues become prevalent). It is assumed those in fuel poverty will raise their temperatures to the average as energy efficiency increases. In practice, the model builds in the impact of energy poverty into the existing dwellings space heating demand and assumes that energy poverty is fully addressed through the retrofit roll-out.

4.3.8. Behaviour Change – Hot Water Demand

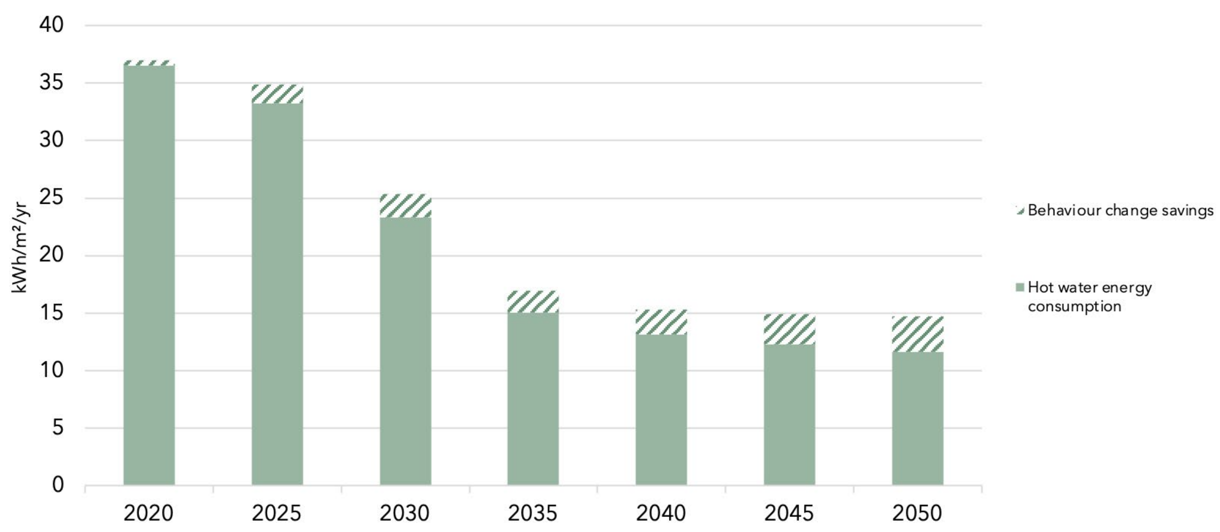

Figure 10: Domestic behaviour change factors – hot water demand

Projections for reductions in water demand use 140l/p/d as a current baseline.[22] The Environment Agency has set a target of 110l/p/d by 2050 as being one that represents the changes most likely to be required in the long term and as being in line with their high ambition for environmental improvement.[23]

4.3.9. Behaviour Change – Lighting Demand

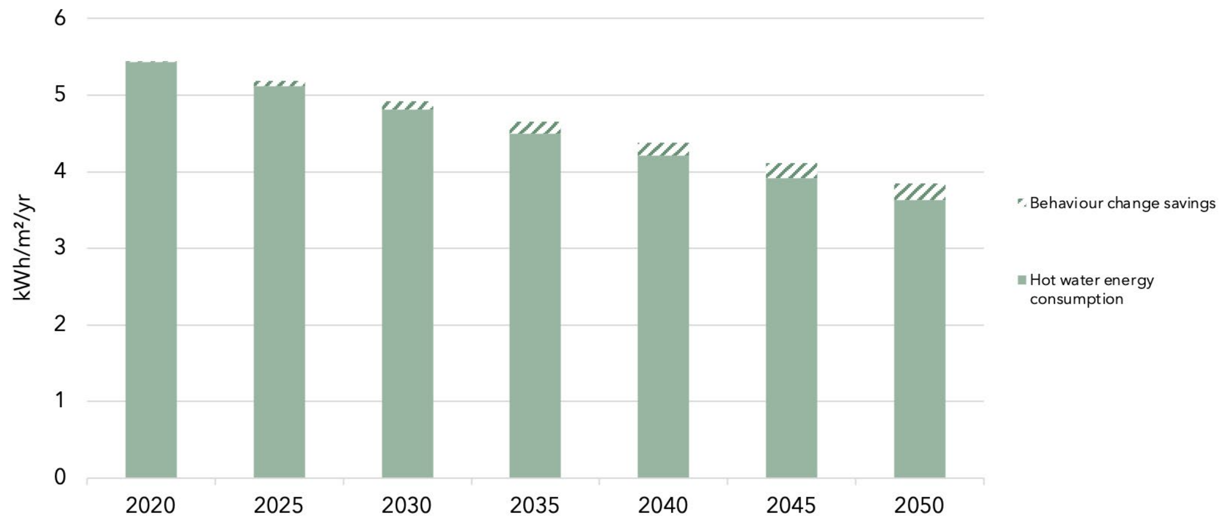

Figure 11: Domestic behaviour change factors – lighting demand

Projections for lighting demand reduction are derived from the CCC's assumption that behaviour change can deliver annual savings of 0.4TWh by the 15 years to 2035.[11] It is assumed that not all behaviour change opportunities will be exhausted by then but that progress in the second 15-year period to 2050 will be half that in the first 15-year period.

4.3.10. Installed PV Capacity

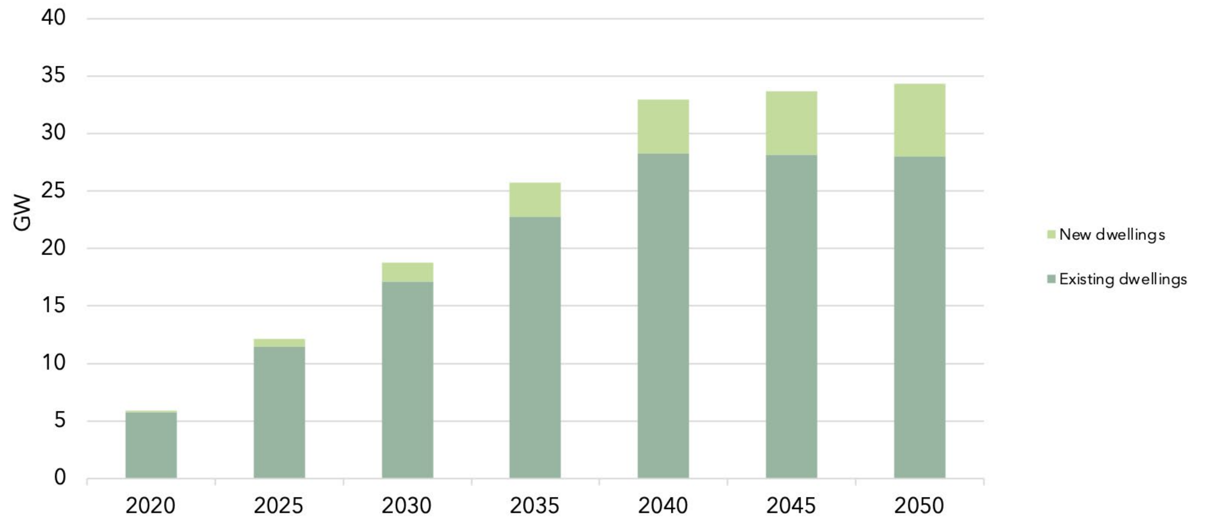

Figure 12: Domestic installed PV capacity

Individually, installing domestic PV is a householder decision and may be included in new dwellings to meet building standards or installed at a later date in existing dwellings. UK-wide, however, domestic PV installations are a significant contributor to a decarbonised energy network. For this reason, the model targets 35 GW of domestic PV, corresponding to a 4kWp installation in 25% of homes. This aligns with the FES assumptions, which means that the carbon saving is captured by the FES grid emissions factor and no additional benefit needs to be calculated by the model.

4.3.11. Installed Solar Hot Water Generation

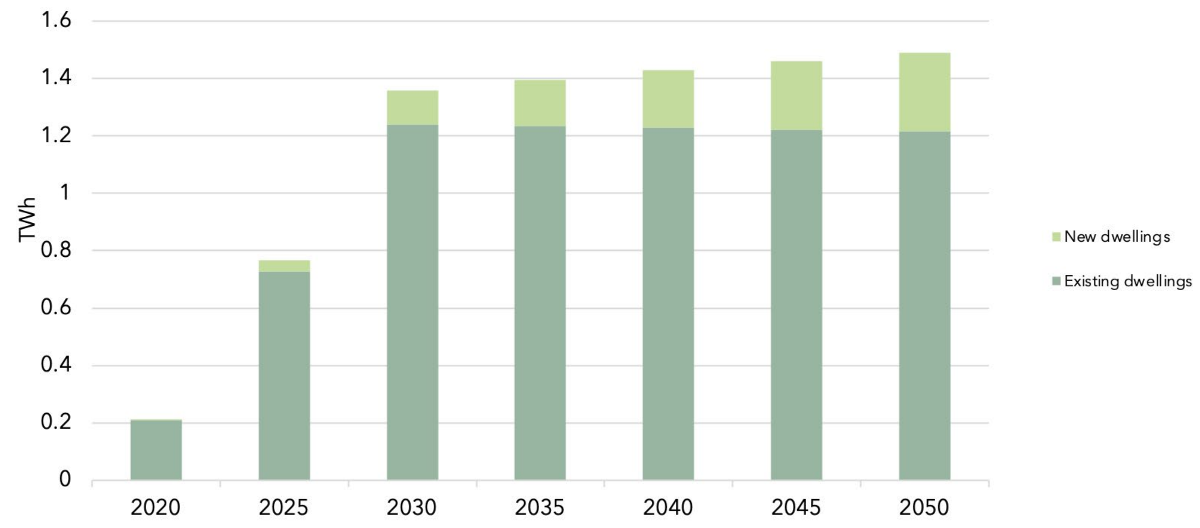

Figure 13: Domestic installed SHW capacity

It is assumed that with heating electrification, the need for solar thermal will be displaced. It has been assumed that solar thermal is a cost-effective solution for properties where storing large amounts of hot water is feasible (e.g., communal housing) and that there will be the largest uptake over the next 10 years while heat battery technology is establishing, with a slower uptake after that. 3m² is the optimum area required and this remains static. It is anticipated that solar thermal will be added to 3% of properties.

4.3.12. Domestic Cooking Energy Consumption & Fuel Mix

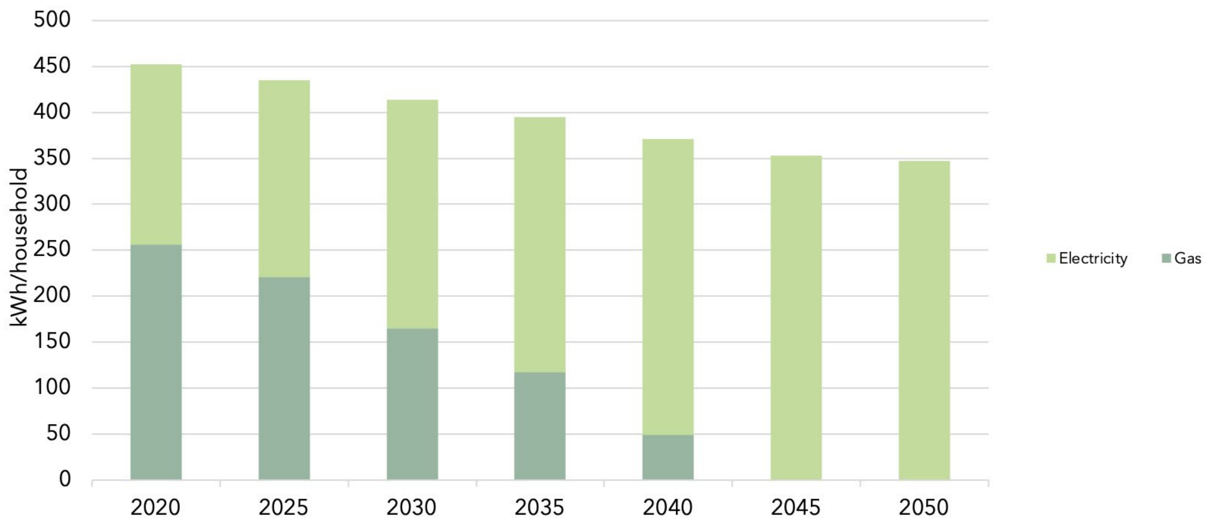

Figure 14: Domestic cooking energy usage

Total 2019 domestic gas and electricity cooking demands were taken from ECUK 2020 end use data.[24] The number of homes with an electric hob in 2019 was taken from ECUK 2020 electrical products data.[25] Domestic gas demand for cooking across all homes up to 2050 (kWh/dwelling) was then calculated from the derived annual reduction in gas cookers, total 2019 domestic gas cooking demand, and number of homes up to 2050. Gas cooking demand is assumed to reduce in line with the removal of gas boilers from the heating mix.

4.3.13. Domestic Appliance Energy Consumption

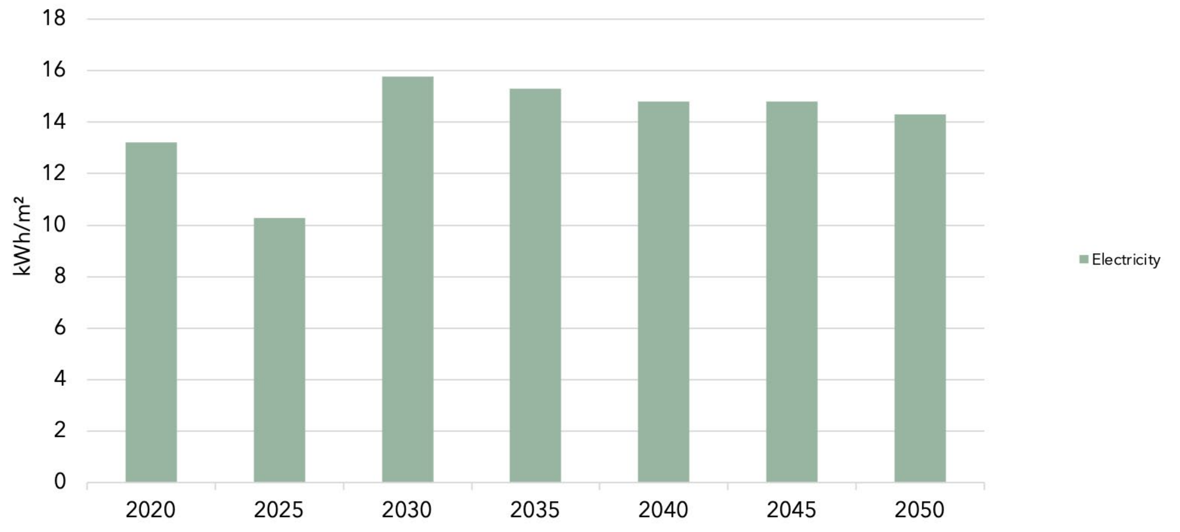

Figure 15: Domestic appliance energy consumption

Annual domestic energy demand for appliances was taken from the FES projections and converted to kWh/m²/year using the average dwelling floor area.

With the step-change in dwelling energy efficiency, an additional 6 kWh/m²/year was added to allow for mechanical ventilation with heat recovery (MVHR) systems in highly-insulated homes.

4.3.14. Resultant Energy Use Intensities

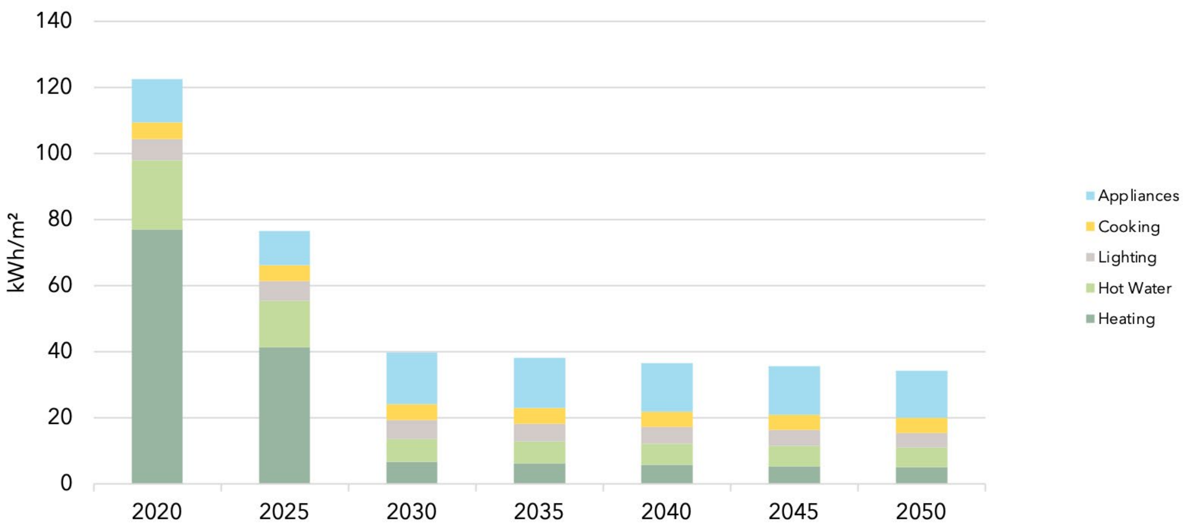

Figure 16: Resultant new dwelling energy use intensity (kWh/m²/yr)

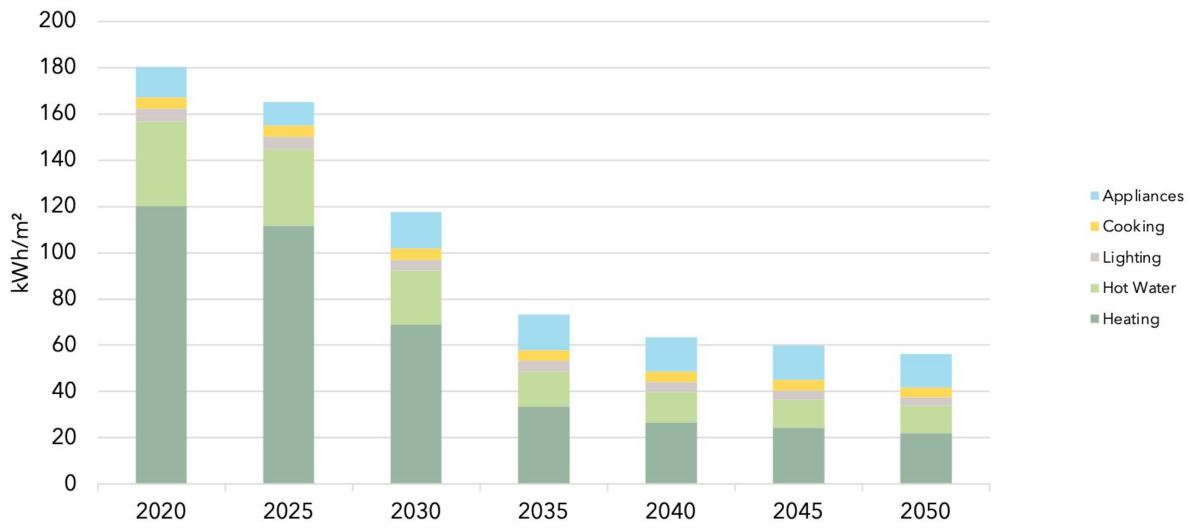

Figure 17: Resultant existing dwelling energy use intensity (kWh/m²/yr)

The energy use intensity of new and existing homes is an intermediate output step of the model, based on the inputs detail in the previous sections (space heating demand, behaviour change factors, heating technology mix and efficiencies, appliance, and cooking energy, etc). Appropriate carbon factors are then applied to derive operational carbon emissions within the model. The projected energy use intensity data for new and existing homes is presented here in Figure 16 and Figure 17 for reference against industry guidance and benchmarks.

4.4. Scenario Definition – Non-Domestic Buildings

4.4.1. Non-Domestic Sectoral Growth & Demolition Rates

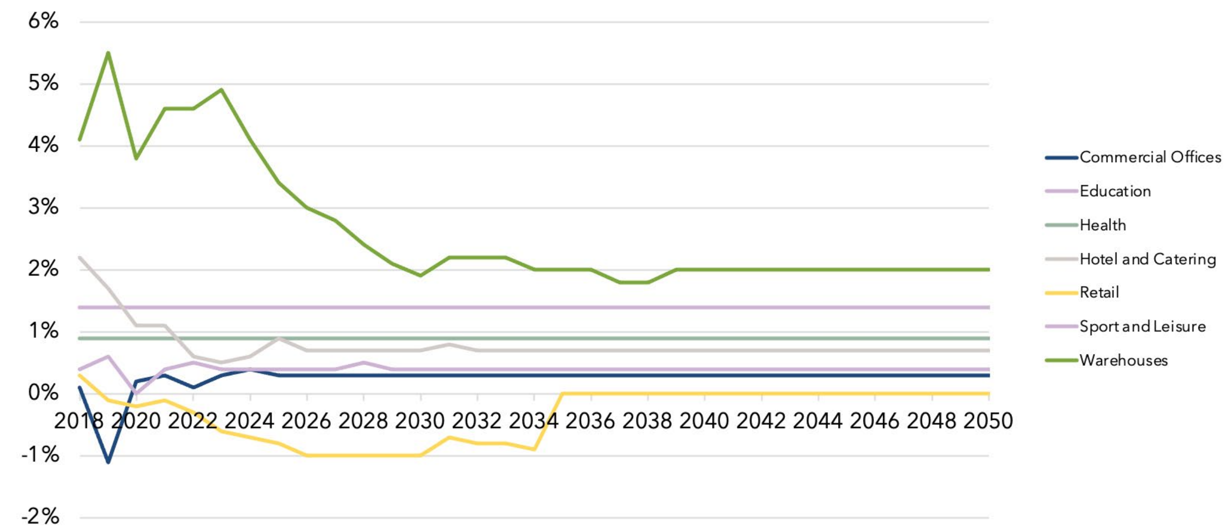

Figure 18: Non-domestic building growth rates

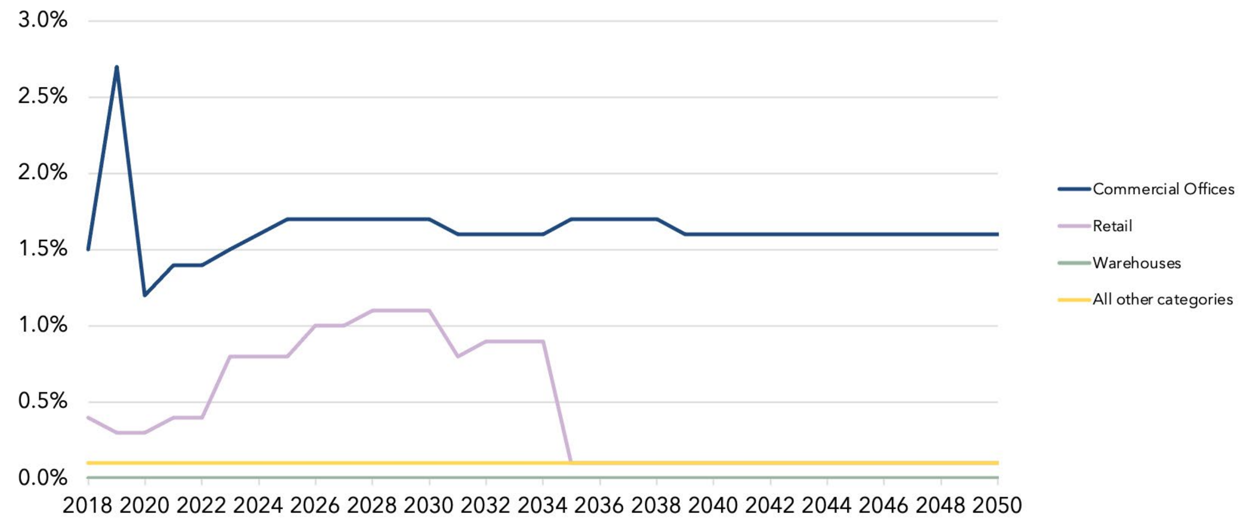

Figure 19: Non-domestic building demolition rates

Projections for non-domestic sector growth rates are derived from PMA UK Forecast Service Stock Projections which estimate growth rates until 2030.[26] PMA are a leading independent real estate research consultancy specialising in property forecasting. Projections post 2030 for commercial property and hotels and catering are based on historic rolling averages. Healthcare and education historic stock are estimated from rateable values, and forecast growth is projected to match the historic growth rate.

4.4.2. Non-Domestic Existing Building Heating Technology Mix

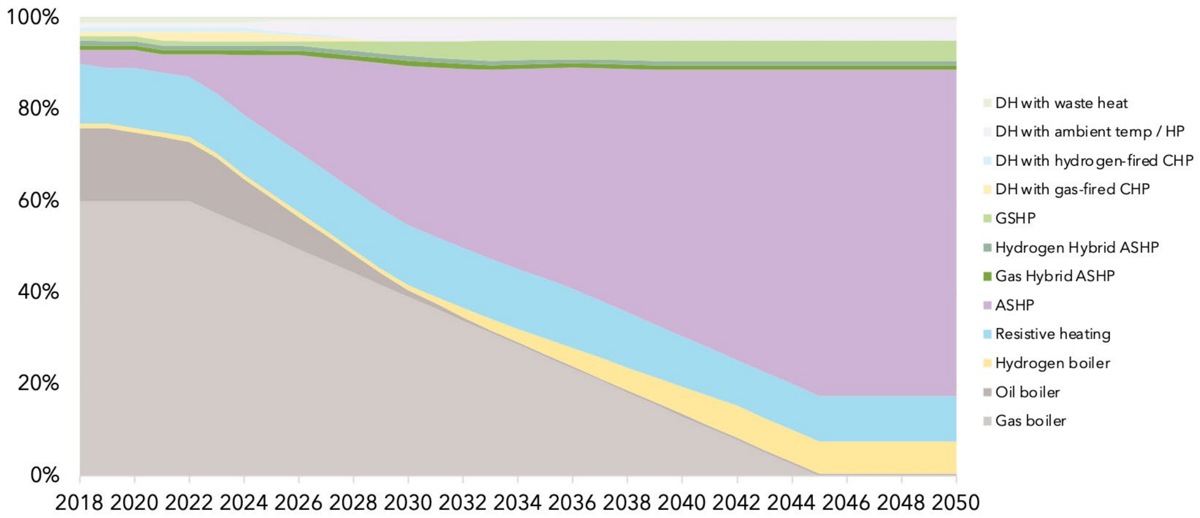

Figure 20: Non-Domestic Existing Building Heating Technology Mix

The projected heating technology mix for the existing non-domestic building stock was derived with reference to the Building Energy Efficiency Survey (BEES) research, based on coverage by total non-domestic stock floor area percentage[27]. Gas boilers are phased out by 2045 in line with domestic buildings, while oil boilers are phased out by 2032. Hydrogen boilers increase by 0.5% annually between 2030 and 2042 reaching 7%, while the remaining demand is met by ASHPS and GSHP. District Heating (DH) with gas-fired CHP is phased out by 2030, replaced by ambient temperature heat pump systems.

4.4.3. Non-Domestic New Building Heating Technology Mix

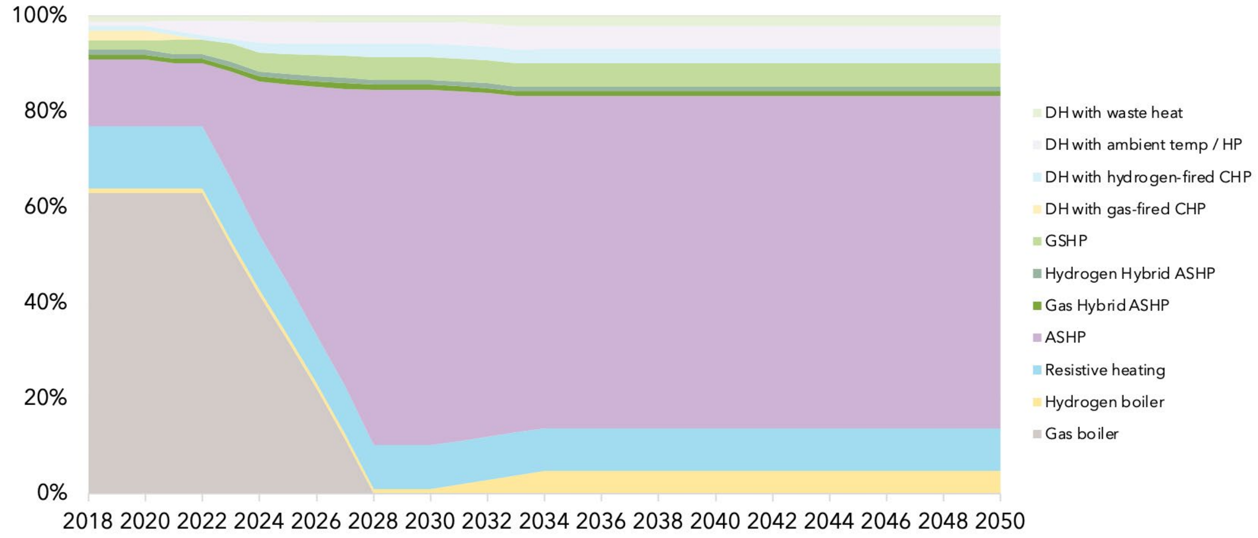

Figure 21: Non-Domestic New Building Heating Technology Mix

The assumptions for new non-domestic buildings were determined through adjustments to the BEES research values for existing buildings[30]. No usage of oil boilers was projected, while gas boilers are phased out by 2028 with a shift to ASHPs. Hydrogen boilers increase from 2030 as a by-product of industrial heat decarbonisation. ASHPs see a gradual increase up to c.70% due to the switch from boilers and direct electric, and additional 3% from switch away from oil boilers for off-gas grid properties. Electric resistive heating declines as heat pumps gain market share. District heating with gas-fired CHP is displaced by ambient temperature heat pump systems from 2025.

4.4.4. Non-Domestic Heating Technology Efficiencies

Heat technology efficiencies in non-domestic buildings are assumed to be the same as those in domestic buildings (see Table 2).

4.4.5. Non-Domestic Cooling Technology Efficiencies

Table 3: Cooling technologies efficiencies (SEER, current and future)

Technology	2018	2050
Standard Air-Cooled Chiller <750kW	400%	550%
Standard Air-Cooled Chiller >750kW	450%	600%
Absorption chiller	70%	70%
Standard Water-Cooled Chiller <750kW	500%	600%
Standard Water-Cooled Chiller >750kW	550%	650%
ASHP VRF/VRV	500%	600%

Efficiencies for cooling technologies are applied within the model to the various technology types deployed. Efficiency data was derived from a variety of sources, including the Non-Domestic Building Services Compliance Guide and ASHRAE HVAC Systems & Equipment (2020).

4.4.6. Non-Domestic Existing Building Retrofit Measures – Performance

Table 4: Non-domestic existing building retrofit measures – performance

Measure	Description	Heat	DHW	Cool & Vent	Light
Improve solid element u-values	Increased / replace insulation to wall and roof areas	30%	0%	-5%	0%
Improve glazing u-values	Replace glazing for more efficient glazing	15%	0%	5%	0%
Improve glazing solar performance	Either as part of above or by adding solar film	-5%	0%	25%	0%
Voltage optimisation and power factor correction	Reducing incoming voltage to 220v and applying power factor correction	0%	0%	5%	0%
Heat recovery ventilation	Improve the heat recovery within the ventilation systems	15%	0%	5%	0%
New lighting and controls	-	-5%	0%	5%	60%
Sub-metering and recommissioning	Installation of sub-metering of all heating, cooling and power requirements	10%	10%	10%	0%

Given the variation in building performance characteristics within each non-domestic building type, retrofit measures are modelled using a high-level performance impact approach. This is necessarily simplistic, but it has the advantage of avoiding the need to characterise the entire non-domestic building stock with a small set of dynamic thermal models.

The performance impacts on building energy end-uses for different retrofit measures were estimated with reference to the 2013 Routemap Model and the Second Cost Optimal Assessment for the United Kingdom (MHCLG, 2019)[28]. These factors are applied to each building type, adjusting the 'business-as-usual' energy demands taken from the measured data in the ECUK 2018 dataset.

4.4.7. Non-Domestic Existing Building Retrofit Measures – Replacement Cycles

Table 5: Non-domestic existing building retrofit measures – asset life (years)

Measure	Description	Slow	Med	High
Improve solid element u-values	Increased / replace insulation to wall and roof areas	55	40	25
Improve glazing u-values	Replace glazing for more efficient glazing	55	40	25
Improve glazing solar performance	Either as part of above or by adding solar film	55	40	25
Voltage optimisation and power factor correction	Reducing incoming voltage to 220v and applying power factor correction	40	25	15
Heat recovery ventilation	Improve the heat recovery within the ventilation systems	40	25	15
New lighting and controls	-	15	10	5
Sub-metering and recommissioning	Installation of sub-metering of all heating, cooling and power requirements	40	25	15

Table 6: Non-domestic existing building retrofit measures – replacement cycles

Measure	Description
Commercial Offices	MEDIUM
Education	SLOW
Government	SLOW
Health	MEDIUM
Hotel and Catering	FAST
Other	MEDIUM
Retail	FAST
Sport and Leisure	MEDIUM
Warehouses	MEDIUM

Retrofit measures are deployed in the model at different time-steps based on the asset life of different building systems and components (see Table 5). The asset life is used to calculate the proportion of the building stock that is retrofitted each year. Depending on commercial priorities, different sectors can be expected to replace their systems, fabrics, and indeed buildings on different timeframes. The selected replacement cycles for each building type are given in Table 6 and are taken directly from the 2013 Routemap Model.

4.4.8. Non-Domestic New Buildings

Energy demands in new buildings in 2019 are estimated to be 30% less than the stock average energy demands reported in the measured data in the ECUK 2018 dataset.

Unlike the domestic sector, there is a much less clear policy pathway for future non-domestic standards. In the absence of this, a small additional annual improvement (i.e. < 2%) is added to ensure that new build standards continuously improve. This was calibrated for new offices to ensure that the resultant energy use intensity aligned with the UKGBC benchmark target data[29].

4.4.9. Non-Domestic Buildings – Installed PV Capacity

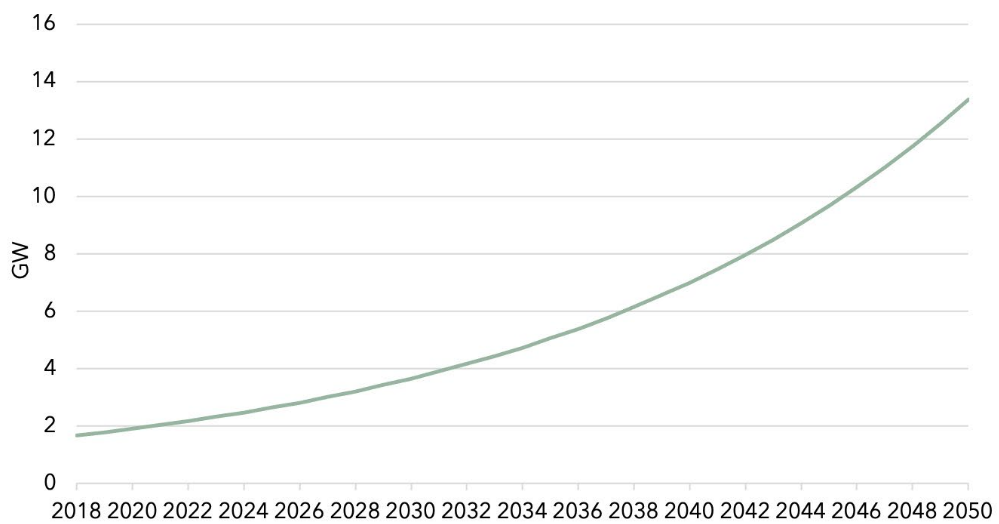

Figure 22: Non-domestic buildings installed PV capacity

The installed PV capacity assumes an average annual increase of 6.71%MW, based on BEIS Solar Photovoltaics Deployment average annual system installation trends from 2018-2020.[30]

4.4.10. Non-Domestic Buildings – Unregulated Energy Consumption

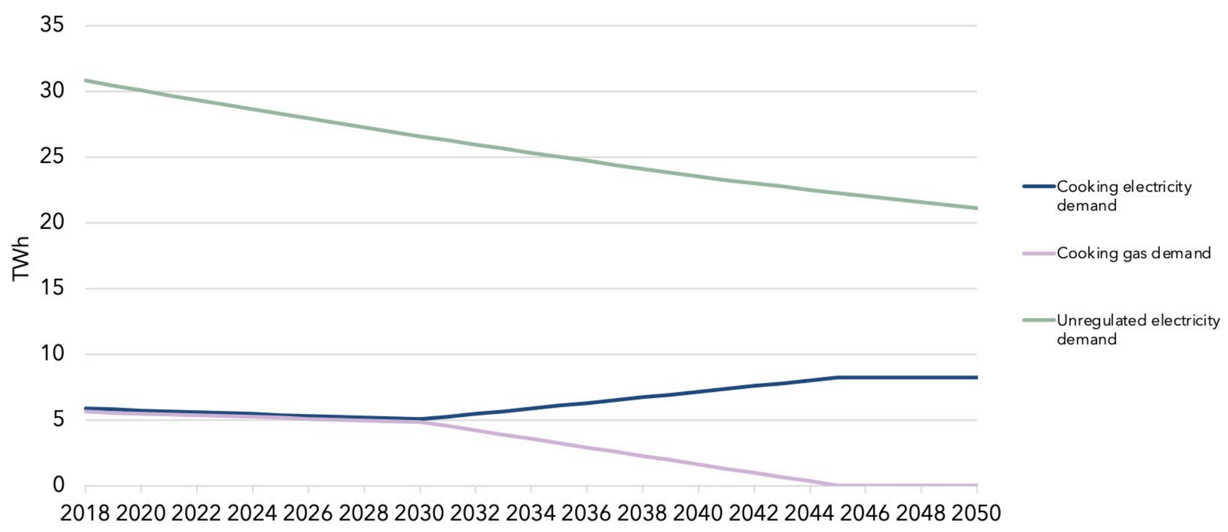

Figure 23: Non-domestic buildings unregulated energy consumption

Projections for unregulated or process energy loads within non-domestic buildings are derived from the BEES research data [31]. Trending information from 2015 – 2020 shows an average reduction of 1.22% annually for electricity consumption (taken from BEIS energy trends[32]) which is projected forward through to 2050.

In line with the removal of gas boilers from the heating mix, gas demand for cooking transitions to electricity by 2045.

4.4.11. Non-Domestic Existing Buildings – Resultant Energy Use

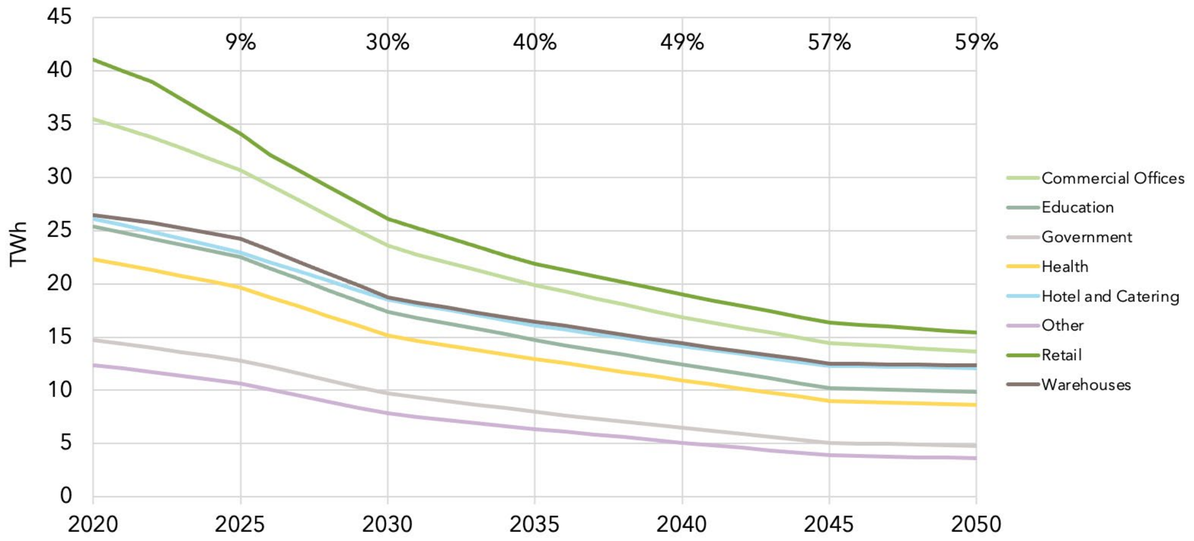

Figure 24: Non-domestic existing buildings energy demand projections

The projected energy use of the existing non-domestic building stock is an intermediate output step of the model, based on the inputs detail in the previous sections (heating and cooling technology mix and efficiencies, retrofit performance factors and replacement cycles per sector, etc). Appropriate carbon factors are then applied to derive operational carbon emissions within the model. The projected energy use for each non-domestic building type is shown in Figure 24. The values at the top of the figure represent the total reduction in all non-domestic energy use.

4.4.12. Non-Domestic New Buildings – Offices Energy Use Intensity

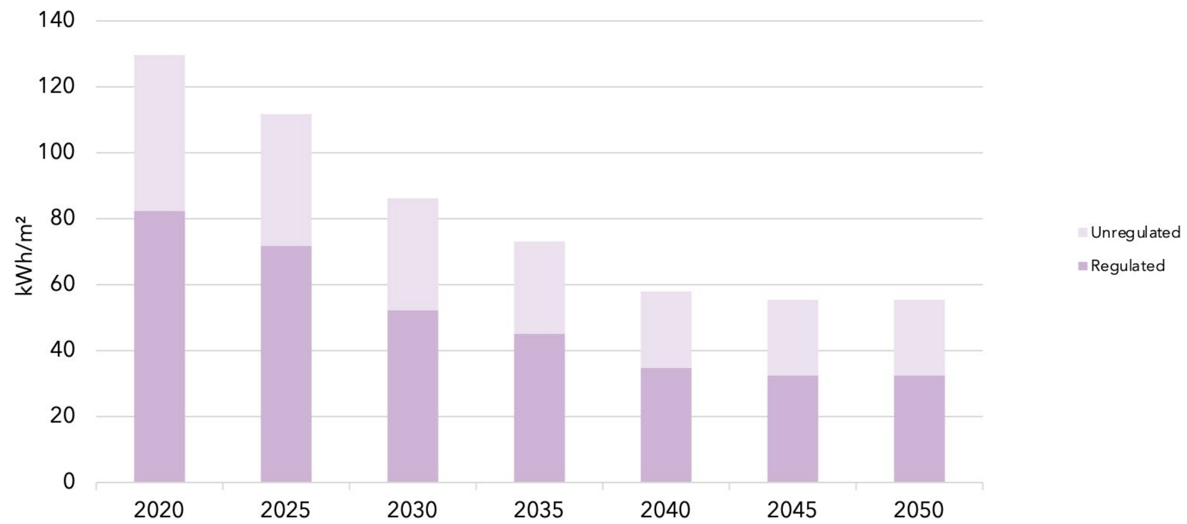

Figure 25: Non-domestic new offices energy use intensity

The projected energy use intensity of new offices is an intermediate output step of the model, based on the inputs (as described above). Figure 25 shows the energy use intensities over the period.

4.5. Scenario Definition – F-gas

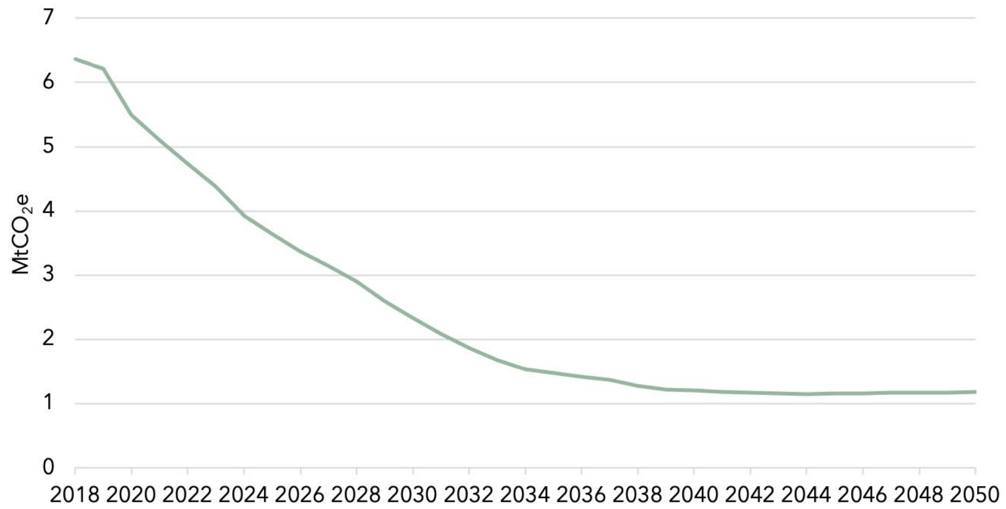

Figure 26: Non-Domestic Existing Building Energy Use Intensity Projections

The CCC provided a breakdown of F-gas emissions for the Sixth Carbon Budget Balanced Pathway. The sub-categories from Refrigeration, Air Conditioning and Heat Pump (RACHP) related to the built environment were identified in 2020, accounting for 42% of RACHP F-gas emissions. This percentage was applied backwards to the 2018 and 2019 reported data. The Balanced Pathway projection data was used for future years thereby including the impact of significantly more heat pumps in the built environment.

4.6. Scenario Definition – Infrastructure

4.6.1. Infrastructure Spend Projections

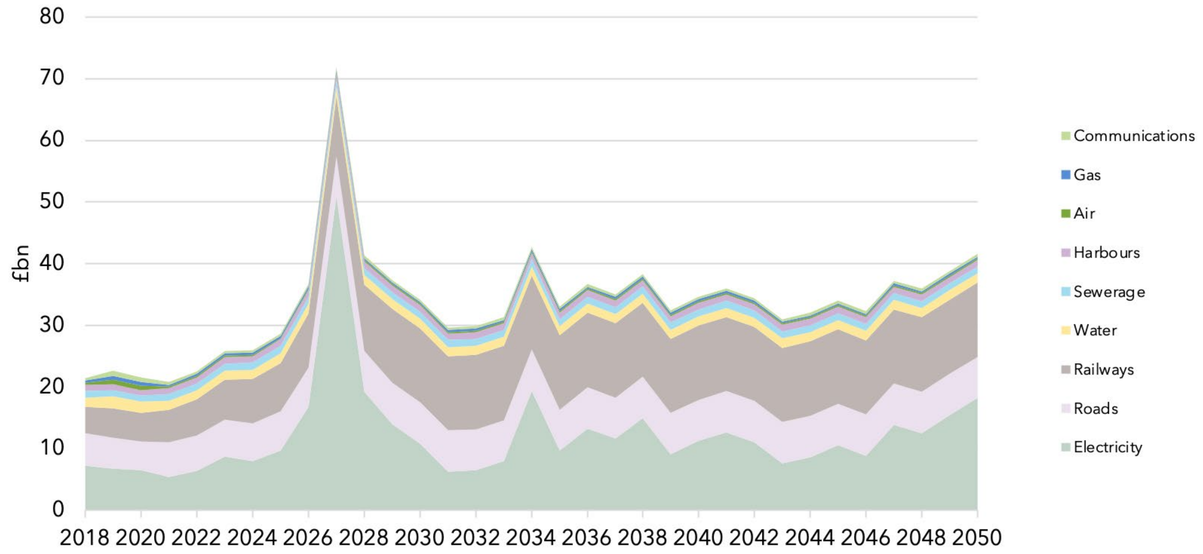

Figure 27: Infrastructure Spend Projections

The infrastructure spend projections for listed sectors (excluding electricity and gas) were based on a Fitch Solutions Market Insights study which contains estimates based on ONS data and industry forecasts in relation to the expected growth rates in each sector up to 2029.[33] Sewerage, gas and communications are not explicitly itemised but can be inferred from the more general construction growth forecasts. The air forecast combined the CCC Sixth Carbon Budget Aviation Summary growth projections for 2021 onwards with the Fitch report projections for 2018-2020[34]. The electricity projections were based on capital expenditure from electricity system modelling conducted by Aurora Energy Research for the National Infrastructure Commission which assumed the electrification of heating, 60% renewable production by 2050, and 2.9 $MtCO_2e$ of emissions from the power sector by 2050.[35] The gas projections were based on the Pathways to Net Zero report from the Energy Networks Association and assumes a Balanced Future Energy Scenario with a 2020 baseline.[36]

4.6.2. Change in demand – External lighting

Following the 2013 Routemap Model, annual growth was assumed to be 0.1%. This does not allow for new technology and services provided through existing street lighting infrastructure.

4.6.3. Change in efficiency – External lighting

In 2014, 10% of UK streetlights were LED, with 89% penetration expected by 2026. Analysis suggests that switching to LEDs saved 50% energy consumption, which increases to 80% when integrated with a central management system[37]. Interpolating for deployment by 2018 implies a further 68% reduction possible by 2050.

4.6.4. Water and Wastewater

Following the 2013 Routemap Model, the average historic energy use for water and wastewater was applied to population growth to project future energy use.

4.6.5. Construction & Demolition Waste – Destinations

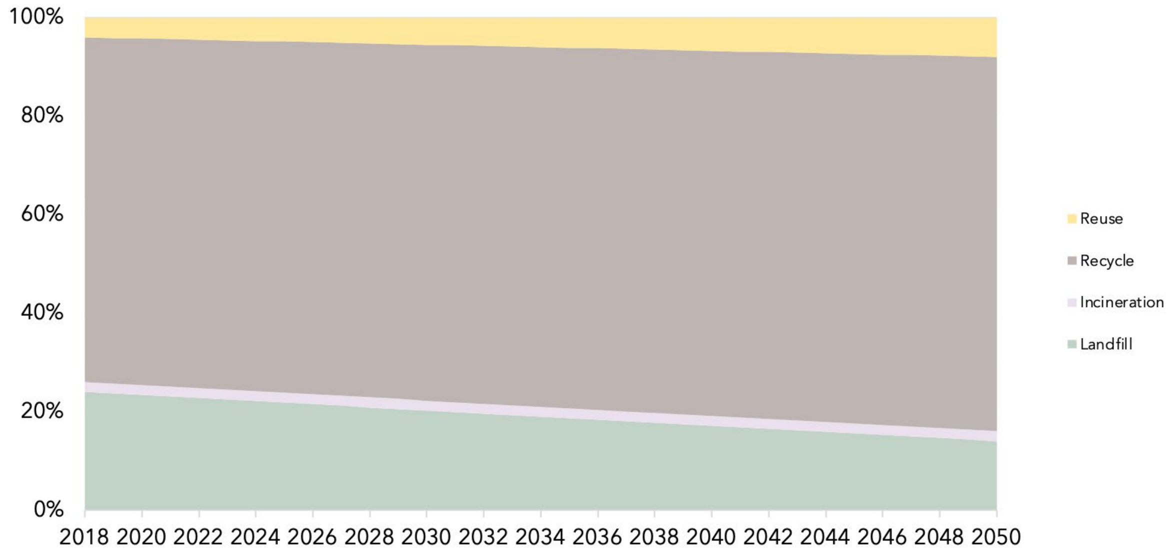

Figure 28: Construction & Demolition Waste – Destinations

Projections for construction and demolition waste destinations were derived from BRE's SmartWaste system, which is used on many construction projects.[38] KPIs and benchmarks are generated including for waste arisings (tonnes/£100k of project value) and diversion of waste from landfill. The task group made assumptions as to the change in % of different waste disposal routes in 2050 compared to SmartWaste figures and Defra historic data. Assumptions were based on a review of relevant industry literature and task group insights. Incineration was assumed to stay static at 2%, with any increase in rates of incineration offset by reduction in waste generation. Recycling rates were assumed to increase 6% by 2050 on the assumption of the best 10% of industry achieving a significantly higher rate than presently. Rates of reuse were assumed to double (4-8%) as an ambitious estimation, though this remains substantially lower than targets by industry groups like the Ellen MacArthur Foundation and C40 Cities, who propose reuse rates of 15-22%. Landfill was assumed to make up the remaining 14% of disposal routes at 2050.

4.6.6. Construction & Demolition Waste Arisings and Emissions Intensity

Projections for construction & demolition waste figures are derived with reference to UK statistics on waste from Defra[39], with a 5% decrease projected by 2050. A 2% figure for waste processing emission reductions was assumed based on Defra historical range of 1-8%.

4.7. Scenario Definition – Embodied Carbon

4.7.1. Reduction Factors – Materials, Site & Transport

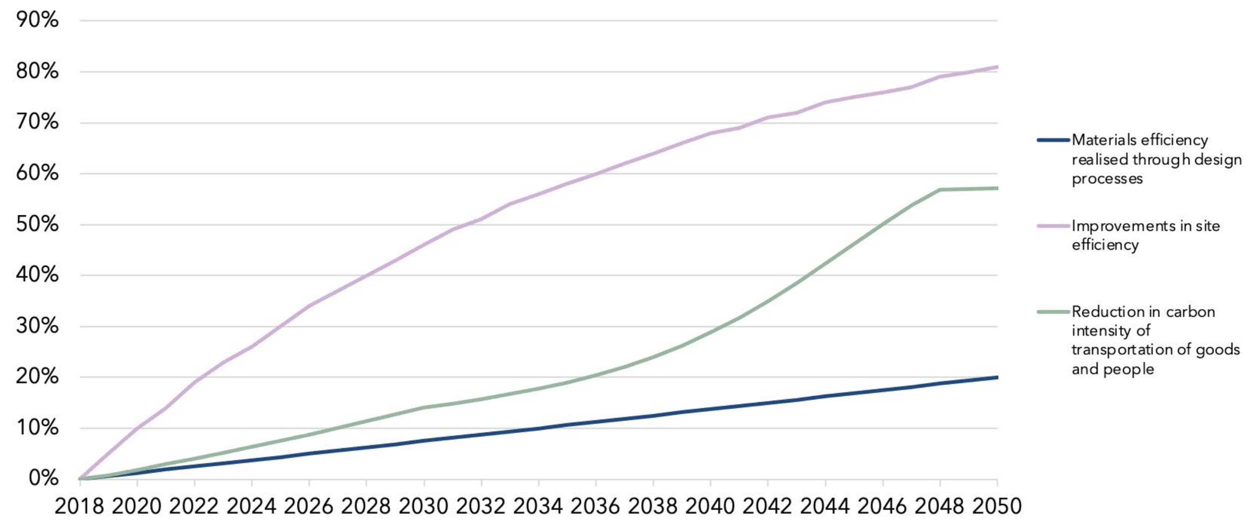

Figure 29: Improvements in design material efficiency, transportation of materials and construction site practices.

Transportation

For transportation, different modes of transport are decarbonising at different rates. For road freight, which is the largest mode used in construction, the significant milestones are the phase out of new petrol or diesel LGVs from 2030, and from 2035 all new HGVs must be zero emission (HM Government Ten Point Plan).[40] The National Grid Future Energy Scenarios were used for the trajectory and scaled to the relative reduction in internal combustion engines (as per Department for Transport data).[7] For rail, Network Rail's environmental strategy commits to net zero carbon emissions by 2050.[41] The trajectory was scaled in line with rail electrification targets. The International Marine Organisation strategy for shipping commits to a 40% reduction by 2030 and a 50% reduction by 2050 (from a 2008 baseline).[42] The trajectory was a linear interpolation of these targets. No reduction was assumed in the carbon intensity of air freight which accounts for a small share of emissions from transportation of goods and people.

Design Efficiency

Projections for improvements in design efficiencies were estimated based on a number of studies that give a wide range of predictions for possible design savings. The IEA predict an 11% saving for cement and 17% for steel by 2050 (pro-rated down from their 2060 figures)[43], whilst UNEP use a figure of 20% for reinforced concrete design and 15% for steel beams[44] (the UNEP report also noted that this "is somewhat lower than the assumption by Milford et al.")[45]. A study into steel frames published by Dunant et al showed potential savings of 40%[46], and a similar study for a single as-built project by Poole showed 34%[47]. On the basis of the range of available reference sources, an overall projection of 20% reduction of material usage through design efficiency was projected on a linear basis.

Site Efficiency

Data from major contractors (BAM Nuttall and Skanska) indicates that over the past 10 years on average, 5% construction phase carbon emissions reductions have been achieved.[48] This is as a result of continued technological developments that the industry has deployed over that time such as; optimising construction processes, digitizing construction operations and processes, value engineering, plant and equipment drive train technologies, electrification of site power supplies and some small plant, and training and behaviours pertinent to reducing carbon. The drivers for these measures have been largely commercial to mitigate the impact of increased fuel costs, carbon taxation and to comply with policies such as the Non-Road Mobile Machinery (NRMM) regulations and more recently the Ultra Low Emissions Zones (ULEZ) in London.

However, there is nothing currently that suggests this long term trend in carbon reduction will slow – in fact it is likely to accelerate should further punitive measures on carbon emissions be introduced, the ending of red diesel tax relief in April 2022 for example could have a dramatic effect on the financial case for electrification of plant and additionally drive the industry to more bio-fuel options. However, it seems sensible to remain conservative on projections of further efficiency gains that may come about in the near to medium term, as a result the projections continue the historically observed 5% annual emissions reduction trend.

4.7.2. Industry Intensity Factors

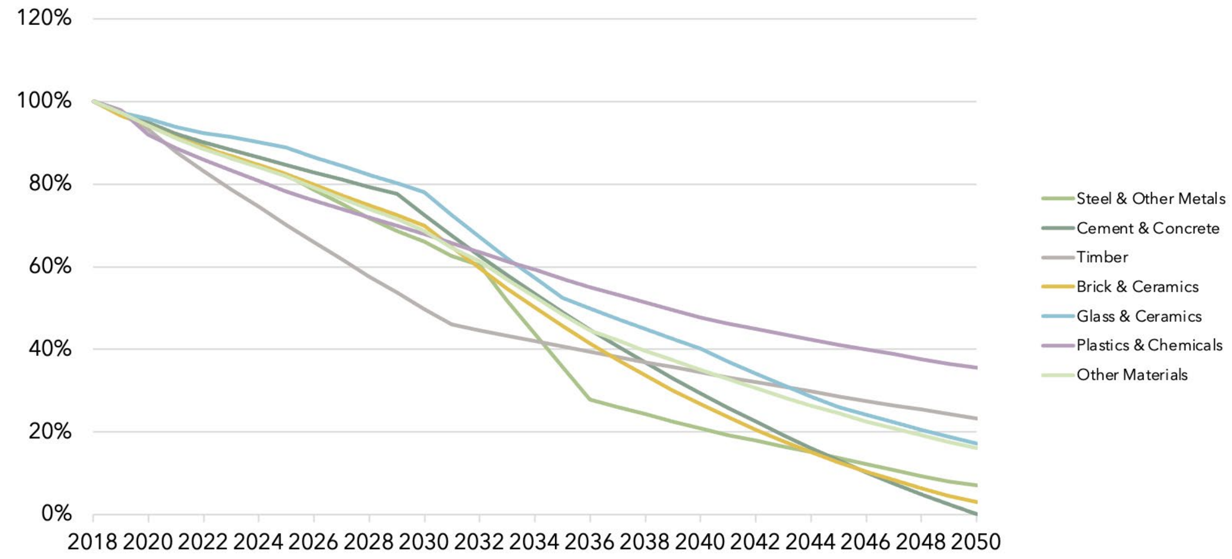

Figure 30: Carbon intensity (non-electricity emissions) per material category

Figure 30 above shows the change in non-electricity carbon intensity of the different material categories. Timber has the quickest rate of reduction, before slowing from 2030. Notably, Cement & Concrete is fully decarbonised by 2050.

The reductions available from improvements in manufacturing supply chains were derived from a number of sources. Reductions from grid decarbonisation were applied separately from reductions in non-electricity emissions to ensure a consistent grid trajectory across the roadmap scenario. Reductions from carbon capture and storage were applied to residual emissions after the incorporation of other improvements.

Cement & Concrete

The projected reductions in emissions for cement and concrete were based on the MPA (2020) UK Concrete & Cement Roadmap to beyond net zero.[49] This reflects the implementation of some of the identified decarbonisation levers (for transport, low carbon cements and concrete and fuel switching) and is a continuation of significant decarbonisation initiatives demonstrated by the industry in the UK already. The trajectory anticipates implementation of full-scale cement CCS in the UK commencing around 2030 following development of existing demonstration projects, assuming support from Government and other stakeholders to facilitate technology deployment. The use of carbon capture with a high proportion of biomass fuels means that there are no residual fossil emissions once other levers have been deployed.

Steel & Other Metals

Projections for the process improvements and mitigation of residual non-electricity emissions due to uptake of CCS from steel produced in the UK were taken from the CCC's Sixth Carbon Budget analysis. Projections for imported steel were taken from the Eurofer report "Pathways to a CO_2 Neutral European Steel Industry"[50].

Plastics & Chemicals

Given the high dependence upon imported products, and as little data could be found specific to process improvements in the UK plastics and chemicals sector, global chemical sector data was considered. The International Energy Agency (IEA) have estimated global CO_2 emissions reductions in the chemical sector between 2019 – 2070 and point to considerable emissions savings in the short to medium term (2020-40) through technology performance improvements and fuel switching. Technology performance data alone provides a 26% cumulative reduction in emissions between 2019 -2050. The scenario projections were also informed by consultation of other sources [51,52,53,54].

Commentary from Element Energy states similarity in CCS potential between UK chemicals and oil refining sectors[55,56]. Chemicals and oil refining sectors are likely to be most comfortable with capture separation technologies given the plants usually have high water availability required for these technologies. Given data specific to the plastics sector is not well documented, the oil refining and chemicals industries have been used. The data suggests a plausible sequence of CCS could reduce emission by 11% by 2025. Research from the International Energy Agency[57] implies a linear increase in CCS uptake for the chemicals sector from 2030-2050 and plateauing thereafter, therefore, data from Element Energy has been extrapolated linearly beyond 2025 to 2050.

Glass

The process improvements in the glass decarbonisation projections were based on the 'Maximum Technical Pathway Without CCS' model from the DECC/DBEIS 'Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050 – Glass'[58]. The Maximum Technical pathway assumes an increased switch to electric melting, fuel switching to biogas and increased use of recycled glass in production, deployed as varying rates as per the descriptions in the Maximum Technical Pathway section of the aforementioned report. The decarbonisation closely follows the 'current trends' line in Figure 26 of the source document, but modified to remove impacts of grid decarbonisation, as previously mentioned. The source material is considered robust, as this is the source material for the glass sectors 'Industrial Decarbonisation and Energy Efficiency Roadmap Action Plan'[59].

The CCS model for glass is based on the 'Maximum Technical Pathway With CCS/U' model. As noted in the document it is only deployed at scale from 2035 onwards, to reach 75% deployment by 2050. There is still some industry uncertainty about the suitability of CCS deployment for the glass industry given the relative size of annual emissions compared to other industrial sectors, but as it is still a technically feasibly deployment its impacts were included in the scenarios.

Brick & Ceramics

Data sources referenced in development of the trajectory included a variety of national strategy documents from the UK and Europe as well as manufacturer specific decarbonisation plans that were used to analyse whether the planned trajectories were being implemented in reality[60,61,62,63,64,65]. It was noted the ceramic industry had more specific quantitative reduction pathways; for the brick industry it was narrative based aspiration rather than quantitative commitment. Where data was found, a 40-60% reduction from process improvements by 2050 was considered realistic. Issues around the temperature and dilution of CO_2 that may impact upon CCS viability were assumed to be partially overcome.

Timber

Development of a Net-Zero Carbon Strategy for the Timber industry in the UK is in progress following the recent merger of the Timber Trade Federation (TTF) and Timber Research and Development Association (TRADA) into Timber Development UK (TDUK), in conjunction with other industry bodies. Ongoing initiatives to reduce emissions within the industry include measures to improve efficiency within forestry activities, plant and machinery, processing, and emissions from end of life processes. However, currently no quantitative data is available to indicate the improvements expected through these measures. The scenario was therefore based upon expert judgement and the actions from a small number of industry leaders.

Other Materials

A plethora of other materials are used in smaller quantities by the construction sector. Developing bespoke trajectories for each of these materials was not practical, so reductions in 'Other Materials' were based upon an average of levels achieved in specified material supply chains. This translated into a 46% reduction from improvements in processes by 2050, with 60% of residual emissions captured by CCS.

4.7.3. Buildings Change-of-Use, Utilisation, and Material Re-use

Change of Use

Conversion refurbishment projects which change the use of existing buildings rather than demolishing and rebuilding from scratch have the potential to temper the need for new construction and therefore embodied carbon. Recent changes in the planning system (permitted development rights) have increased the potential for such projects, and between 2015 – 2020 approximately 15,000 homes were delivered per year through PDR conversions[66]. 89% of these were office conversions[65], and proposed changes to the PDR legislation will increase the potential for such conversions in existing stock in other sectors. Asset level LCAs[67],[68] indicate that embodied carbon of a buildings structure is typically 45-55% of the total.

On the basis that some degree of work will typically be required to modify existing structures, a reduction factor of 25% has been applied to the capital carbon intensity factor within the trajectory for 15,000 of the new build dwellings, to account for carbon savings via the retention of existing structure through PDR conversions. This factor is applied to 25,000 new homes per year from 2025 to represent the increased potential for this type of project.

Building Utilisation

Evidence from multiple sources suggests that over-supply exists within certain sectors of the current building stock, and that potential also exists to better utilise floor area of the existing stock. Multiple sources have highlighted the current over-supply of retail floor-space in the UK. The Ellen Macarthur Foundation 2015 report ('Potential for Denmark as a Circular Economy[69]) estimates potential for reduction in demand for new floorspace of 9-10% between 2015 and 2035, assuming both improved office efficiency and home working, and increased sharing of residential space. The recent experience of mass home working during the Covid-19 pandemic is further evidence for the potential for home working. Policy Exchange research[70] indicates that the 2011 Census data suggests 12.4m under-occupied homes in England and Wales, with 1.1m homes with two spare bedrooms or more occupied by one person aged 65 or over living alone.

The wide potential for improved building utilisation through various opportunities has been represented in the trajectory by reducing demand for new office and residential by 10% by 2041 (allowing a 20-year period, as per research for Denmark), with a linear interpolation from 0% in 2021.

Material Re-use

The existing building stock is full of high value materials which have the potential to be re-used in new development through a circular economy model, dampening the demand for new materials. The C40 / Arup Buildings and Infrastructure Consumption Emissions report[71] referenced a study from Amsterdam (PUMA: Prospecting the Urban Mines of Amsterdam[72]) and set a target of 11% reduction in virgin metal and petrochemical-based materials by 2050, through circular re-use of existing building elements. The report notes that effective deconstruction requires preparation (so not always possible today) and an established market for deconstructed building components.

To represent this opportunity in the trajectory, demand for virgin metal and petrochemical-based materials has been reduced by 11% across all building sectors by 2041, with a linear interpolation from 0% in 2021.

5. Net Zero Scenario – Results

5.1. UKGBC Scenario Trajectory

This section includes a summary of some of the key results from the net zero scenario analysis. Full results, discussion and recommendations are included in the accompanying Pathway Report.

5.1.1. Total Carbon

Total carbon drop rapidly by 2035, with earlier reductions driven by decarbonising grid electricity. The impact of the large-scale domestic retrofit intervention shows in 2028-2031 with reducing operational emissions and increased embodied carbon emissions. The residual emissions in 2050 are <10 $MtCO_2e$.

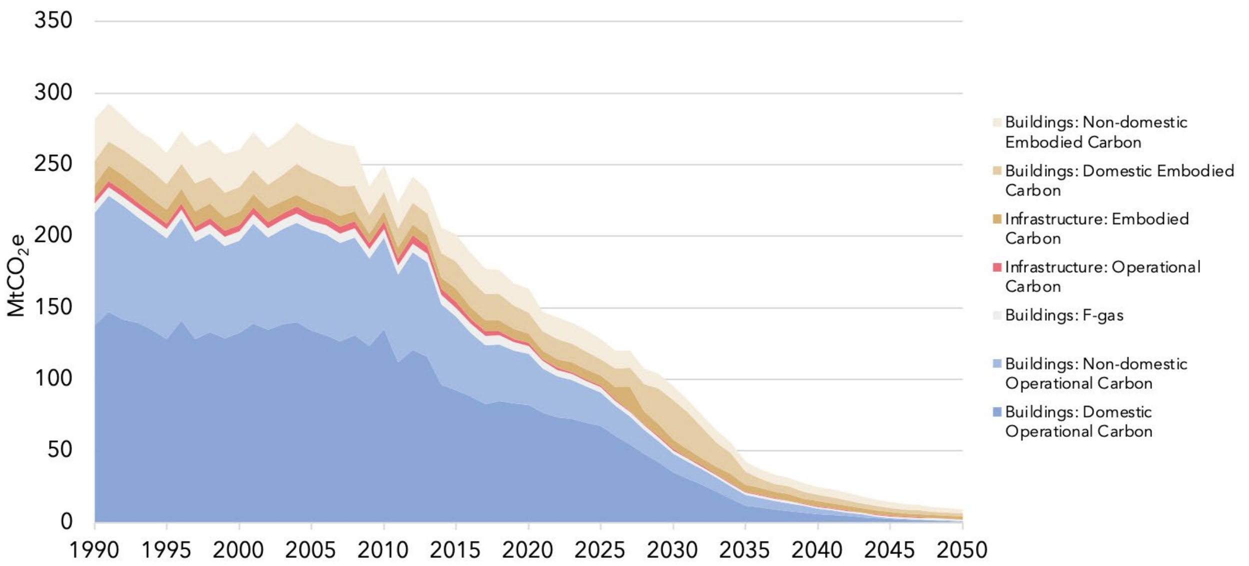

Figure 31: Overall carbon trajectory for the built environment (1990 – 2050)

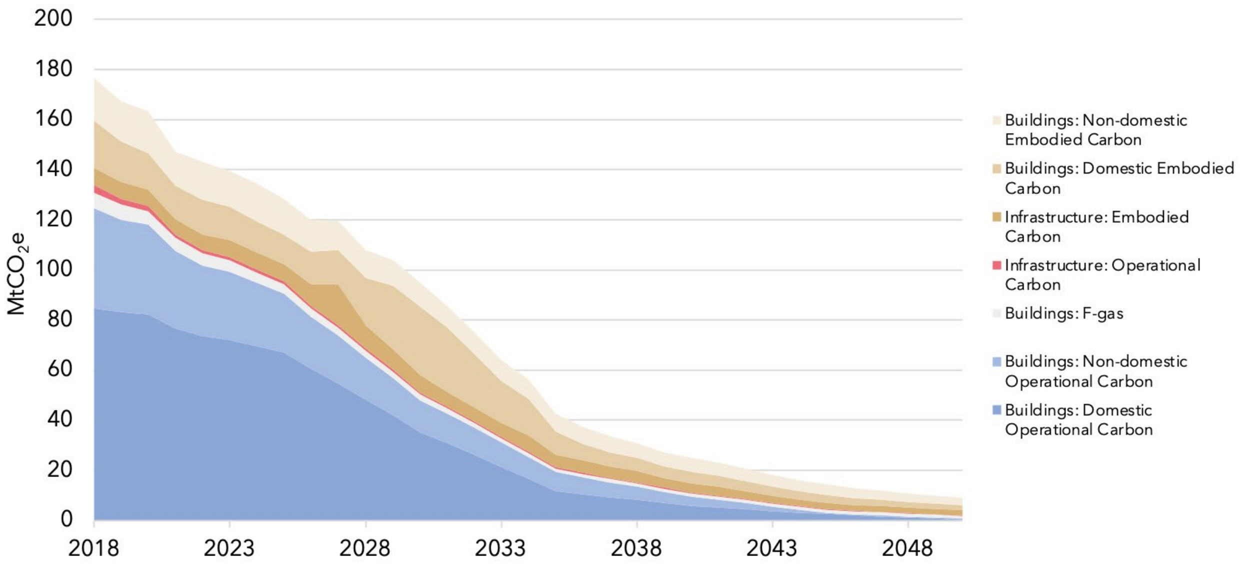

Figure 32: Overall carbon trajectory for the built environment (2018 – 2050)

5.1.2. Operational Carbon

The domestic sector is the largest source of operational carbon. Considering all buildings, the majority of operational carbon is in existing buildings, with emissions from heating greater than emissions for other electrical uses.

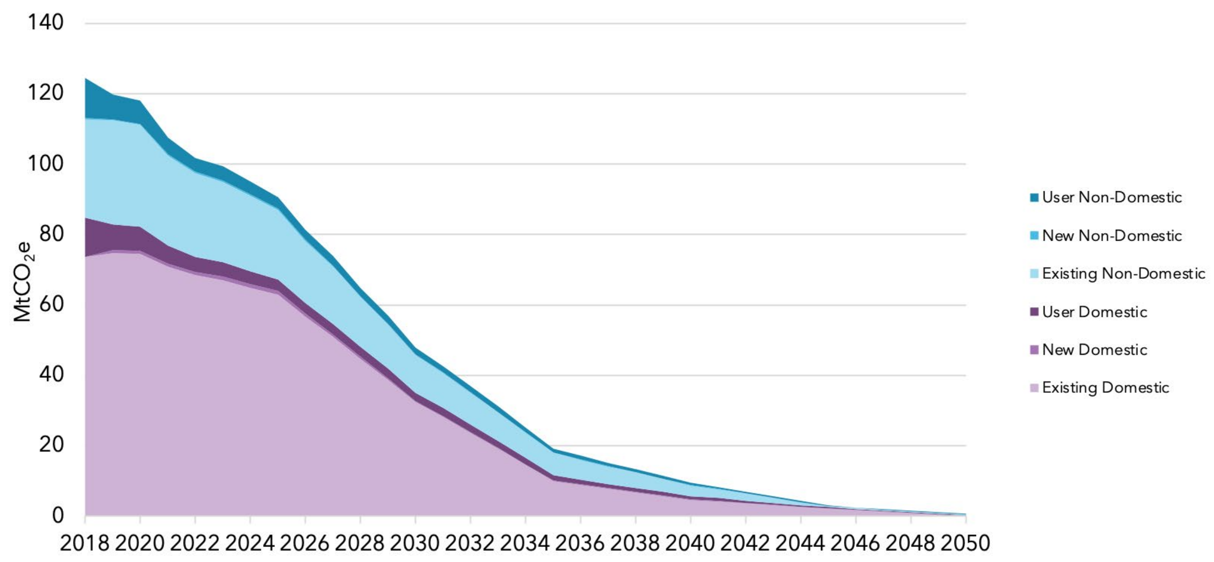

Figure 33: Operational carbon of buildings

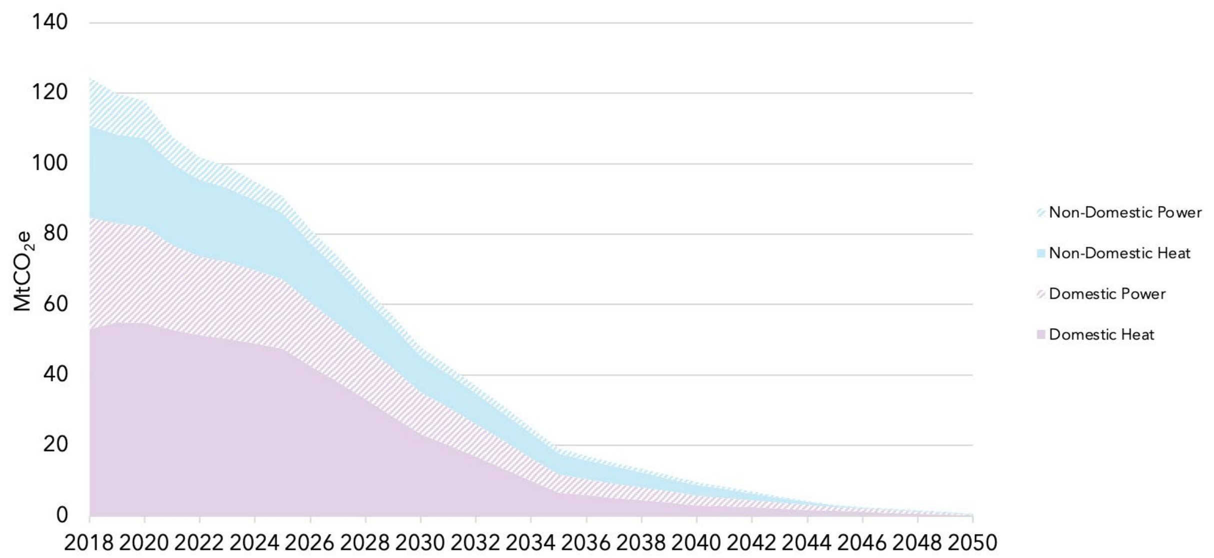

Figure 34: Operational carbon of buildings split by heat / electricity

5.1.3. Embodied Carbon

The large-scale domestic retrofit intervention causes a significant increase in overall demand and consequently a large increase in embodied emissions. The impact of decarbonised supply chains is clearly visible from 2035 to 2050.

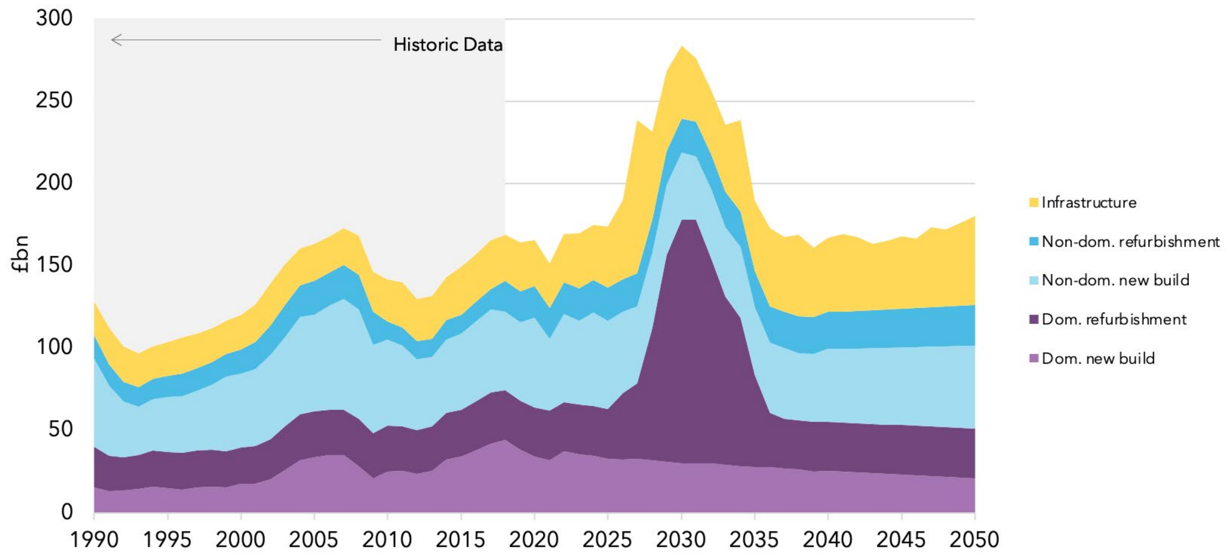

Figure 35: Total construction demand split by buildings and infrastructure

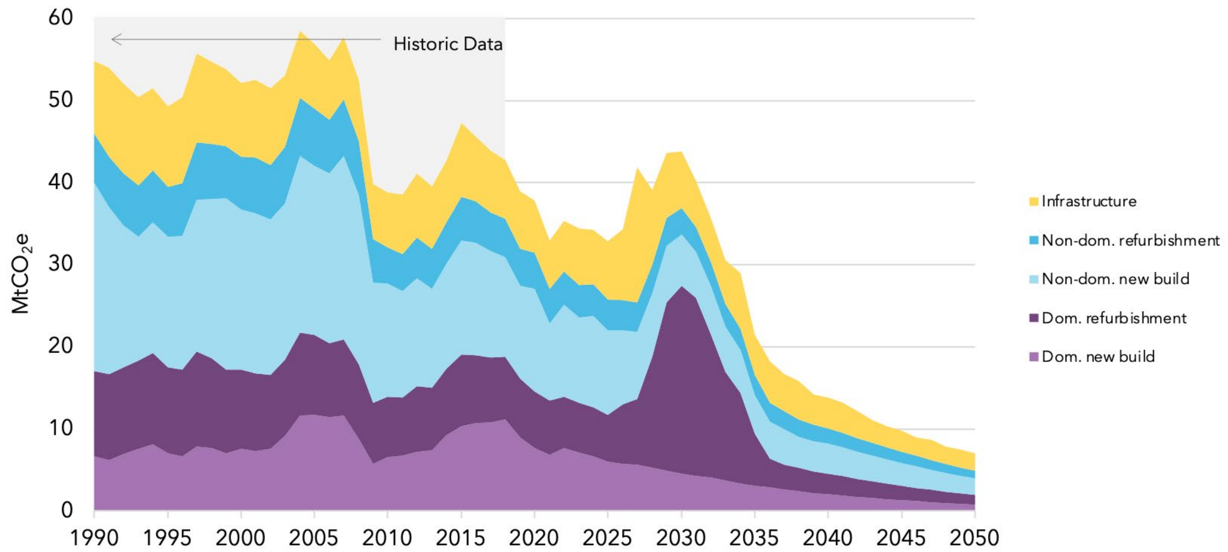

Figure 36: Total embodied carbon split by buildings and infrastructure

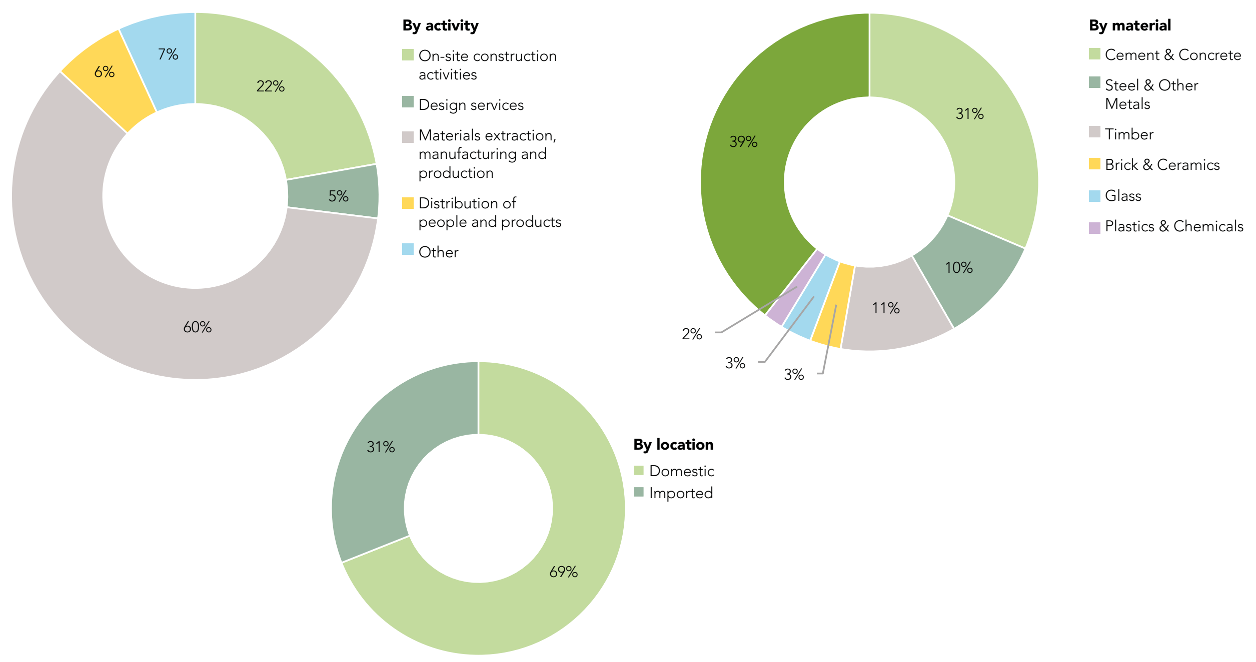

Figure 37: Embodied carbon breakdown (2018 data)

6. Net Zero Scenario – Sensitivities

6.1. Embodied Carbon

In addition to the main net zero scenario described in this report, certain additional sensitivity analyses were undertaken to highlight the impact of key inputs on embodied carbon, as shown in Figure 38. The scenarios considered are as follows, and the impact of each is shown separately, i.e. not cumulatively.

No improvement in site or material efficiency

In this case, the improvements in site processes and material design efficiency described above (Figure 29) were discounted, and the current status quo projected to 2050 for these factors. This scenario has the highest impact on cumulative emissions throughout the analysis period.

"Build build build"

This scenario represents a situation of strong economic growth with heavy investment in the built environment. It is based on the construction of 300,000 new homes each year, with non-domestic new build and refurbishment activity consistently matching the highest observed level from the last 30 years through to 2050. Domestic refurbishment and infrastructure demand profiles are unchanged from the main scenario (as these already represent unprecedented levels). This translates into an average of £37bn a year extra of final demand.

No CCS

This scenario excludes reductions from CCS.

Slower grid decarbonisation (steady progress)

This scenario shows the impact of the National Grid FES "Steady Progress" scenario for grid decarbonisation.

2018 final demand continued to 2050

This scenario fixes construction demand at 2018 levels through to 2050, i.e. no growth in any sectors and no mass domestic retrofit programme, as an alternative baseline.

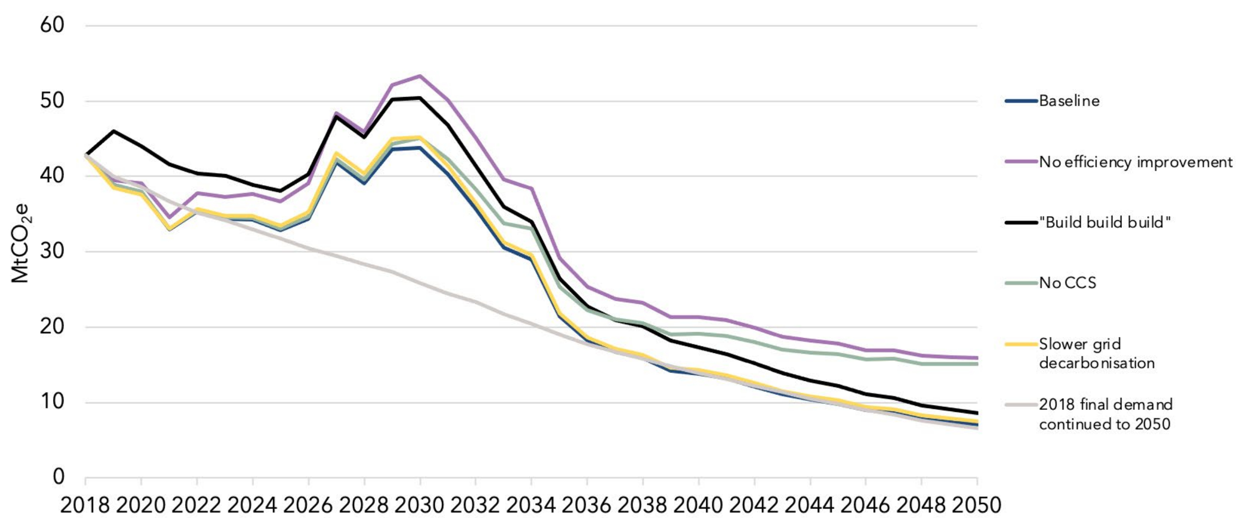

Figure 38: Embodied carbon scenarios

6.2. Reference Scenario (Business as Usual)

As described in section 3.6.1, the reference (or business as usual) scenario is a projection based on the BEIS

Energy and Emissions Projections (EEPs), which analyse and project future energy use and greenhouse gas emissions in the UK, to a create a forward "business as usual" scenario based on government policy outlook.

The EEP projections allow BEIS to monitor progress towards meeting the UK's carbon budgets and are used to inform energy policy and associated analytical work across government departments. The projections are based on assumptions of future economic growth, fossil fuel prices, electricity generation costs, UK population and other key variables regularly updated. They also give an indication of the impact of the uncertainty around some of these input assumptions.

Each set of projections takes account of climate change policies where funding has been agreed and where decisions on policy design are sufficiently advanced to allow robust estimates of policy impacts to be made.

The roadmap trajectory modelling takes a simplified approach where-by the future emissions profile (curve shape) presented in the selected BEIS scenario will be applied from the baseline year of built environment emissions. As the BEIS data only projects to 2040, the scenario will utilise the profile data to 2040, with the trending line then extended to 2050.

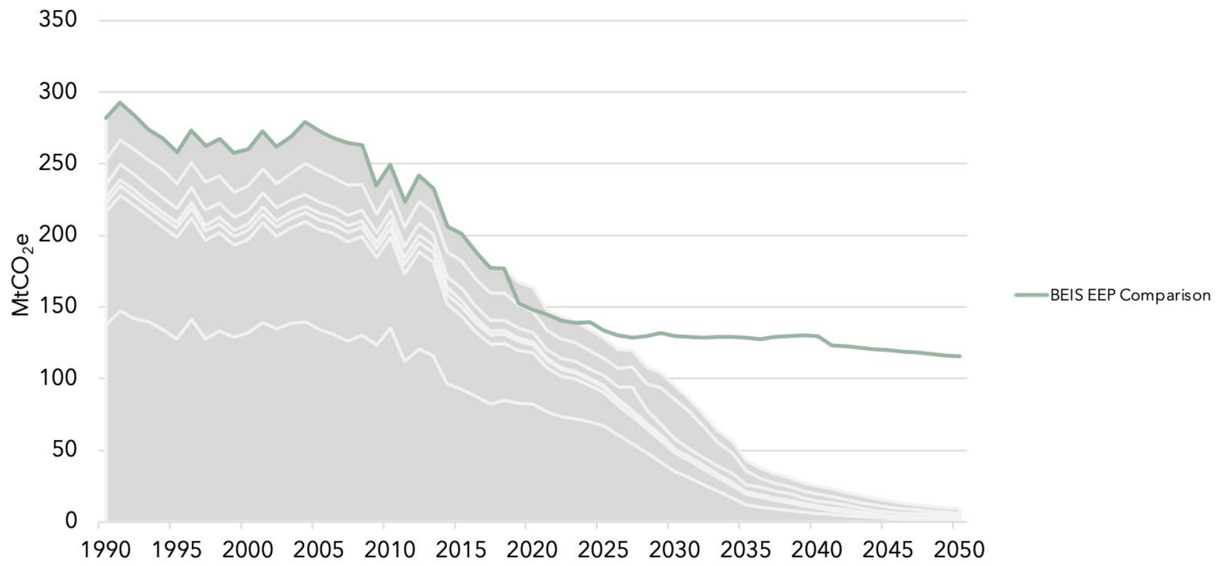

Figure 39: Reference scenario (Business as Usual)

Figure 39 above maps the Reference Scenario results onto the net zero scenario. As can be seen, the reference scenario initially projects slightly lower emissions than the net zero scenario in the short term, however these quickly tail off with a very shallow reduction profile forecast, leading to significant residual emissions in 2050 (approximately equal to the total residual emissions quantum for the UK forecast by CCC).

This indicates the transformative and systemic changes required in strategic policy and investment that will need to be brought forward in order to align with a forecast to Net Zero in 2050.

6.3. CCC Comparison

The intention of the CCC Aligned Scenario is to provide reference against the Balanced Pathway as published by the CCC in their Sixth Carbon Budget report. To enable comparison, it is necessary to align scopes. As detailed in this report, the net zero scenario is calculated on a consumption basis, including emissions from imported materials. The CCC balanced pathway and the UK Net Zero target is based on territorial emissions, i.e. only those emissions arising within the UK. The approach taken has been to present the UKGBC Scenario showing domestic territorial emissions only, i.e. excluding imported emissions.

This comparison was established through dialogue with the CCC and its published work. The comparison maps the national emissions budgets established by the CCC, alongside the net zero scenario, alongside emissions from the CCC balanced pathway relating to the built environment definition and scope as defined by the project.

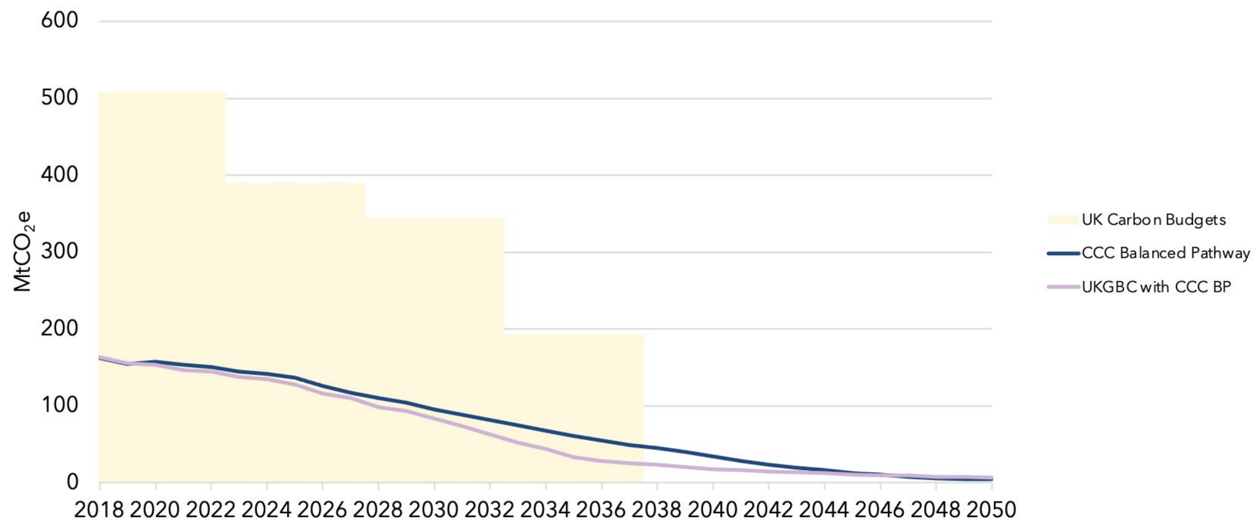

Figure 40: Comparison of CCC Balanced Pathway and UKGBC net zero scenario (*note boundary differences detailed below).

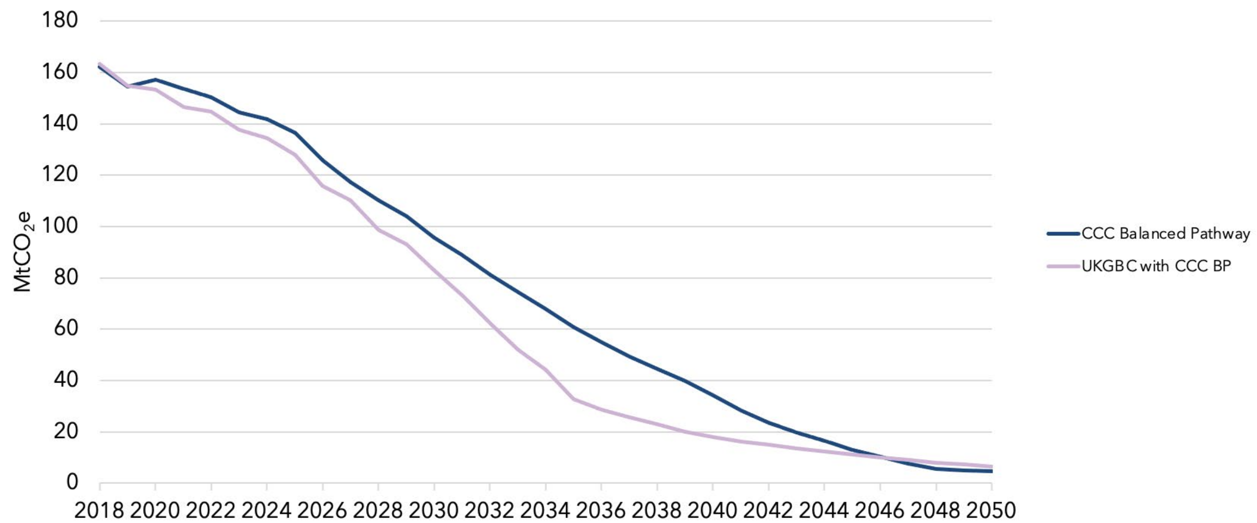

Figure 41: Comparison of CCC Balanced Pathway and UKGBC net zero scenario (*note boundary differences detailed below).

Although all efforts have been made to enable a like-for-like comparison, certain boundary differences remain which mean the comparison is imperfect. The purple CCC Balanced Pathway dataset includes the CCC's Residential Buildings, Non-Residential Buildings, part of the Manufacturing & Construction, Electricity Supply and F-gas sectors. Not all Manufacturing & Construction sector emissions relate to the built environment, and hence the slight differential in starting point. Figure 42, Figure 43 and Figure 44 show a more detailed comparison of embodied carbon emissions, against a subset of CCC Manufacturing & Construction emissions which have been estimated as those which relate to the built environment.

Other scope boundary differences include the inclusion in the net zero scenario of emissions from construction design services, and elements of surface transport which relate to the distribution of people and products related to construction in the built environment.

Other driving factors in the differences include the net zero scenario projections for construction demand (see Figure 35) which show steady growth in almost all sectors in the years to 2050. Construction demand also factors in the anticipated domestic retrofit programme which creates a significant spike around 2030 as this transformative programme to retrofit 27m homes by 2040 enters its most accelerated phase between 2030-2035.

Figure 42 shows the change relative to 2018 in the CCC's baseline emissions projections for the share of the manufacturing and construction sector that we estimate is attributable to the built environment. We estimate this share based upon the proportion of final output from these sub-sectors that is purchased by construction sectors (SIC 41-43) according to UK National Accounts for the most recent year. The UKGBC final demand profile is predicted expenditure on construction activity relative to 2018 levels.

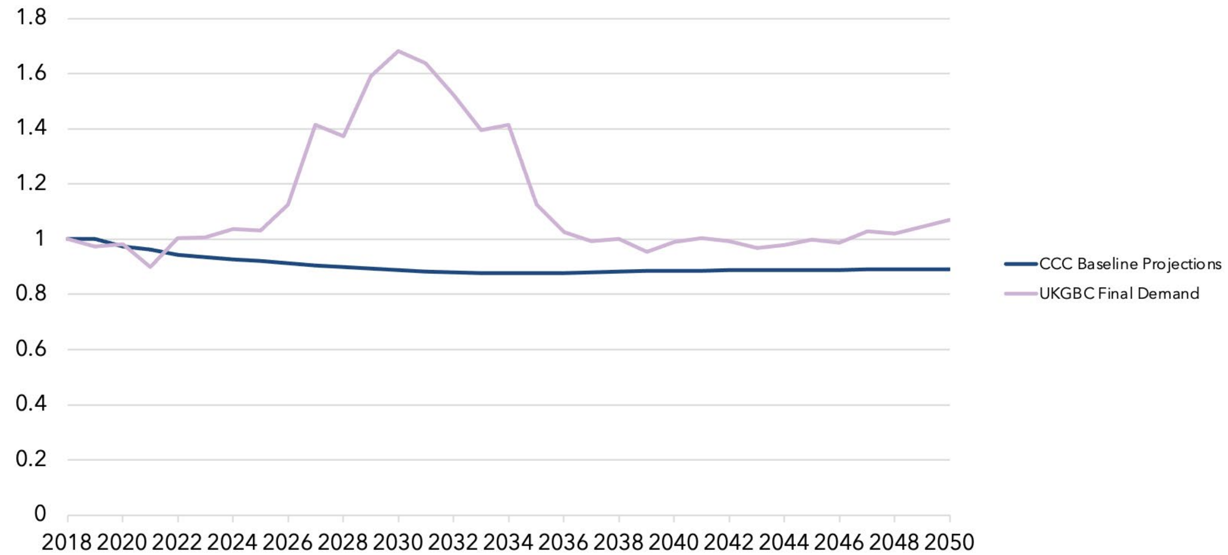

Figure 42: Comparison of CCC Balanced Pathway and UKGBC net zero scenario for construction output

Figure 43 below shows under the CCC's Balanced Pathway the relative change in emissions attributable to the share of the manufacturing and construction sector that we estimate is attributable to the built environment. It compares this with the relative change in the total carbon intensity (i.e. average embodied carbon emissions per £ of spend on construction) in the UKGBC pathway.

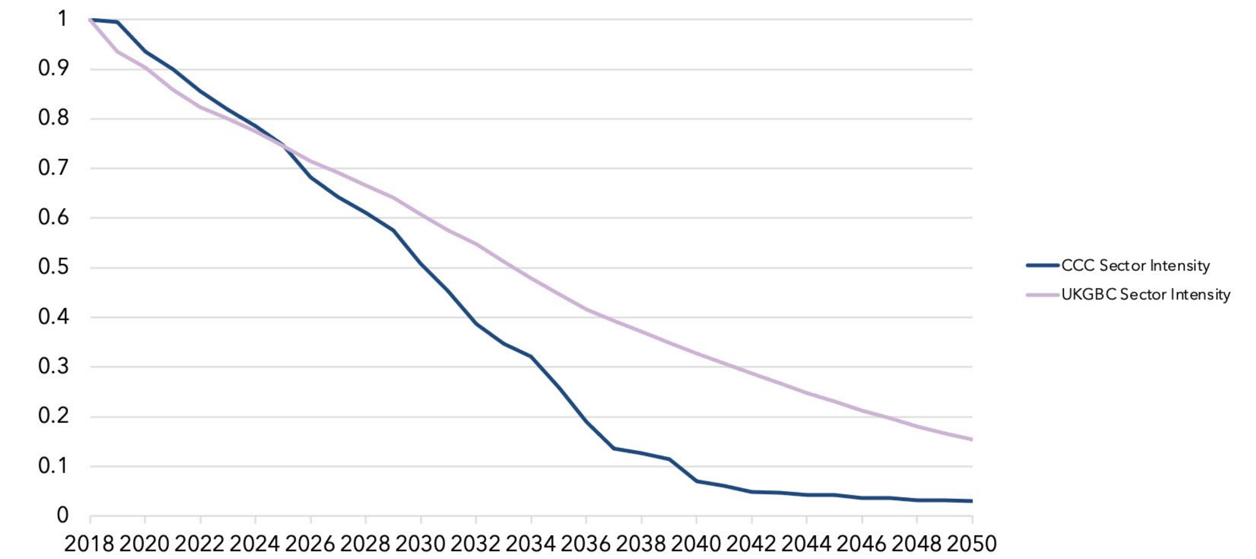

Figure 43: Comparison of CCC Balanced Pathway and UKGBC net zero scenario for the carbon intensity of construction materials

Figure 44 below compares the overall change in domestic (i.e. territorial) embodied carbon emissions under the UKGBC pathway with the emissions under the CCC's Balanced Pathway from the share of the manufacturing and construction sector that we estimate is attributable to the built environment.

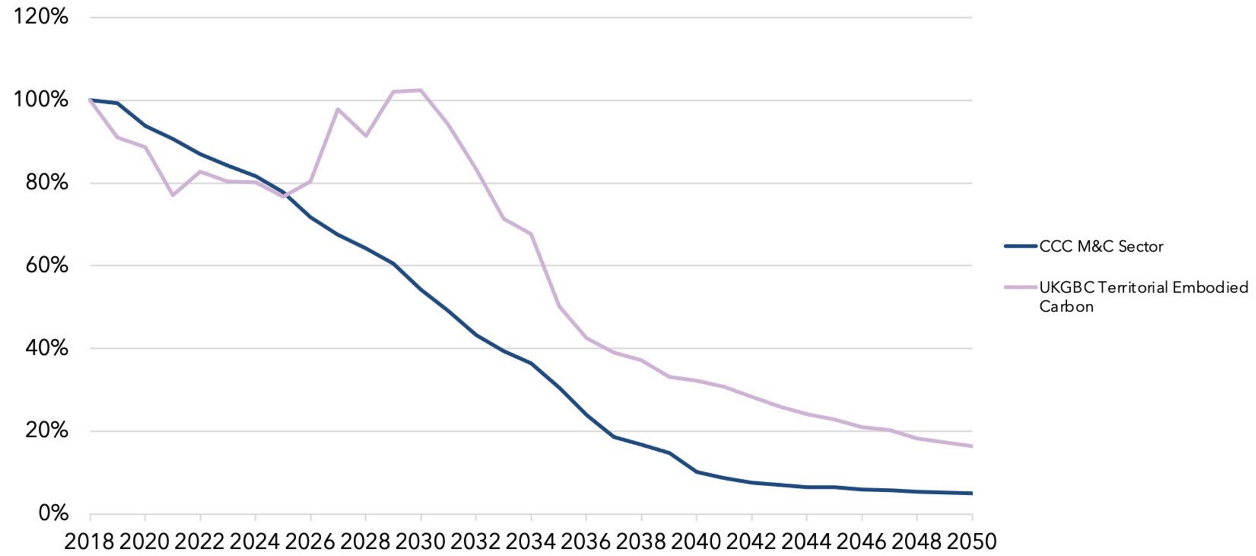

Figure 44: Comparison of CCC Balanced Pathway and UKGBC net zero scenario for embodied carbon attributable to the built environment

Within operational carbon there are numerous variations between the Balanced Pathway and the net zero scenario, most notably a deeper and more accelerated domestic retrofit programme in the net zero scenario, but with more conservative projections for domestic behaviour change.

For consistency, this sensitivity analysis used grid electricity carbon factors calculated from the CCC Balanced Pathway data workbook.

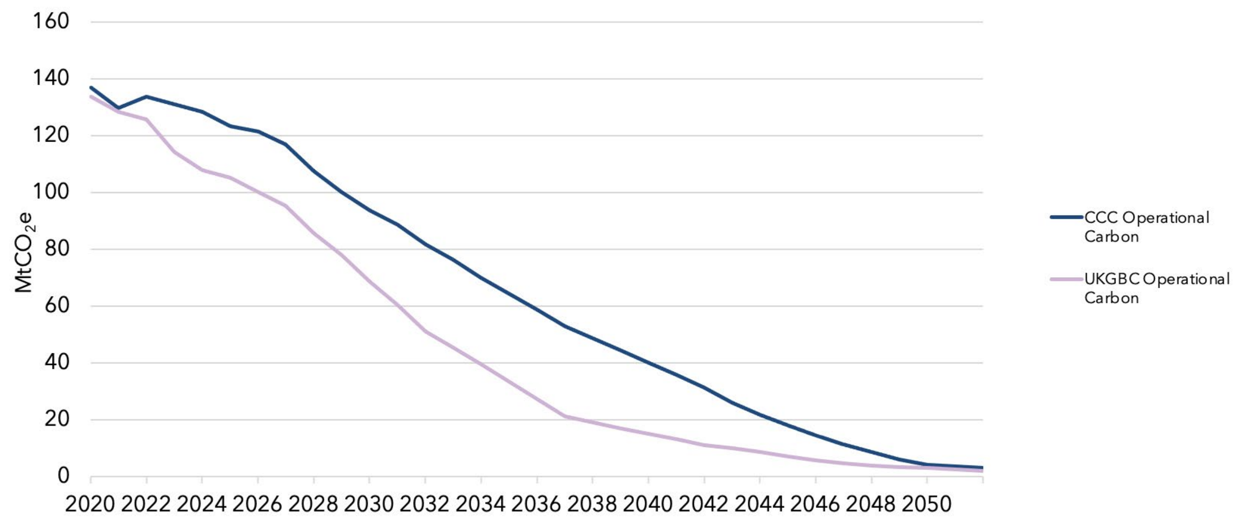

Figure 45: Comparison of CCC Balanced Pathway and UKGBC net zero scenario for operational carbon

7. Summary

The Net Zero Whole Life Carbon Roadmap for the Built Environment provides a shared vision and set of actions for achieving a net zero carbon UK built environment by 2050, in relation to the construction, operation, and demolition of buildings and infrastructure.

This technical report provides detail of the project structure, the process for data collection, and the key features of the calculation methodology. A key aspect of the project approach was to ensure that The Roadmap was co-created by the industry. To facilitate this engagement, UKGBC convened a project Steering Group and four Task Groups, who focused on New Build, Domestic Retrofit, Non-Domestic Retrofit and Infrastructure. This report records the data inputs from the project team, which set out the required pace and scale of mitigation measures across the built environment.

The Roadmap created a carbon footprint of the UK built environment based on the most up to date emissions data. This shows that the UK Built Environment is currently responsible for 25% of total UK greenhouse gas emissions (buildings and infrastructure).

The Roadmap model provides a timeseries approach to its calculations including historical outturn emissions from 1990 to a baseline calculation year of 2018 (the most recent year in which full emissions datasets are available); and then the ability to apply projected emissions scenarios to 2050. The modelling exercise produced the carbon trajectory for the net zero scenario. This showed that total carbon drops rapidly by 2035, with earlier reductions driven by decarbonising grid electricity. The impact of the large-scale domestic retrofit intervention shows in 2028-2031 with reducing operational emissions and increased embodied carbon emissions.

The Roadmap's approach was to capture all of the emissions related to the built environment under one sectoral umbrella. The Roadmap trajectory can thus be seen as compatible with the CCC's balanced pathway and national carbon budget, as near identical end points are reached, albeit with some differences in the approaches taken to drive decarbonisation.

In the Roadmap carbon trajectory, operational emissions from buildings are effectively reduced to zero by 2050, however, a small level of embodied and F-gas emissions remain. The final residual emissions for the built environment resulting from the trajectory detailed in this report equate to 6.9 MtCO_2e considering domestic (territorial) emissions, and 9.1 MtCO_2e including all consumption emissions (i.e. imported materials). The CCC projection for total UK removals by 2050 is 97 MtCO_2e (territorial). Therefore, the built environment's residual territorial emissions equate to approximately 7% of the estimated total.

The Roadmap is a resource for the sector that establishes urgent priorities and actions for decarbonisation. Achieving the net zero 2050 target is feasible, but will require a transformative shift in industry practices, as well as Government policy and investment into key delivery programmes and technologies.

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