NATIONAL
INFRASTRUCTURE
COMMISSION

Congestion, Capacity, Carbon: priorities for national infrastructure

Modelling Annex

NATIONAL INFRASTRUCTURE COMMISSION

Contents

1

Introduction

The National Infrastructure Commission has been tasked with putting together a National Infrastructure Assessment once a Parliament. The Assessment will analyse the UK's long-term economic infrastructure needs, outline a strategic vision over a 30-year time horizon and set out recommendations for how identified needs should begin to be met. It will cover transport, digital, energy, water and wastewater, flood risk and solid waste, assessing the infrastructure system as a whole. It will look across sectors, identifying and exploring the most important interdependencies.

The Assessment's recommendations will be built upon a wide evidence base and analytical underpinning, which will incorporate modelling of a range of scenarios. This will help outline how the UK's infrastructure requirements could change in response to different assumptions about the future. Scenarios are a widely-used approach to addressing uncertainty.[1] Quantifying scenarios is a crucial part of modelling policy options.

This annex sets out the Commission's approach to infrastructure modelling and scenario development. The scenarios developed are based on available empirical evidence about past trends and quantitative and qualitative forecasts of changes in the economy, population and demography, climate and environment, and technology. This analysis has been published in separate discussion papers, each devoted to one of the key drivers of infrastructure supply and demand.

The scenarios are tested using the national infrastructure systems model (NISMOD), which was developed by the Infrastructure Transitions Research Consortium (ITRC) and used to inform the National Needs Assessment, as well as models used by Government departments for the water, solid waste, transport and energy sectors. The Commission is relying on existing models and approaches, which have been independently quality assured. The modelling results are further tested through sensitivity analysis of selected parameters.

The analysis assumes a 'do minimum' policy, which provides a baseline for the Commission against which it can compare policy options and recommendations as part of the Assessment. The results from the baseline analysis will provide evidence on the potential challenges for each sector through identifying the likely scale of future infrastructure requirements and will support the development of infrastructure recommendations that are robust to future uncertainty.

The Commission is grateful for the support it has received from the ITRC and from Government analysts in this modelling. The inputs into these models reflect the Commission's scenarios and judgements not those of the model owners, and responsibility for the conclusions therefore lies with the Commission.

[1] For more detail please see section on 'Addressing uncertainty through scenario-based planning' in Strategic Infrastructure Planning – International Best Practice, OECD and National Infrastructure Commission.

2

Analysis for Congestion, Capacity, Carbon: priorities for national infrastructure

2.1 Objectives and approach

2.1.1 Objectives

The key modelling objective for *Congestion, Capacity, Carbon: priorities for national infrastructure* is to help identify and assess the UK's future **infrastructure needs** across a range of agreed scenarios, which will provide evidence on potential **challenges** for each sector.

The purpose of this analysis is not to 'predict the future' but to provide the **likely scale** of future infrastructure requirements and inform recommendations that are **robust under a number of possible futures**.

In the time available, the Commission was not able to develop its own models and thus relied on existing models. Results have been validated by **sensitivity analysis of selected parameters** and by comparing outputs from **different models**, which have been independently quality assured.

This work concludes the first phase of modelling for the first National Infrastructure Assessment. The second phase of modelling will test policy options to address the challenges identified in *Congestion, Capacity, Carbon: priorities for national infrastructure*. These options will be modelled and compared against the baseline constructed in the first phase.

As set out in the Commission's Process and Methodology Consultation, scenario modelling intends to provide context for the Commission's judgements, but it is not a substitute for them. Models are representations of the real world which add insight, but necessarily simplify.

2.1.2 Approach

The Commission's approach to scenario development and modelling broadly followed the six steps outlined below. Further details of each of these steps are given in the following sections.

I. Analysis of key infrastructure drivers to identify trends which will affect future infrastructure needs

To inform the scenario development, the Commission has identified four key drivers of supply and demand for infrastructure services: economic growth and productivity; population and demography; climate change and environment; and technology. Each driver has been analysed to identify probable trends which are likely to affect supply and demand for infrastructure services over the long term.

II. Selection of variants for each driver to form the basis of our scenarios

The level of uncertainty surrounding the trends in each driver was carefully considered and scenarios used by reputable external organisations were reviewed. This led to the selection of key 'variants' of the four drivers to form the basis of the Assessment's scenarios. These variants are not inherently more likely than others, but should rather span the range of plausible outcomes.

III. Scenario generation based on all possible combinations of the variants and scenario selection based on agreed criteria in order to obtain a manageable set of scenarios that explore a range of possible futures

All possible combinations of the variants of the four drivers were used to generate scenarios. As this offers too many possible combinations to analyse and explain, a smaller set of scenarios was chosen from all possible combinations.

IV. Definition of a 'do minimum' policy baseline

A modelling baseline was defined for each sector, which attempts to develop a plausible scenario in which the government takes the minimum amount of action necessary, so that the reasons for more interventionist actions can later be judged against this scenario. Given the different ways in which the government has intervened in the different sectors considered in the past, the baseline scenarios are not identical across sectors.

IV. Scenario testing using ITRC's NISMOD and government departments' models for the water, waste, transport and energy sectors

Model structure is a key source of uncertainty which is addressed in part by running equivalent scenarios through two sets of models, where two models were available. The selected scenarios were run through two sets of models in the case of the energy, solid waste and transport sectors, and only in the ITRC model for the water sector.

For digital infrastructure, there was a lack of suitable models available to consider long-term need. For flood risk, the Commission has relied on Environment Agency modelling.

The Commission and the Environment Agency are currently engaged in the potential development of complementary modelling to LTIS, the EA's model to estimate long-term flood and costal risk management investment.

IV. Consultation with stakeholders to discuss the outcomes of the analysis and iterate accordingly

This was done both informally, by sharing results and assumptions with departmental and academic stakeholders and through two roundtables involving experts from the modelling community and beyond.

2.2 Infrastructure drivers

The Commission has identified **four drivers of infrastructure supply and demand,** each impacting infrastructure needs to varying degrees depending on the sector:

I. Changes in the economy
II. Changes in population and demography
III. Changes in climate and environment
IV. Changes in technology

The Commission consulted on whether these were the most important infrastructure drivers and responses showed broad agreement. Other drivers were also mentioned as important, such as consumer behaviour, policy and political risk. Although the Commission recognises that changes in these drivers can be important drivers of future outcomes, these are extremely difficult to model and it was decided that they would not explicitly form the basis of scenarios. The Commission will instead consider the extent to which its scenario-based modelling is sensitive to key parameters that might change through behavioural or government policy change.

The behavioural change element is analysed for the solid waste and transport sectors in the first phase of modelling, and policy change will be modelled in the second phase of modelling.

The four drivers have been assumed to be exogenous for modelling purposes, though in some instances this distinction is not clear-cut – for instance, there may be two-way causality between infrastructure investment and population growth, or infrastructure investment and economic growth. For simplicity, however, no feedback loops were considered in this analysis.

Each driver has been analysed to identify **probable trends** which are likely to affect supply and demand for infrastructure services over the long term – these trends form the basis of the **driver variants**. Papers discussing each driver have been published. This subsection sets out the variants for each driver and the rationale which informed its selection and development.

2.2.1 Economic growth and productivity

The Commission’s economic growth projections are based on the analysis undertaken in the economy driver paper. The starting point for the economic growth inputs are Office for Budget Responsibility (OBR) long-term growth projections. The OBR provide 50-year economic and fiscal projections in their Fiscal Sustainability Report (FSR). The remit for the Commission requires the Commission to use the OBR’s FSR projections for its ‘fiscal remit’, a limit set by Government on the level of public expenditure on infrastructure within which the Commission is required to make recommendations.

The economic growth variants used by the Commission are shown in Table 1, on the following page.

Table 1 – Long-term annual productivity, GDP and GDP per capita growth, per cent

	productivity	GDP*	GDP per capita
central variant	2.0	2.3	1.9
low variant	0.8	1.2	0.7
additional variant	1.8	2.2	1.7

**under the ONS 2014-based principal population projection, will vary in other population variants*

As is the case with all the Commission's driver variants, these variants are not inherently more likely than others, but should rather span the range of plausible outcomes and reflect the significant uncertainty around future GDP. The rationale for each of these is set below.

a) Central variant

The central variant is based on the OBR's central long-term economic projection, the main official projection from the UK's independent economic and fiscal forecaster. This would imply long-run GDP growth per capita of 1.9% per year, on average. However, in the OBR's projection, productivity growth does not reach its long-run level until 2026/27, so growth in GDP per capita until then is somewhat lower. Overall, this projection would leave GDP per capita in 2050 74% larger than in 2020.

b) Additional variant

The historical data show that economic growth rates can vary. Partly driven by concerns about very low productivity growth since 2008, there is a considerable debate about potential future growth prospects. This has been captured in sensitivity analysis for the OBR's short-term forecasts. It is therefore sensible to include variants to the central projection that reflect lower possible growth rates.

The additional variant assumes more modest growth with an average long-term growth rate of GDP per capita of 1.7% per year. This is based on an extension of the OBR's central 5 year forecast, with productivity growth remaining at 1.8% per year (as assumed at the end of the Economic and Fiscal Outlook forecasting period), rather than returning to 2.0% as the OBR assume in their central long-term projection.

It thus weights the more recent period of very low productivity more heavily. This would imply that GDP per capita in 2050 would be 66% larger than in 2020.

c) Low variant

This weak growth variant assumes long-term productivity growth (output per hour) of 0.8% per year, with GDP per capita growth of 0.7%. This is in line with the arguments made by economists such as Bob Gordon and Tyler Cowen and the recent trend of very weak productivity growth since 2008.

This figure is similar to values of GDP growth per capita in the 19th century, reflecting the argument that the great inventions of the 20th century will not be repeated. It is also consistent with an extension to the OBR "weak productivity" scenario (that only covers the period 2016/17 to 2021/22) across the full period. This would imply that GDP per capita in 2050 would be 23% larger than in 2020.

The Commission has considered whether a more optimistic variant would also be useful. However, the central variant is already based on productivity growth over a period which included significant innovation, including the internet, and broader technological change.

The historical data do not point to the likelihood of a significant period of growth above this trend rate even if further significant innovations are developed. While growth was somewhat higher in the immediate post-war period, this partly reflected 'catch-up' following the Second World War.

2.2.2 *Population and demography*

The starting point for the population and demography inputs into the Commission's scenarios are Office for National Statistics (ONS) UK population projections. The ONS are the main provider of UK population projections and provide a range of variant projections which include the Assessment's forecasting window to 2050.

The variants chosen by the Commission are based on the analysis in the population driver paper. The options are intended to cover the range of realistic possible outcomes based on the analysis in this paper. Variants for the total population (central, low and high) reflect uncertainty in the level of UK-wide demand, which will arise directly from people using infrastructure services themselves, and indirectly through those elements of business, government and third sector demand which relate to the size of the population.

Variants for where people live (population redistribution variant) reflect the uncertainty in location-specific demand. Scenarios using these inputs should ensure that potential infrastructure investments are tested against the range of plausible uncertainties in future demand arising from these key dimensions of population and demography.

The four variants used by the Commission are:

a) Central variant

ONS 2014-based principal population projection – 77.5m people in the UK in 2050.

b) Low variant

ONS 2014-based low migration population projection – 73.7m people in the UK in 2050.

c) High variant

ONS 2014-based high fertility population projection – 80.1m people in the UK in 2050.

d) Additional variant

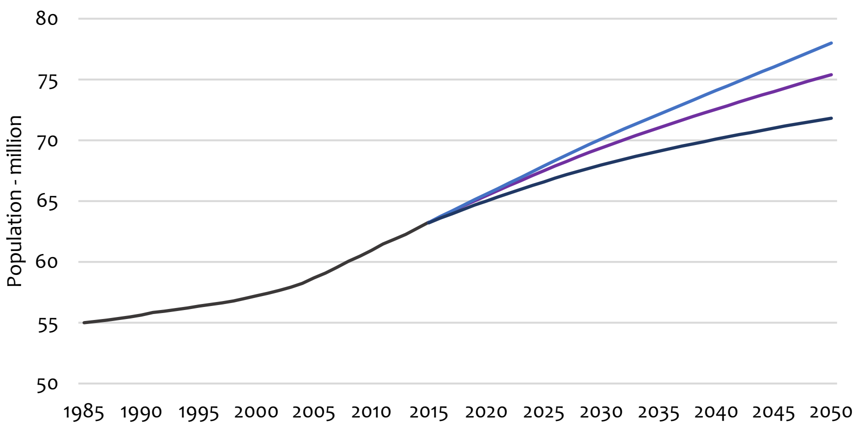
Population moves away from London and the Southeast due to lack of housing availability – 77.5m people in the UK in 2050 as in the central variant, but the subnational population distribution differs.

Population growth in Scotland and Wales is equivalent to the ONS central projections, with redistribution occurring only within individual constituent countries.

These variants also have different implications for the age structure of the population so they would allow age-related factors to be taken into consideration. For this publication, however, the Commission was not able to explore different demographic scenarios in more detail.

Figure 1 shows the central, high and low variants. Figure 2 illustrates the difference in population growth in the Government Office Regions of England in the redistribution and central variants.

Figure 1 – National population variants



Source: constructed by the Commission using 2014-based ONS population projections.

Figure 2 – Population growth between 2016 and 2050 in English regions

Source: constructed by the Commission using ONS data and the Commission's scenario data.

Subnational projections

The ONS produce subnational population projections for England up to 25 years ahead from the base year. Subnational projections for Scotland and Wales are produced by National Records of Scotland (NRS) and Stats Wales respectively and are also available up to 25 years ahead. The subnational projections are produced for shorter time frames as the ONS point out in their Subnational population projections Quality and Methodology Information that projections become less accurate as they are carried forward, particularly for smaller geographical areas.

Although the Commission recognises this, the models used require subnational projections out to 2050 as inputs and simplifying assumptions about the size of the population in each area were made. The Commission generated subnational projections for 2040-2050 by rolling forward trend growth in each local authority district/administrative area and constraining subnational projections to the equivalent national projections for each UK country. As the ONS, NRS and Stats Wales subnational population estimates are also based on the continuation of recent demographic trends, this simplified approach was considered to be appropriate for the purposes of this modelling.

The modelling only included Northern Ireland in the energy sector. Subnational population variants were not required to run the energy models.

Population redistribution variant

The shift in population in the redistribution variant is motivated by the assumption that population growth is constrained by housing availability in each local authority/administrative area. Population growth in each area is therefore proportionate to dwelling construction in that area.

House construction trends are assumed to carry on as they have for the last years (between 13 and 15 years, depending on data availability) in each area. Data on net additional dwellings (i.e. houses built and converted minus houses demolished) for England was obtained from the Department for Communities and Local Government (DCLG), for Scotland from NSR and for Wales from Stats Wales.

Household size projections

Household size will have an impact on demand for infrastructure services, but for modelling purposes the Commission will assume that household size will evolve as per DCLG's projections across all scenarios.

2.2.3 Climate change

The variants chosen by the Commission are based on the analysis in the climate change and environment driver paper. The modelling for UK 2050 only considers climate change explicitly in the water sector. Although climate change is also likely to affect the transport, solid waste and energy sectors in future this was not modelled using the scenario approach as most of the models used do not account for this.

Uncertainty in climate projections

The most up-to-date climate scenarios available for the UK are from the 2009 UK Climate Projections (UKCP09). Until these are updated in 2018, these will remain the best available evidence for projected changes in the UK climate. Climate projections focus on how the average seasonal climate is expected to change over extended periods of time – averaging masks the potential for weather extremes within individual years, caused by the 'noise' of natural variability combining with the long-term climate change 'signal'. To address this, projections are presented as probability distributions.

There is an additional layer of uncertainty – probabilistic projections do not include the effect of uncertainty in future greenhouse gas (GHG) emissions, determined by the interaction between drivers such as demographic development, socio-economic development and technological change on a global scale. To account for this UKCP09 project climate variables under different emissions scenarios: high emissions (A1FI); medium emissions (A1B) and low emissions (B1). The Commission has linked its climate change variants to these three emissions scenarios.

Future flows

An ensemble of 11 scenarios for future river flows was derived by the Future Flows project for the UKCP09 medium emissions scenario and can be used to address the uncertainty in this climate variable, which is particularly relevant for the water sector.

The relative probability of each scenario is unknown, but each contains alternative regional distributions and thus the range of scenarios provides a means of exploring the uncertainty facing individual water companies.

New research, which was commissioned by the Committee on Climate Change (CCC) from HR Wallingford to inform the Climate Change Risk Assessment 2017 has been used to provide updates to these scenarios to include the UKCP09 high and low emissions scenarios. The combination of 11 future flows scenarios for each of the three emissions scenarios provided 33 possible hydrological variants for the water sector modelling.

Each of the 33 variants was run through the water model and the following variants were chosen:

a) Central variant

The future flow variant within the medium emissions scenario in the middle range of aggregate water balance for Great Britain

b) Low variant

The future flow variant within the low emissions scenario with the highest aggregate water balance for Great Britain

c) High variant

The future flow variant within the high emissions scenario with the lowest aggregate water balance for Great Britain.

2.2.4 *Technological change*

Despite the challenges associated with developing technology scenarios, the Commission has decided to explicitly consider technological change as part of these scenarios.

The rationale for this is that although policy can act as an incentive (or disincentive) to the dissemination of technology, certain technologies will diffuse regardless of policy intervention and facilitation, and could significantly impact infrastructure needs (e.g. smartphones and the associated mobile data demand).

For the purposes of scenario development, the Commission considers that:

› Technology **variants** provide a set of assumptions on: what technologies are available (i.e. cost-effective and widely accessible) in each sector; when they disseminate; and their impact on infrastructure.

› **Policies** may determine whether, and at what pace, certain technologies are incorporated into infrastructure systems.

In the modelling for *Congestion, Capacity, Carbon: priorities for national infrastructure*, the technology variants are based on pathways of exogenous technological development without policy intervention, in addition to what has already been committed. The methodology for developing technology variants is set out below in steps I to III.

I. Technology pathways

Through internal and external discussions, including workshops, the Commission has established two likely pathways for technological development over the next thirty years, which constitute the technology variants:

a) Central variant

New technologies are developed and made available in infrastructure systems at a steady pace, similar to that observed in recent years.

b) High variant

New technologies are developed and made available in infrastructure systems, at a faster pace than observed in recent years.

II. Technology options

Through the research undertaken for the technology driver paper the Commission has identified a list of technology options which could significantly impact infrastructure systems should they be taken-up at scale over the next 30 years. The Commission considered qualitatively, and quantitatively where possible, the ways in which each of these could impact infrastructure:

- Reduce the need to build new infrastructure
- Create demand for additional infrastructure
- Lower the cost of supplying infrastructure
- Create demand for an infrastructure system
- Drive a decrease in demand for an infrastructure system

The Commission then shortlisted the technology options identified by selecting those that:

- Could have a significant impact on infrastructure – the term significant is subjective, so in order to reach a decision this issue was subject to internal discussion and informal consultations with external experts.
- Are or will be available and sufficiently mature within the Commission's time horizon – as above, this was subject to informal consultation with external experts.

The technologies remaining after this step are set out below:

- **Smart technologies and demand-side response (DSR)** – refers to the 'smart' management of infrastructure systems, using a combination of technologies such as the internet of things (IoT), artificial intelligence, smart meters, cloud storage, big data analytics, sensors, etc.
- **Advanced manufacturing** – refers to improvements in manufacturing techniques, including the use of 3D printing, robotics and computer numeric control (CNC)
- **Electric vehicles** – refers to the take-up of plug-in electric or plug-in hybrid cars and LGVs

- **Carbon capture and storage (CCS)** – and its use in decarbonising energy generation and industrial processes which contribute significantly to greenhouse gas emissions
- **Energy storage** – refers to the conversion of energy to economically storable forms
- **Renewable energy generation technologies** – refers to the generation of energy from renewables including wave, tidal (stream and range), solar, offshore and onshore wind, bioenergy and energy from waste
- **Autonomous vehicles** – refers to vehicles with high levels of automation (level IV according to SAE International's levels of automation)

The Commission proceeded to further narrow down this list based on the following additional criterion:

- Is the technology likely to exist in the baseline? (i.e. are the required conditions for its diffusion across an infrastructure system in place)

This judgment was based on the technological readiness of each technology (and how certain its diffusion is considered to be in the literature), knowledge of future policy commitments (e.g. legislation being consulted on to enable autonomous vehicles) or investments (e.g. funding approved for a carbon capture and storage project) which would enable its diffusion.

If a technology was judged to require policy intervention or investment which cannot currently be expected, policy options which could incentivise it may be explored during the next phase.

Advanced manufacturing and **CCS** were removed from the first round of modelling based on this criterion. Although advanced manufacturing could lead to an increase in manufacturing within the UK, with potentially big impacts on energy demand, there is significant uncertainty around its implications for the industry and lack of evidence on the size of the impact on energy demand. CCS was eliminated based on a lack of current policy commitment to the technology. The Commission intends to revisit this technology when it models policy options for the National Infrastructure Assessment.

The Commission assumes no policy intervention to incentivise the uptake/cost reductions of the remaining five technologies (autonomous vehicles, energy storage, EVs, smart technologies/DSR and renewable energy generation) in the technology variants, in addition to what has already been committed.

III. Variant quantification

In order to model the impact of the different technology variants on the supply and demand of infrastructure services in the UK, for each shortlisted technology the Commission:

- Estimated the decade in which it is likely to become available under each technological development pathway (**when**)
- Considered the ways in which it could impact infrastructure, based on the six effects mentioned above (**how**)
- Quantified the size of the impact based on published research and expert judgment, under each technological development pathway (**what**)

2.2.5 *Fuel prices*

As fuel prices are also important determinants of supply and demand for infrastructure in certain sectors, assumptions on the future path of fuel prices were made. The fuel types which are inputs into sector models are set out below:

Table 2 – Fuel types

	transport	energy	solid waste
petrol	o		
diesel	o		
electricity	o		
crude oil		o	
gas		o	
coal		o	
biomass		o	
uranium		o	
waste		o	o

Fuel prices are difficult to forecast and internal analysis did not find any set of projections that performed particularly well historically. A consistent set of prices was therefore used across all of the Commission's scenarios, most of which were based on the latest 'central' fuel price projections from the Department for Business, Energy and Industrial Strategy (BEIS).

The fuel price sources used in the ITRC's NISMOD are set out below:

› Electricity, petrol and diesel prices are based on the 'existing policies' scenario from BEIS' 2016 Updated Energy & Emissions Projections.

› Crude oil, gas and coal prices are based on the 'central' scenario from BEIS' 2016 Fossil Fuel Price Assumptions.

› Biomass and uranium prices are based on the 'central' scenario from BEIS' Electricity Generation Price report, November 2016.

› Waste prices in the ITRC model are based on the E4Tech's Modes Project 1.

The Department for Transport's (DfT) models used equivalent fuel prices. BEIS' UK TIMES also used BEIS' central fossil fuel prices.

2.3 Scenario development

All possible combinations of the variants of the four drivers were used to generate 72 scenarios. As this offers too many combinations to analyse and explain a smaller set of scenarios was chosen from the 72 combinations based on the following criteria:

› **Diversity** – scenarios that are diverse enough to provide robustness against future uncertainty

› **Plausibility** – scenarios that are realistic, internally consistent and probable

› **Relevance** – scenarios that are relevant to the Commission's objectives and to interdependencies across sectors

The Commission's methodology for scenario development differs to some well-known approaches, such as Shell's scenarios, which are narratives of visions of the future designed to help in 'thinking outside the box'. The Commission's scenarios have been constructed as combinations of different drivers and aim to extend the range of outcomes in order to test the flexibility of policy options. This approach intends to move away from finding optimal policies towards finding policies which are robust across a range of scenarios. Some of the merits of this type of approach are outlined in the paper "Addressing uncertainty through scenario-based planning in Strategic Infrastructure Planning – International Best Practice" published by the OECD with the Commission's contribution.

The Commission intends to focus on realistic, probable scenarios rather than extreme events as these scenarios are meant to help policy-makers when making long-term policy and investment decisions.

The process for narrowing down the list of possible scenarios involved:

› Removing very central (not relevant or diverse) scenarios – the Commission chose to remove the combination of all central variants as it does not wish to produce 'point estimates'. The outputs in UK 2050 are therefore shown as a range.

› Removing very extreme (not plausible) scenarios – the Commission chose to remove scenarios which were made up of combinations of three or four 'extreme' variants. Although the Commission recognises the value in testing extreme scenarios, it takes the view that chosen scenarios allow for a wide enough range of outcomes to provide robustness against uncertainty, while remaining informative for policy-makers.

› The Commission then engaged with both internal and external stakeholders to inform the selection of scenarios.

This process left **twelve scenarios**, shown in Table 3.

Table 3 – Modelled scenarios for Congestion, Capacity, Carbon: priorities for national infrastructure

	scenario description	economic growth	population growth	climate change	technological change
1	High population growth	central	high	central	central
2	Low population growth	central	low	central	central
3	Population reallocation	central	redistribution	central	central
4	Low economic growth	low	central	central	central
5	High technological development	central	central	central	high
6	High climate change	central	central	high	central
7	Low climate change	central	central	low	central
8	High population growth and technological development	central	high	central	high
9	High climate change and technological development	central	central	high	high
10	High population growth and climate change	central	high	high	central
11	Low population growth and modest economic growth	modest	low	central	central
12	Low economic growth and high technological development	low	central	central	high

3

Modelling assumptions

3.1 Modelling framework

The Charter which clarifies the compact between the government and the Commission sets out the government's commitment to produce new analysis to support the Commission's work. In light of this, the Commission was able to request new modelling from the Department for Transport, the Department for Environment, Food and Rural Affairs and the Department for Business, Energy and Industrial Strategy.

The Commission also chose to use a set of interlinked models created by a consortium of seven UK universities – the Infrastructure Transitions Research Consortium (ITRC). This gave the Commission flexibility to test a greater number of scenarios and assumptions. This also allowed for greater exploration of certain interdependencies which were of interest to the Commission, particularly the link between transport and energy.

The use of two sets of models also allowed the Commission to account for uncertainty in model structure, which is a key source of uncertainty in any modelling exercise. The models used by the Commission are listed below.

Academia

ITRC's National Infrastructure Systems Model – Long-Term Performance (NISMOD-LP), which is made up of water, transport (road and rail), solid waste and energy sub-models.

NISMOD validation occurred through different researchers using NISMOD for various research projects, checking the validity of the vast number of possible model parameter and scenario combinations, and through peer review of their published works. The outputs of previous NISMOD model runs were peer reviewed within the ITRC consortium and through the publication of results, as well as by the leading sector practitioners from the UK and abroad that constituted the ITRC's Advisory Board.

Government departments

Transport – Department for Transport (DfT):

- Road – National Trip-End Model (NTEM), National Transport Model (NTM)
- Rail – Exogenous Demand Growth Estimator (EDGE), Network Modelling Framework (NMF)
- DfT's models follow the department's Strength in Numbers framework of analytical assurance.

Solid waste – Department for Environment, Food and Rural Affairs (Defra):

- Arisings – Waste Arisings Model
- Treatment – RouteMap
- The Defra models have been quality assured by processes including peer assessment, coding spot-checks, inputs review, and an analytical review of outputs. Significant uncertainty remains over the projections related to the C&I sector.

Energy – Department for Business, Energy and Industrial Strategy (BEIS)

- Demand – Energy Demand Model (EDM)
- Generation and emissions – UK-TIMES
- BEIS' models follow the department's quality assurance processes which are compliant with the HM Treasury Aqua book.

3.2 Baseline policy

For each sector, the 'do minimum' policy baseline was carefully considered in order to ensure it presented an appropriate counterfactual against which to compare the Commission's policy options, which will be modelled as part of the National Infrastructure Assessment.

For the **water** and **transport** sectors

- It is assumed that there is no further capacity expansion in addition to projects which have already been committed.
- In this case, the baseline modelling is expected to highlight the location and the extent to which **future demand** will put **pressure on existing and pipeline capacity.**

For the **energy** and **solid waste** sectors

- It is assumed that there is always sufficient capacity to meet the projected demand.
- In this case, the baseline modelling is expected to highlight the **carbon challenge** if capacity expansion is determined by least-cost optimisation.
- In line with the above, the models are **not constrained** to meet the UK's greenhouse gas emissions targets but include a carbon price considered by the Commission to be consistent with a minimal level of policy intervention (constructed by rolling forward the current carbon floor price).

Sections 3.3 to 3.6 describe the models used in more detail as well as the scenario and baseline assumptions made in each model. Some of the functionalities of these models have not been used by the Commission for the purposes of this modelling, but are described in the following sections nevertheless.

3.3 Water

3.3.1 ITRC water model[2]

In the water sector only ITRC's NISMOD was used. Defra's main water model is used for projecting impacts of future scenarios on water bills rather than water balances. This will be of interest to the Commission in the second phase of modelling when policy options are tested, but was less relevant to the baseline modelling.

The water supply model in NISMOD-LP is a high-level semi-distributed model of water supply systems, demand for water, infrastructure planning and decision making in Great Britain to 2050. The model consists of four modules applied to 130 zones based on Water Resource Zones of England and Wales and the Mega-Zones of Scotland (abbreviated to 'WRZ').

Supply module

The hydrology and water supply module uses the relationship between river flows and catchment sizes to calculate future water levels in rivers and reservoirs, subject to various demand levels and incorporating abstraction rules concerning maximum daily and yearly abstractions and minimum residual flows for rivers and reservoir intakes.

Base year river flow data at a single point within the WRZ is provided by CEH's Future Flows Hydrology dataset, whereas the catchment size estimated at that point, including river intakes and reservoir storage, is performed by Digimap's Digital Elevation Model.

Future river flows are introduced through 33 alternative scenarios – also provided by CEH as the Future Flows dataset – which represent different scenarios of future river flow under climate change conditions in three emissions pathways.

Demand module

The demand module forecasts future water demand to 2050 based on projections of population growth, household per capita water use, leakage, and non-domestic water uses.

Population data are based on the Commission's four population variants. Initial data on water use and leakage are taken from water companies' annual reports. Future assumptions about leakage and per capita consumption are linked to the Commission's two technology variants.

Costing module and decision module

After both supply and demand are estimated, the costing module assesses water availability in each WRZ every 5 years and identifies the maximum water deficit over a 20 year period. The module then selects the most suitable infrastructure options to be built in each WRZ and calculates the associated CAPEX and OPEX costs. The functionality of this module was not used for the baseline modelling as it was assumed that no infrastructure was built in addition to the pipeline.

When all infrastructure types are costed, the decision module selects and builds the discounted least-cost option through a built-in objective function.

[2] Model descriptions adapted from information provided by the ITRC for the Commission.

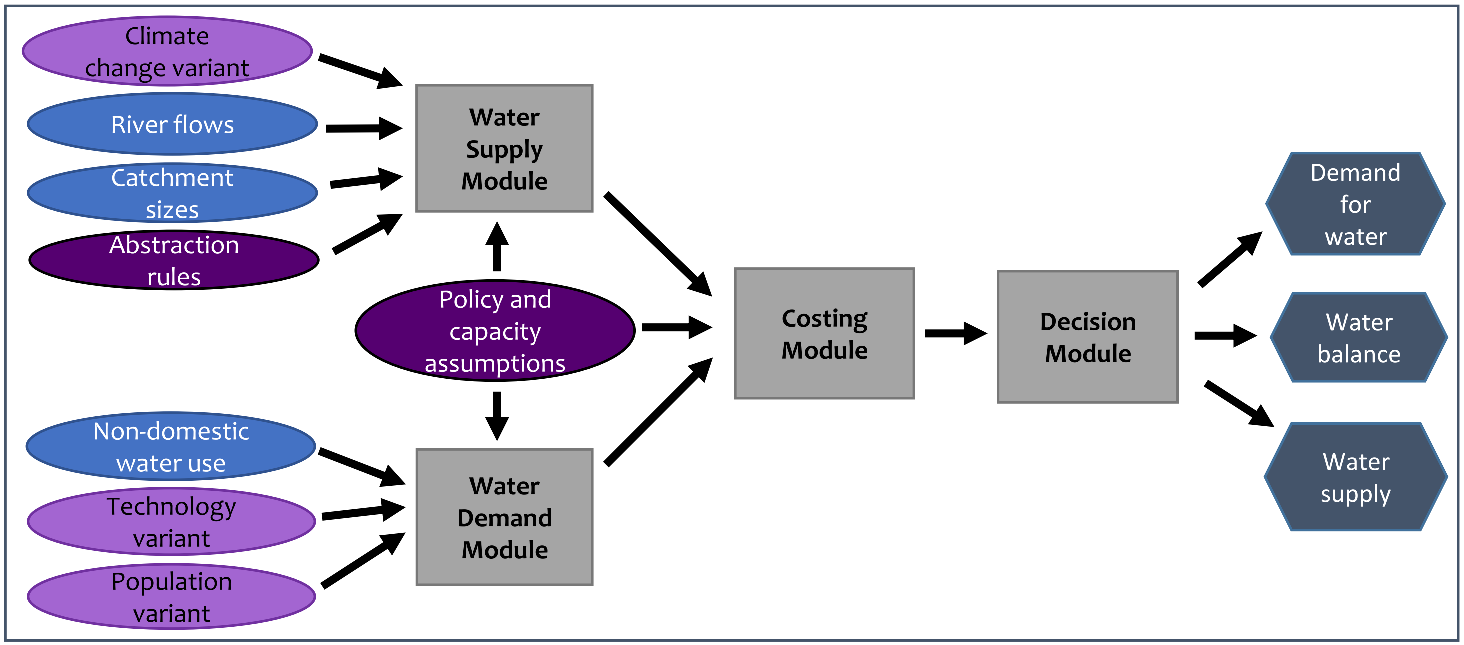
The functionality of the costing and decision modules was not used for the baseline modelling as it was assumed that no infrastructure was built in addition to the pipeline.

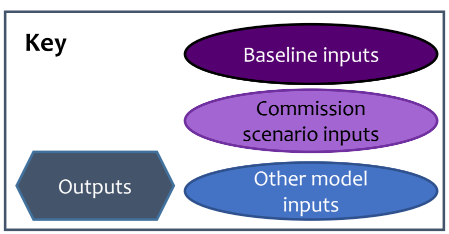
Model outputs

The model outputs national and disaggregated results for water demand (total and per capita), supply (deployable output) and balance, yield of catchments and leakage (Ml/year).

Figure 3 gives an indication of how the model and its sub-modules utilise input assumptions from the Commission's population, technology and climate change variants, the policy and infrastructure baseline and other general model inputs to generate outputs on demand for water, water supply and water balance. The model also produces outputs which were not utilised by the Commission (e.g. costs) and are therefore not shown in the schematic.

Figure 3 – ITRC water model schematic





Source: simplified model schematic created by the Commission based on model description in The Future of National Infrastructure: A System-of-Systems Approach, ITRC.

3.3.2 Baseline scenario modelling

The Commission constructed a baseline for the water sector which would allow it to address the following key question:

"What is the risk of drought if nothing is built in addition to the current infrastructure pipeline?"

The main assumptions made in order to practically model this baseline case are set out below.

Capacity

No further capacity expansion is assumed, in addition to projects included in the 2015 National Infrastructure Pipeline (NIP). Cheddar Reservoir, which was part of the 2015 NIP was removed as the project was not approved by Ofwat.

Water trading

No additional inter-regional water trading is assumed. This is because the required infrastructure is not currently in place or in the pipeline of projects.

Demand management

No further demand management policies are assumed. Any changes in per capita water consumption and leakage are assumed to come about due to technological improvement and are therefore linked to the technology variants. These are described in greater detail in the next page.

Abstraction

Future sustainability reductions in abstraction licences replicate those in Water UK's Water Resources Long-term Planning Framework "base" scenario. The Water UK analysis used the confirmed/likely sustainability reductions defined in Water Resource Management Plans 2014 (WRMP14) as a starting point and included an allowance for sustainability reductions described as "unknown" at the Environment Agency's National Environment Programme Phase 5 (NEP5), as well as an allowance for licence reductions likely to be required to prevent water body deterioration.

Water UK asked companies to provide values for their total unknown NEP reductions (in order to restore sustainable abstraction) and an estimate of their maximum feasible losses to prevent further deterioration and included 25% of both these values in the base scenario. It was decided at a steering group meeting for the Water UK project, which included most water companies, the EA, Ofwat and Natural England, that allocating 25% of the "unknown" impacts to the baseline scenario was a reasonable assumption given the limited time available to quantify impacts.

3.3.3 Technology assumptions

Technological change in the water model is assumed to lead to faster reductions in **per capita water consumption** as well as faster reductions in **leakage.**

These improvements are not related to policy change, but are assumed to come about due to the availability and deployment of ‘smart’ systems technologies (such as the internet of things, big data analytics, sensors, etc.) which allow water companies to more cost effectively detect and control leakage. Reductions in per capita consumption could come about due to more efficient (i.e. less water intensive) appliances, home fittings etc.

The per capita consumption and leakage assumptions in the central and high technology variants in shown in Table 4.

Table 4 – Leakage reduction and per capita consumption assumptions

	per capita water consumption (l/h/d)		annual leakage reduction (Ml/d)
	level reached in 2050	average annual reduction	
central variant	124	-0.3%	-0.1%
high variant	116	-0.5%	-0.3%

Source: constructed by the Commission based on EA and Water UK data.

The central technology variant is based on 2014 WRMP ‘baseline’ scenario for leakage reduction and per capita consumption reduction.

The high technology variant is based on the ‘extended’ scenario in Water UK’s Water resources long-term planning framework.

The PCC levels above are assumed to apply to each individual Water Resource Zone (WRZ) by 2050.

3.3.4 Water scenarios

As economic growth is not an input in the water model scenarios 11 and 12 were removed. The remaining modelled scenarios are shown in Table 5.

Table 5 – Modelled scenarios in the water sector

	scenario description	population growth	climate change	technological change
1	High population growth	high	central	central
2	Low population growth	low	central	central
3	Population reallocation	redistribution	central	central
4	Low economic growth	central	central	central
5	High technological development	central	central	high
6	High climate change	central	high	central
7	Low climate change	central	low	central
8	High population growth and technological development	high	central	high
9	High climate change and technological development	central	high	high
10	High population growth and climate change	high	high	central

3.4 Transport

3.4.1 ITRC transport modelling[3]

The NISMOD-LP transport model is an elasticity-based model that forecasts volumes of traffic, capacity utilisation and congestion for road, rail, air and seaborne transport to 2100. Only the road and rail elements of the model were utilised for this piece of work.

The model divides Great Britain into 144 local authority zones. London and the Metropolitan boroughs are aggregated into seven zones (Greater London, West Midlands, Merseyside, Greater Manchester, South Yorkshire, West Yorkshire, and Tyne and Wear). Road and rail traffic is modelled between adjacent zones (*interzonal*) and within individual zones *(intrazonal).*

Model structure and inputs

Traffic levels for each transport mode are calculated as a function of population change, trip rates, economic growth (GVA), speed of travel, infrastructure capacity utilisation and cost of travel. Elasticity values, based on the best evidence found in the literature, are applied to each explanatory variable to estimate the traffic response to a change in the levels of these variables.

The rail module of the model is based on the rail passenger forecasting methodology and guidance in the Passenger Demand Forecasting Handbook (PDFH).

Input data to the model are either sourced from official statistics and the literature or correspond to the Commission's population and economic growth variants.

It is also possible to model endogenous factors (i.e. within the control of the transport sector), such as the impacts of policies and long-term technological and behavioural trends through the use of 'strategy' data sets, including factors such as toll, fuel and carbon taxes, uptake of alternative fuel vehicles (e.g. electric cars), fuel efficiency improvements, impacts of ICT on travel behaviour, and the construction of new infrastructure. The Commission adapted these endogenous assumptions to reflect its baseline and technology variants.

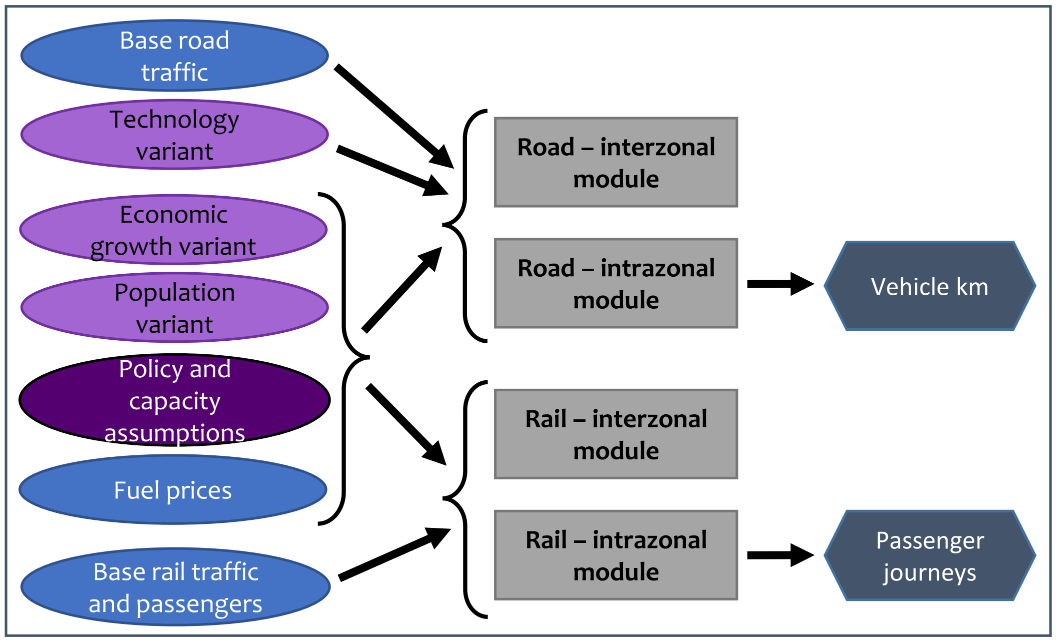
Model outputs

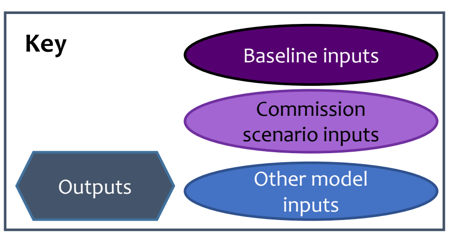
The model outputs both national and spatially disaggregated forecasts for road traffic (intrazonal vehicle km and interzonal passenger car units), road congestion (traffic speed in km/h and number of congested hours for interzonal links), road capacity utilisation, rail traffic (no. of interzonal trains and passenger journeys within zones), rail congestion and capacity utilisation. Aggregate estimates of levels of investment in new infrastructure, fuel consumption and greenhouse gas emissions are also generated.

[3] Model descriptions adapted from information provided by the ITRC for the Commission.

Figure 4 gives an indication of how the model and its sub-modules utilise input assumptions from the Commission's population, technology and economic growth variants, the policy and infrastructure baseline and other general model inputs to generate road outputs for congested hours and vehicle km and rail passenger journeys. The model also produces outputs which were not utilised by the Commission and are therefore not shown in the schematic.

Figure 4 – ITRC transport model schematic





Source: simplified model schematic adapted from The Future of National Infrastructure: A System-of-Systems Approach, ITRC.

3.4.2 DfT transport modelling[4]

National Trip End Model (NTEM)

The National Trip End Model (NTEM) forecasts growth in "trip ends" up to 2051 (number of trips generated at home and number of trips attracted to different locations) for use in transport modelling.

The forecasts take into account projections of population, employment, housing, car ownership and trip rates.

DfT analysts ran five of the Commission's scenarios through their models for the first round of modelling, using the Commission's assumptions on population growth and economic growth.

The trip end outputs produced by NTEM are used as inputs into the DfT's National Transport Model (NTM).

National Transport Model (NTM)

The National Transport Model (NTM) forecasts road traffic, lost time per vehicle km/travel time (proxies for congestion) and emissions. Its outputs have been published in the DfT's Road traffic forecasts 2015.

Trip forecasts produced at the "NTEM zone" level (7,700 zones) are used as inputs into the NTM to generate outputs by region, area type (15 types), vehicle type and road type.

There are 19 different time periods for the day and the week (e.g. rush-hour, weekend). Traffic forecasts give information on the level of congestion of the road in terms of volume/capacity ratio.

Network Modelling Framework (NMF)

The Network Modelling Framework is used by the DfT to forecast demand on an incremental basis and applies the methodology described in the PDFH, which is published and updated by the Passenger Demand Forecasting Council (PDFC).

New rail links can only be modelled as inputs, and assumptions about new links have to be made exogenously.

Demand is estimated using the Exogenous Demand Growth Estimator (EDGE) and the rail industry's ticket sales database, which provides detailed annual information on trips between stations.

EDGE includes the following drivers of rail demand: GDP per capita, employment, population, bus costs, car costs, air costs and rail fares.

The main NMF outputs used by the DfT are appraisal-centric – i.e. changes in revenue, crowding benefits/disbenefits, time benefits/disbenefits etc.

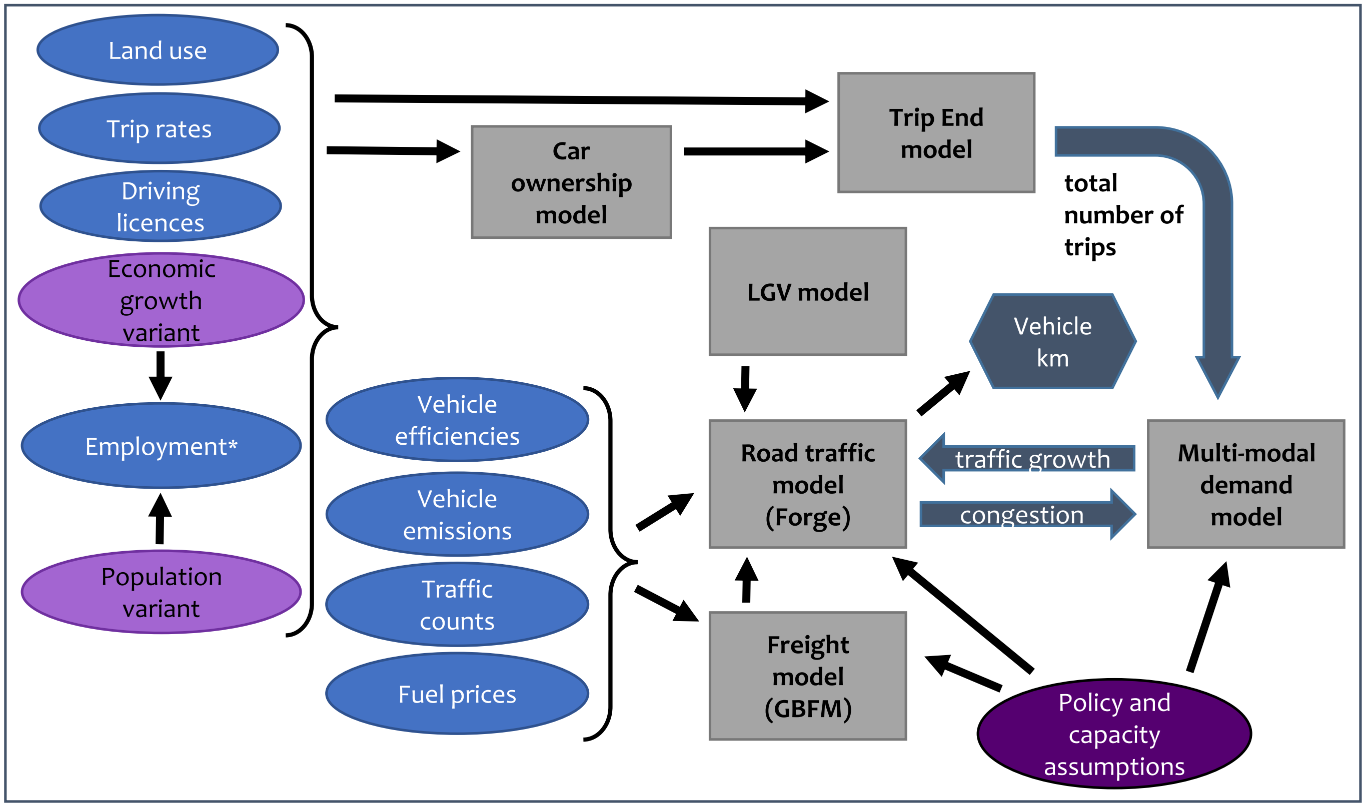
The NMF outputs used by the Commission are passenger journeys, passenger-km and train load factors.

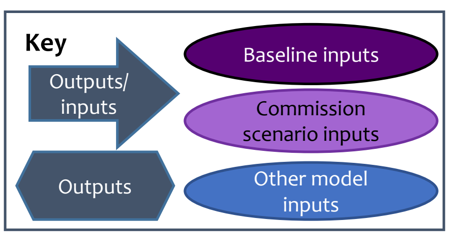
[4] Model descriptions adapted by the Commission from the DfT's Road Traffic Forecasts 2015 and Network Modelling Framework Background Documentation, 2007.

Figure 5 gives an indication of how the models utilise input assumptions from the Commission's population and economic growth (including employment) variants, the policy and infrastructure baseline and other general model inputs to generate outputs for congested minutes and vehicle km.

The model also produces outputs which were not utilised by the Commission and are therefore not shown in the schematic.

Figure 5 – Model schematic of DfT's road modelling (NTM suite)



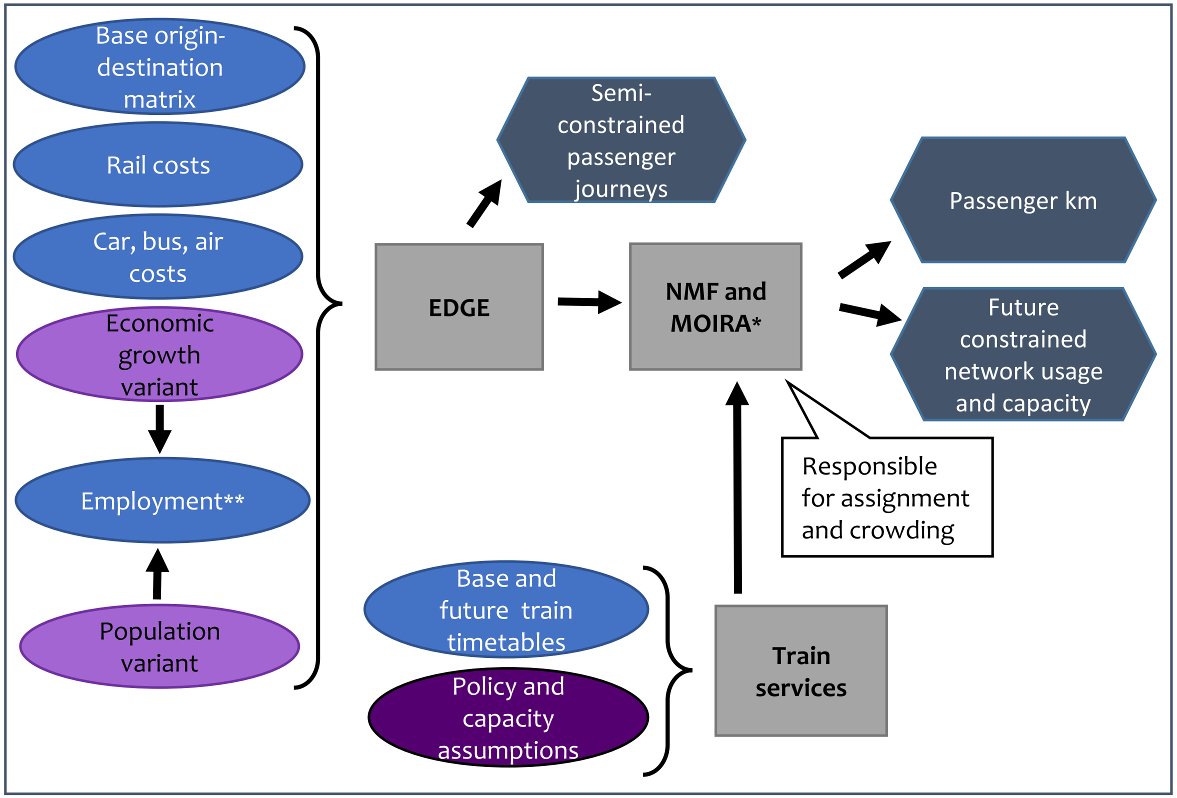


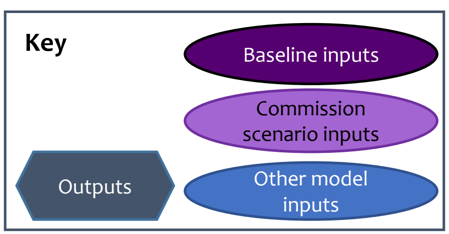
Source: simplified model schematic adapted by the Commission from the DfT's Road Traffic Forecasts 2015.

*Population changes were assumed to lead to corresponding changes in employment at the national level, without changes to the underlying distribution at a local level.

Figure 6 gives an indication of how the model utilises input assumptions from the Commission's population and economic growth variants, the policy and infrastructure baseline and other general model inputs to generate outputs for passenger journeys and passenger km.

Figure 6 – Model schematic of DfT's rail modelling (NMF)





Source: simplified model schematic adapted by the Commission from the Network Modelling Framework Background Documentation, 2007.

*MOIRA is a rail planning tool which provides an estimate of rail journeys based on information from LENNON, the rail industry's ticketing and revenue system.
**Population changes were assumed to lead to corresponding changes in employment at the national level, without changes to the underlying distribution at a local level.

3.4.3 Baseline scenario modelling

The Commission constructed a baseline for the transport sector which would allow it to address the following key question:

"What is the impact on congestion of not building anything in addition to the current infrastructure pipeline?"

The main assumptions made in order to practically model this baseline case were:

Capacity – no further capacity expansion is assumed, in addition to:

- Top 40 projects included in the 2015 National Infrastructure Pipeline.
- Road schemes included in the 2015-2020 Road Investment Strategy (RIS1).
- Major rail schemes included in Network Rail's 2014-2019 Control Period 5 (CP5).

ITRC rail model

- Rail fares are assumed to increase by 1.7% each year on average (real terms, deflated by GDP deflator) – this corresponds to the average increase in rail fares for all ticket types between 1995-2015, according to the Office for Road and Rail's (ORR) published index. This index may overestimate actual fare increases due to fare switching to cheaper fares, such as advanced tickets, as standard prices increase.

DfT rail models

- The impact of HS2 on rail demand was added to the baseline as an off-model adjustment. This was only added to the rail demand outputs, and is not reflected in the rail crowding maps.
- Post CP5, the DfT analysis in NMF also includes future franchise timetables which introduce large improvements to the services by means of new/more rolling stock. This capital expenditure in rolling stock allows for faster journeys and greater capacity.
- Rail fares are assumed to increase by RPI + 1% each year, as this is the current policy stance.

Fuel prices in both models are based on BEIS' 2016 Updated Energy & Emissions Projections.

Technological change is modelled as one of the exogenous scenario variants in the ITRC model.

3.4.4 Technology assumptions

Technological change is considered to be an exogenous driver of transport supply and demand, which will occur to some extent regardless of policy intervention. It is therefore represented in the ITRC model as part of the baseline, in two ways.

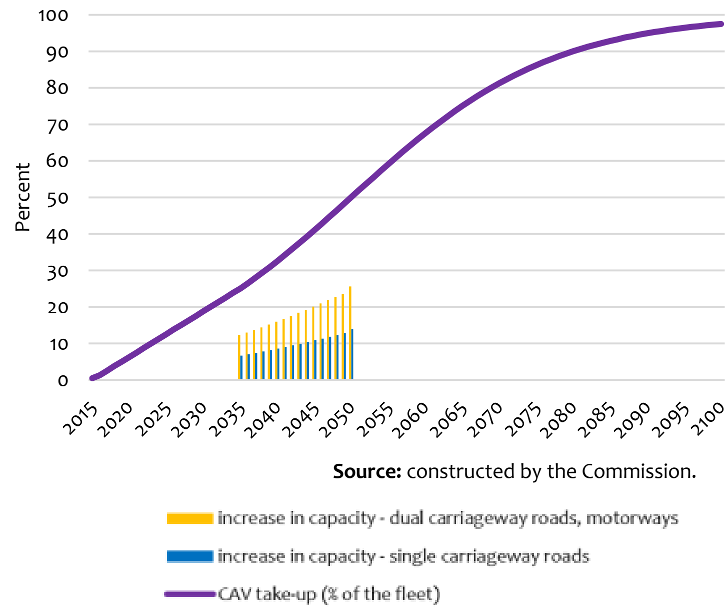
I. Uptake of connected and autonomous vehicles (CAVs)

In the 'high tech' variant, the take-up of CAVs with high levels of automation (i.e. level IV according to SAE International's levels of automation) is assumed to reach 25% of the fleet by 2035 and 50% by 2050, based on research by Litman (2017) and Bierstedt et al (2014) for Australia and the USA. Take-up is assumed to roughly follow an s-shaped curve as is typical for innovation diffusion, reaching 100% post 2050.

The diffusion of CAVs in the fleet is assumed to lead to an increase in effective road capacity, due to increased efficiency in car merging behaviour, changed profiles of acceleration/deceleration and reduction in gaps between vehicles. The impacts of 25% and 50% take-up are based on research by Atkins for the DfT (2016). As no capacity impacts for take-up rates between 25% and 50% were produced by Atkins, the increase in capacity impact between these rates of take-up is assumed to be proportionate to the growth in take-up. The impact on road capacity is assumed to vary depending to some extent on road type, as shown below. No impact is assumed to occur on rural roads.

Although we can reasonably expect CAVs at lower levels of automation to diffuse through the fleet even at current rates of technological development, which would also impact road capacity, for simplicity we have only attempted to model the impact of CAVs at higher levels of automation.

Figure 7 – CAV penetration and impact on road capacity



Source: constructed by the Commission.

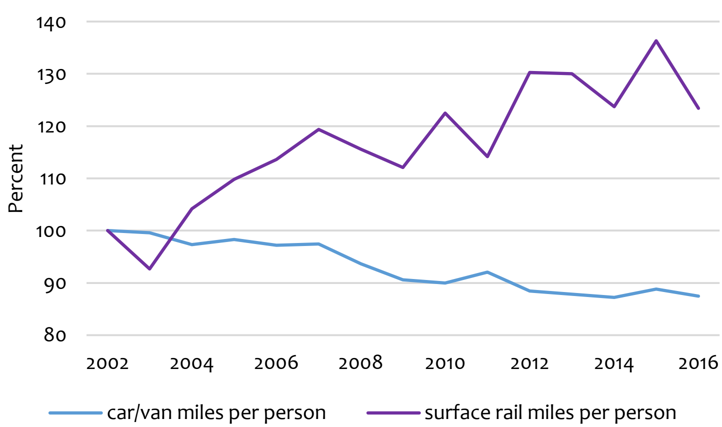
II. Uptake of electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEV)

This has a greater impact on the energy sector, and is therefore described in the energy technologies subsection.

3.4.5 Sensitivity analysis

The demand for travel is dependent on **travel preferences**, but these have been changing in recent years and there is significant uncertainty around how these might continue to evolve in future. Recent figures from the 2016 National Travel Survey indicate that trip rates have been falling in recent years – in 2016 people made on average 15 trips per week, 13% fewer than in 2002. When looking at road and rail trips per person, as well as distances travelled per person, these trends look very different for road and rail. Miles travelled by rail per person (for those who travel by rail) have gone up by 23% between 2002 and 2016, whereas miles travelled by road per person (for those who travel by road) have gone down by 13% over the same period.

Figure 8 – Percentage change in road and rail trips per person



Source: constructed by the Commission using National Travel Survey 2016 data.

Travel preferences have historically been closely linked to **economic growth**. To explore the impact of a change in this relationship on future road travel, an additional model run of the central population growth and central technology scenario was run, setting the **income-elasticity of road travel to zero**. This sensitivity analysis extends the range of future demand outcomes and gives an idea of how much lower road travel might be if the link between economic growth and demand for travel were broken (sometimes referred to as part of the "peak car" debate). This is not a perfect method for taking changing travel preferences into account, but rather a proxy to explore this change.

This approach was not considered to be appropriate for exploring changing rail travel preferences, given the trends in rail trip rates and miles travelled highlighted above. The Commission explored a sensitivity analysis which might lead to higher growth in rail travel but decided against this – the causes behind the increase in rail trip rates are uncertain and the Commission did not consider there to be a clear basis for a sensitivity test.

3.4.6 Transport scenarios

Although climate change may affect the transport sector in future (e.g. increased flooding may damage parts of the network), the models do not account for this. This means that there is no differentiation between some of the scenarios which vary the climate change variant. Scenarios 7, 9 and 10 have been removed in light of this. The remaining scenarios are shown in table 6.

Scenarios 1, 2, 3, 4 and 6 have been produced using the DfT and ITRC models. As climate change is not an input into the transport models used scenario 6 is effectively a central economic growth and central population growth scenario for this sector.

Scenarios 5, 8, 11 and 12 have been produced using the ITRC model only.

Table 6 – Modelled scenarios in the transport sector

	scenario	economic growth	population growth	technological change	income-elasticity
1	High population growth	central	high	central	standard
2	Low population growth	central	low	central	standard
3	Population reallocation	central	redistribution	central	standard
4	Low economic growth	low	central	central	standard
5	High technological development	central	central	high	standard
6	High climate change	central	central	central	standard
8	High population growth and technological development	central	high	high	standard
11	Low population growth and modest economic growth	modest	low	central	standard
12	Low economic growth and high technological development	low	central	high	standard
	Zero income-elasticity	low	central	central	zero

3.5 Solid waste

3.5.1 ITRC solid waste modelling[5]

The solid waste model in NISMOD-LP is a life-cycle based environmental and financial assessment model for waste management. It simulates waste from the point of generation through collection, treatment and disposal while quantifying the environmental impacts and financial costs.

Waste production module

Households and the industrial and commercial sectors generate waste in the model according to waste production rules that determine the specific quantity and composition for each producer. These rules are a function of the Commission's regional population and economic growth variants and waste generation rates.

Waste collection module

Once generated, producers discard the waste using collection options (e.g. household kerbside collection recycling, bring banks, Household Waste Recycling Centres) that are made available to them by following predefined waste discard rules. Such rules include a 'target material proportion', which defines the proportion of each type of material that is allocated to each waste collection option, as well as waste contamination and recovery rates. After collection, the waste enters the management system by being divided into waste streams, which are not actual wastes but categories to tag the waste with predefined lists of treatment processes that they can be sent to.

Waste treatment and disposal module

Each of the waste streams is then treated via burning, decomposing or reprocessing, and converted to either commercial products (energy, paper, metals and plastics) or another waste stream that is treated until the residue is sent for final disposal to landfills or exported.

A 'waste manager' agent manages this entire process in each region by choosing the optimal treatment path based on available infrastructure and within specific economic (e.g. energy recovery from waste) and environmental (e.g. waste reduction targets) goals. Each treatment path has differing performance in terms of cost, energy consumption, energy production, materials recovery, etc.

The module uses forecasts of demand and capacity utilisation under different socio-economic scenarios and makes decisions regarding new investment using a range of alternative management strategies (e.g. increasing recycling, reducing waste arisings).

Model outputs

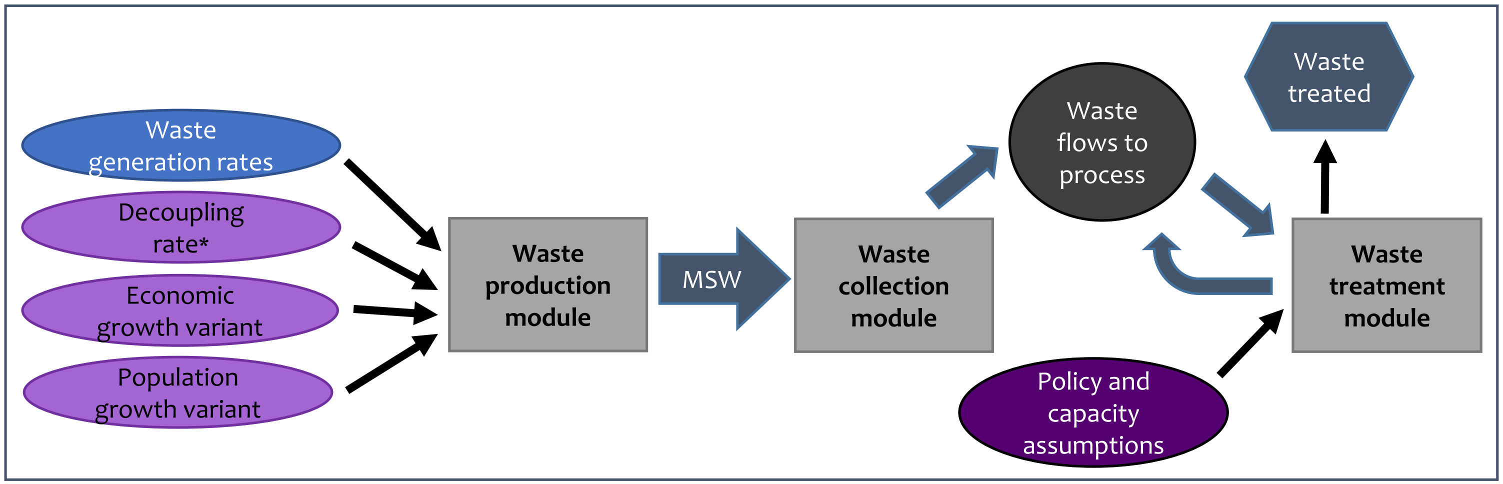
The model outputs national and regional results for total waste produced, managed and treated, collection, transport and treatment costs and greenhouse gas emissions, and energy produced (electricity and heat). Performance indicators like cumulative total costs, capital expenditure are also generated.

[5] Model descriptions adapted from information provided by the ITRC for the Commission.

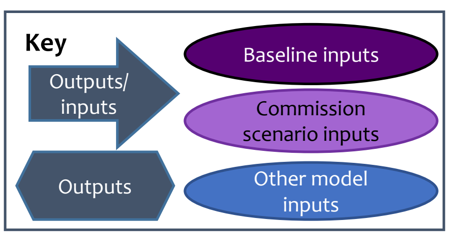
Figure 9 gives an indication of how the model utilises input assumptions from the Commission's population and economic growth variants, the policy and infrastructure baseline and other general model inputs to generate outputs for waste produced and total waste treated.

As waste is sometimes subject to more than one type of treatment (and therefore goes through the system twice, as the figure indicates) total waste treated exceeds waste produced. The model also produces outputs which were not utilised by the Commission and are therefore not shown in the schematic.

Figure 9 – ITRC solid waste model schematic



Source: simplified model schematic adapted from The Future of National Infrastructure: A System-of-Systems Approach, ITRC.



*refers to the annual rate at which economic growth and waste arisings decouple (described further below).

3.5.2 Defra solid waste modelling[6]

The Defra solid waste modelling suite represents the English waste management system. It can estimate future local authority collected waste (LACW) and commercial and the municipal element of commercial and industrial (C&I) waste, the fate of waste arisings and the costs associated with collection, transport and recycling, treatment, recovery or disposal. The output of these waste flows and costs allows the calculation of the climate change impacts of the scenarios tested. The model comprises a series of modules that track the flow of waste from arisings through to disposal.

Local authority collected waste arisings module

The local authority collected waste arisings module generates annual LACW arisings based on a simple econometric relationship. It uses historic waste arisings and consumer expenditure data as inputs. The Commission has assumed in its scenarios that consumer expenditure grows in line with GDP.

Commercial and industrial waste arisings module

Commercial and industrial waste arisings are projected forward in line with economic growth in the commercial and industrial sectors, measured by gross value added (GVA). Outputs that include any element of the C&I sector are particularly uncertain as the available data on C&I arisings tends to be incomplete.

Collection module

The collection module takes arisings and assumptions around the composition of waste for each local authority as inputs and produces projections on the amounts of waste collected and corresponding costs across different collection systems (recycling, kerbside biowaste etc).

Different collection scenarios can be included that specify the types of bins, materials collected and frequency of collection for each local authority.

Waste management module

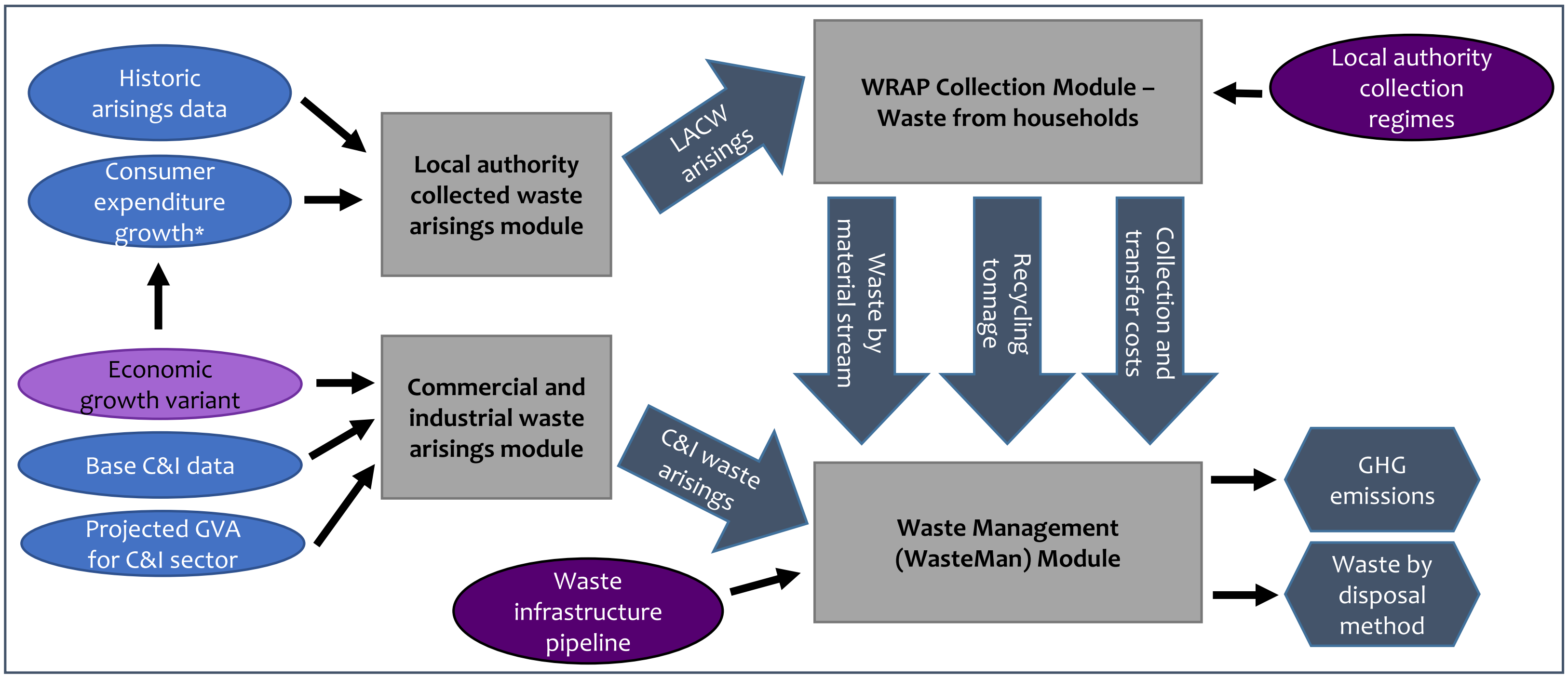
The waste management module is consistent with the Waste Infrastructure Delivery Programme Infrastructure Project List and estimates the number and capacity of each of the treatment technologies required to deal with the different types of waste collected. The assumed residual treatment infrastructure build-rate post-2025 is 200kT per year. The model assumes Materials Recovery Facilities are built to meet whatever demand there is from recycling collections. It then determines the need for any additional residual waste infrastructure taking into account arisings, recycling rates, landfill targets and gate fees.

[6] Model description adapted from Defra's internal RouteMap documentation.

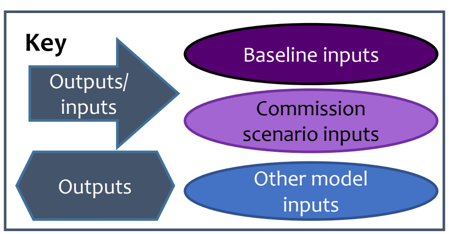
Figure 10 gives an indication of how the model utilises input assumptions from the Commission's economic growth variants, the policy and infrastructure baseline and other general model inputs to generate outputs for waste produced, total waste treated by disposal method and greenhouse gas emissions.

As waste is sometimes subject to more than one type of treatment (and therefore goes through the system twice) total waste treated exceeds waste produced. The model also produces outputs which were not utilised by the Commission and are therefore not shown in the schematic.

Figure 10 – Defra solid waste modelling schematic



Source: simplified model schematic, adapted from schematic produced by Defra for the Commission.



*economic growth and consumer expenditure growth are equivalent in the Commission's scenarios.

3.5.3 Baseline scenario modelling

The Commission constructed a baseline for the solid waste sector which would allow it to address the following key question:

"What is the impact on waste arisings and greenhouse gas emissions of minimal policy intervention in the waste sector?"

The main assumptions made in order to practically model this baseline case were:

- Waste is treated and disposed using the least costly available technology in both models, so long as treatment capacity is available.
- The composition of waste is assumed to be fixed throughout the period in question.

Certain assumptions differ in the two models:

ITRC model

- **Waste treatment capacity** – treatment capacity built out to 2018 is based on the Eunomia (2013) report, which describes capacity under construction and consented. Projects which have subsequently been cancelled or decommissioned were removed from the pipeline. When waste arisings exceed existing capacity the least costly treatment option is built in the model.
- **Main reduction targets and regulations** – the EU Waste Framework Directive 2020 recycling target of 50% of household waste is assumed to be met, and remains fixed thereafter. Constraints on the amount of waste allowed to go to landfill from the 1999 Landfill Directive are enforced.

Defra model

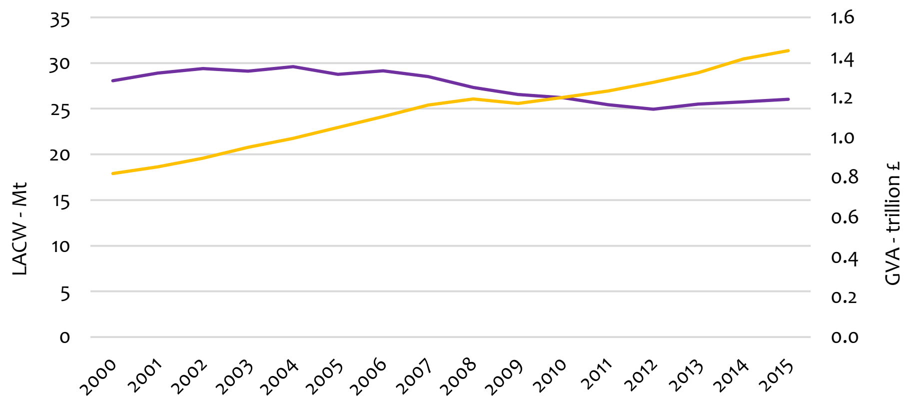
- **Waste treatment capacity** – treatment capacity out to 2025 is based on projects in the Waste Infrastructure Delivery Programme. Capacity for residual waste treatment increases by 200kT per year post-2025 – this constant infrastructure build-rate does not account for potential market adjustment, which is likely to be invalid in high waste-growth scenarios. Any waste exceeding capacity goes to landfill.
- Mass of recycling per household is assumed to be constant up to 2031. Post-2031, mass of recycling is assumed to increase in proportion to the arisings growth rate.
- C&I exports of RDF for incineration are assumed to be constant from 2016 onwards.

3.5.4 Sensitivity analysis

Historical data show that waste generation is correlated with economic activity. However, as can be seen in Figure 11, recent trends indicate that **economic growth** and **waste arisings** may be **decoupling** (i.e. using less resources and generating less waste per unit of economic activity).[7]

[7] For a full discussion on the decoupling of waste from economic growth see WRAP UK's report on Decoupling of Waste and Economic Indicators.

Figure 11 – Local authority collected waste arisings and GVA, England



Source: historic LACW from Defra's Waste and recycling statistics, regional GVA published by the ONS.

In the Commission's core scenarios the relationship between economic growth and waste arisings is based on income-elasticity estimates identified in the literature, as set out in the Commission's economy driver paper. An income-elasticity of **0.45** was assumed, corresponding to the midpoint of the elasticities found (0.2-0.7).

To explore the possibility of future decoupling between waste arisings and economic growth, a sensitivity analysis was carried out in NISMOD using an income-elasticity of waste arisings of **-0.27**. This corresponds to the income-elasticity calculated for LACW arisings in England using GVA data from 2000 to 2015. This period spans the duration of the financial crisis, which may have, at least in part, driven this decoupling.

The income-elasticity estimated using the historical data was applied to all of MSW (its LACW and C&I waste components).

3.5.5 Solid waste scenarios

As with transport, although climate change may affect the waste sector in future (e.g. increased flooding may cause more waste arisings due to property damage), the models do not account for this , so some scenarios have been removed. In addition, technological change was not modelled explicitly in the waste sector, which caused additional scenarios to be removed.

The population redistribution scenario was also removed as the Commission chose not to explore the spatial element for the waste sector as waste can be processed in a different location to where it is produced. Scenarios 1, 2, 4 and 6 have been produced using the Defra and ITRC models. The sensitivity analysis scenario was produced using the ITRC model only.

Table 7 – Modelled scenarios in the solid waste sector

	scenario	economic growth	population growth	income-elasticity
1	High population growth	central	high	standard
2	Low population growth	central	low	standard
4	Low economic growth	low	central	standard
6	High climate change	central	central	standard
11	Low population growth and modest economic growth	modest	low	standard
	High decoupling rate	low	central	historic

3.6 Energy

3.6.1 ITRC energy modelling[8]

Energy demand model

The energy demand model in NISMOD-LP is a simulation model to project energy demand in the UK, as a function of socio-economic drivers and infrastructure investment and policy strategies. The model consists of five sub-modules.

The modules of the residential, services and industry sectors model annual demand for electricity and gas. The models are validated against base year (2010) energy demand from Energy Consumption in the UK (ECUK) data, disaggregated by end-use.

Energy demand for each end-use category in 2050 is then modelled using a set of predefined transition options, for example for energy efficiency of appliances, heating and industrial processes, fuel switching, building insulation and onsite energy generation. The transition pathways are based on the best available research and judgement of UK energy experts of uptake rates under different infrastructure transition strategies.

Underpinning the demand assessment are the Commission's socio-economic drivers. Then, a perfect foresight back-casting approach is used to interpolate between 2010 and 2050, with each end-use transition option following an S-curve.

Energy consumption in the transport sector is estimated by a separate module which uses input data from the bespoke transport model in NISMOD.

Results for annual energy demand from the residential, services, industry and transport modules are then used in the peak load module to model the peak demand for electricity and gas that drives energy supply investment. Peak demand is modelled daily for gas and hourly for electricity.

For most end-use demands, the peak load coefficient (ratio of peak to average load) is derived from historic data. Contributions to peak demand due to potentially important new demands for electricity (e.g. electrification of transport) use expert judgement based on existing niche deployment.

Energy Supply – CGEN+ model

The energy supply model in NISMOD-LP is an optimisation model for the expansion planning of the *combined* electricity and gas infrastructure in the UK. It models assets across the whole value chain of electricity and gas supply, including resources, networks, generation technologies and end energy use.

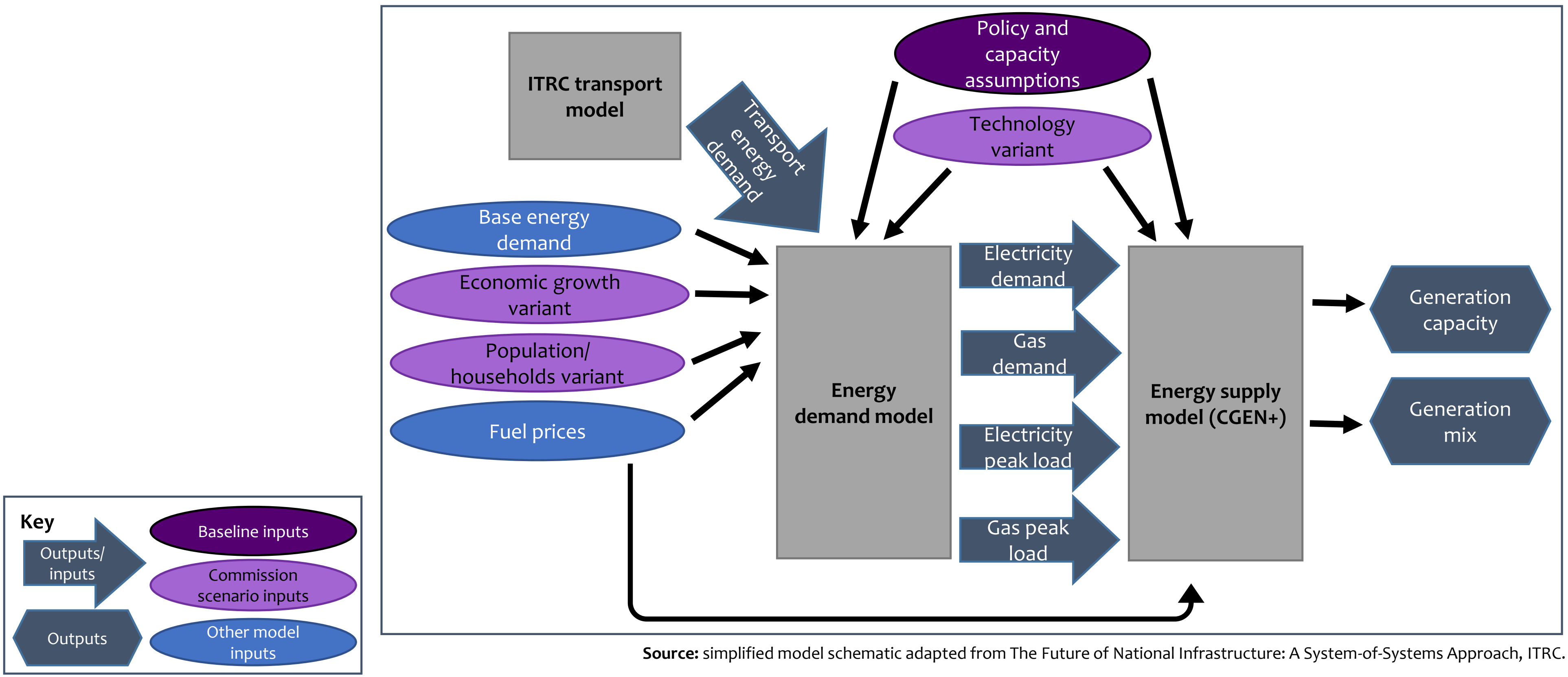
The model performs the expansion of electricity generation by determining the type, capacity, location and timing of additional generation assets. Network expansion is implemented by adding gas pipes, compressors, storage facilities, LNG terminals and import pipelines to the high pressure gas transmission network and increasing circuit capacity to the high voltage electricity transmission network. Expansion is planned by an objective function, which chooses the options that minimise both the capital cost of new investments and the overall system operational costs, at planning intervals set by the user (e.g. 10 years), over planning horizons which can span 50+ years.

[8] Model descriptions adapted from information provided by the ITRC for the Commission.

Capacity expansion is planned to meet various demand regimes and resource constraints (economic and physical). The demand regimes are created by the NISMOD energy demand model. Gas and electricity constraints such as gas flow, pressures, fuel prices, and maximum power generation are imposed within the model.

Figure 12 gives an indication of how the model utilises input assumptions from the Commission's economic growth, population/number of households and technology variants, the policy and infrastructure baseline and other general model inputs to generate outputs for average electricity and gas demand, peak electricity and gas demand, electricity generation capacity and generation mix. The model also produces outputs which were not utilised by the Commission and are therefore not shown below.

Figure 12 – ITRC energy modelling schematic



Source: simplified model schematic adapted from The Future of National Infrastructure: A System-of-Systems Approach, ITRC.

3.6.2 BEIS energy modelling[9]

Energy demand model (EDM)

The BEIS EDM projects fuel demand for energy by sector and sub-sector using a series of econometric and behavioural equations, out to the end of the 5th carbon budget (2032).

The estimates are based on regression analysis of historic fuel demand against drivers of energy use, such as economic growth.

UK TIMES

UK TIMES is a dynamic least cost optimisation model for the whole UK energy system which runs from 2010 to 2060. The model identifies the energy system which meets energy service demands with the lowest discounted system cost, subject to optional constraints such as greenhouse gas targets, technical restrictions and build rate limitations. It assumes 'rational' decision making, perfect information, competitive markets and perfect foresight.

The model encompasses all the steps from primary resources through the chain of processes that transform, transport, distribute and convert energy into the supply of energy services demanded by energy consumers e.g. space heating, lighting industrial processes.

On the energy supply-side, it comprises fuel mining, primary and secondary production, and exogenous import and export. Through various energy carriers, energy is delivered to the demand-side, which is structured into sectors e.g. residential, commercial, agriculture, transport and industry.

The technology processes that transform the primary energy inputs into the end-use services, together with their associated cost, are represented by mathematical relationships within the model.

A number of physical, economic and policy constraints are imposed on the model to reflect the current system.

UKTIMES delivers results based on scenario analysis. A scenario is set up by imposing constraints on the model with the aim to capture various states of the world e.g. minimum share of renewable energy, maximum amount of GHG emissions.

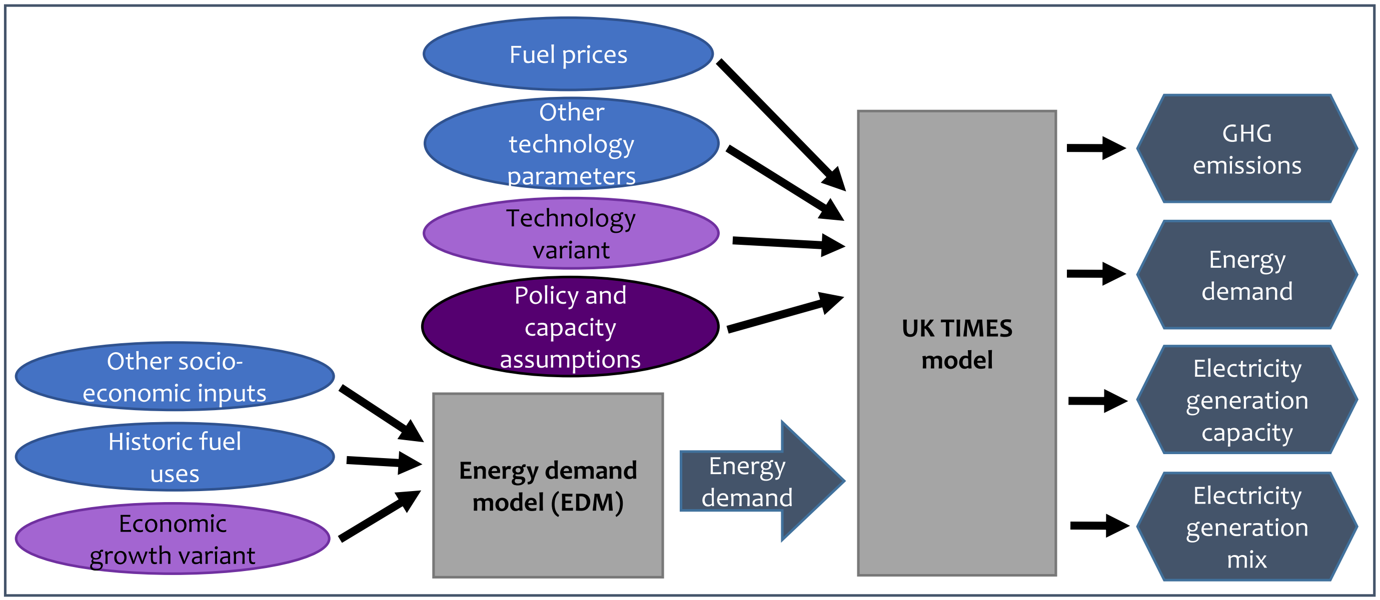
The modelling system was developed by Energy Technology Systems Analysis Program (ETSAP) as part of the International Energy Agency (IEA) Secretariat.

[9] Model descriptions adapted by the Commission from CCC for the EDM; and BEIS and ETSAP for UK TIMES.

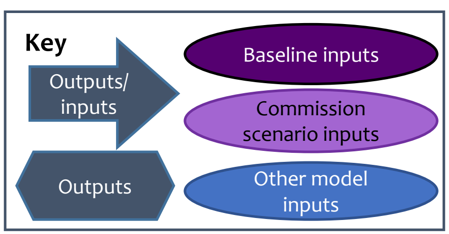
Figure 13 gives an indication of how the models utilise input assumptions from the Commission's economic growth, and technology variants, the policy and infrastructure baseline and other general model inputs to generate outputs for total energy demand, greenhouse gas emissions, electricity generation capacity and generation mix.

The model also produces outputs which were not utilised by the Commission and are therefore not shown in the schematic.

Figure 13 – BEIS energy modelling schematic



Source: simplified model schematic adapted from the CCC for the EDM; and BEIS and ETSAP for UK TIMES.



3.6.3 Baseline scenario modelling

The Commission constructed a baseline for the energy sector which would allow it to address the following key question:

"What is the carbon challenge if the fuel mix is determined by least cost optimisation?"

The main assumptions made in order to practically model this baseline case were:

- The starting point for meeting energy demand is the current fuel and generation mix.
- The current carbon floor price is rolled forward, in line with a minimal level of policy intervention, but no carbon constraints are imposed on the models in order to ascertain the UK's carbon 'challenge'.

Generation capacity:

- The Autumn 2016 National Infrastructure and Construction Pipeline provides the basis for additional capacity going forward. Wylfa B and Moorside nuclear plants were removed from the pipeline as no final investment decision has been made for these projects. Trafford CCGT was also removed as there is significant uncertainty around its future since it reneged on its capacity agreement earlier this year, after failing to meet its financial commitment milestone.
- Hinkley Point C is assumed to come online between 2026-2030.
- All coal plants are assumed to be decommissioned by 2025.
- No onshore wind in addition to what is in the pipeline is built in the modelling time horizon to reflect the current difficulties in building new onshore wind capacity due to planning regulations and exclusion from Contract for Difference auctions.
- In the BEIS model interconnection assumptions are based on the 'no progression' scenario in National Grid's 2016 Future Energy Scenarios (FES). In the ITRC model interconnection is taken up to the point where it is cost-effective to do so under the model's assumptions.

3.6.4 Technology assumptions

Technological change is considered to be an exogenous driver of energy supply and demand, which will occur to some extent regardless of policy intervention. In the energy sector, four technologies have been considered:

I. Renewable energy generation technologies

Technological development is expected to reduce the capital costs of renewable energy generation technologies. If costs are lower, relative to other generation types, renewables could make up a larger proportion of the energy/fuel mix.

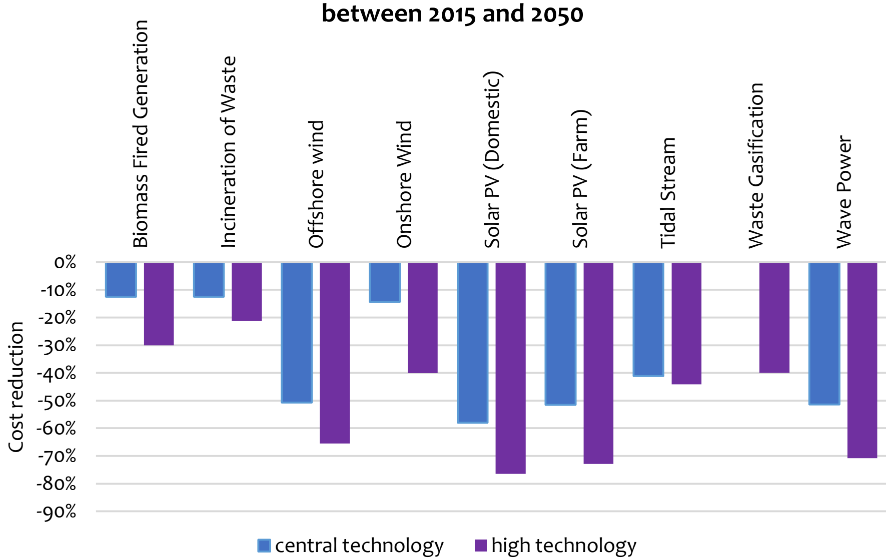
Renewable generation cost curves have been provided by the ETI from their ESME model database for the central technology variant. Further details on data sources can be found in the ESME Data References Book. Their approach to generation costs is policy neutral and based mainly on technology potential as reflected in the sources used and ETI's expert review of them.

There is no explicit assumption made about the nature of policy, but the implicit assumption is that policy enables sufficient deployment of the technology (either in the UK or elsewhere) to support the technical progress and cost reduction built into the cost curves.

Variation of cost curves for each generation technology for the high tech scenario were based on specific judgements taken by ETI technical experts about the range of uncertainty on the future cost of a technology and the maximum possible build/deployment rate for any given technologies in future decades.

The cost of renewable energy generation technologies falls in both technology variants at different rates as can be seen in Figure 14.

Figure 14 – cost reductions of renewable energy generation technologies between 2015 and 2050



Source: constructed by the Commission using data from the ETI, ESME Data References Book

II. Battery storage

Technological development in energy storage is expected to lead to continued reductions in battery costs. The widespread take-up could in turn impact on infrastructure systems by driving a decrease in peak demand for electricity, thus reducing the need to build new infrastructure to meet peak demand, and reduce local network constraints.

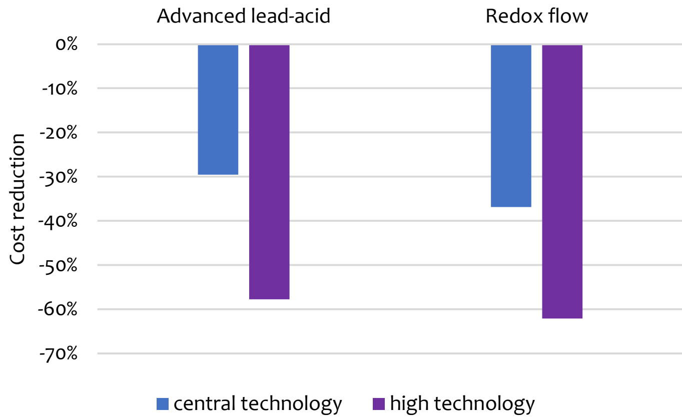
The Commission has chosen to include battery storage technologies that are currently believed to be in the 'medium maturity' bracket, as these will likely see a dramatic cost reduction over the next decade or so.

The size of the impact of further reductions in battery costs is determined by the model used. The inputs required to quantify this impact are capital costs, lifespan and roundtrip efficiency for different types of batteries. This data was provided by the Energy Technology Institute (ETI) from their Storage and Flexibility Modelling project. The ETI used primary sources for base year costs and then applied generic technology cost curves (published by the Energy Networks Association) for future years based on the maturity of the technology.

Assumptions for high and low cost ranges for the high and central technology variants for each battery type are based upon the maturity of the technology. They rely on judgements made by ETI technical experts and are appropriate to use for scenario analysis.

As with generation costs, the costs of battery storage fall more in the high technology variant. Cost reductions of the two battery types considered, in both technology variants, are shown in Figure 15.

Figure 15 – cost reductions of chemical batteries between 2015 and 2050



Source: constructed by the Commission using data from the ETI from the Storage and Flexibility Project.

III. Electric vehicles

A continued reduction in battery costs is also expected to lead to a higher take-up of EVs, which would increase average electricity demand and could significantly increase peak demand.

The size of the impact on electricity demand is estimated by the models used and will depend on the proportion of the fleet which is assumed to be electric. Other parameters affecting demand, including vehicle efficiency (kWh/km) and travel patterns (average annual kilometres), were embedded in the models and not altered across technology variants.

OLEV's baseline (no new policy) scenario for EV uptake was used for the central technology variant. The high technology variant was provided by the ETI and is based on their 'EV push' scenario which assumes that research and development delivers cell improvement to the extent that lithium-ion battery limits are reached by 2030 and significant blending of silicon in the anode is achieved. Current policies such as tax breaks for ultra-low emission vehicles are rolled over and government grants apply as announced. Lower battery costs, rather than new policy intervention, is assumed to lead to EV uptake. The recent Government announcement of an end to sales of new petrol and diesel cars by 2040 is not reflected here as the baseline was developed prior to this announcement. However, this will be considered in the next phase of the work.

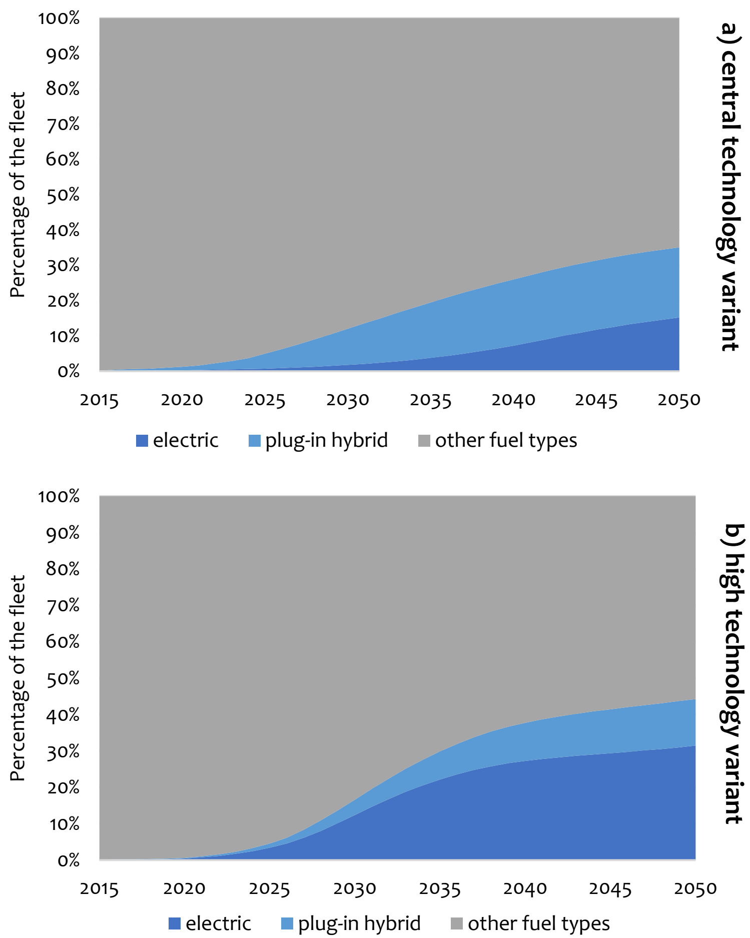
Figure 16 shows the percentage of the fleet made up of electric vehicles and plug-in hybrids under the two technology variants which were used as inputs into UK TIMES and NISMOD.

IV. Efficiency of lighting and electric appliances

UK TIMES

In UK TIMES, the high technology variant allows the model to take up any cost effective electrical efficiency measures that are included; the central technology variant limits electricity efficiency improvements. This is done by proxy, by assuming no improvement in the efficiency of LEDs in buildings.

Figure 16 – Percentage of EVs and PHEVs in the car fleet



Source: constructed by the Commission using data from the ETI and OLEV.

NISMOD

The ITRC constructed a series of 'strategies' for their energy model which are combinations of parameter values, including technology parameters. As it was the Commission's intention to represent a "no policy" baseline, the ITRC's "minimum policy intervention" strategy was chosen to represent the Commission's central technology variant. This strategy was parametrised by the ITRC and implies that 10% of efficiency and fuel switching potential is reached by 2050.

For the Commission's high technology variant, some parameters associated with energy efficiency were set to match those in the ITRC's "local energy and biomass" (LEB) strategy which is the ITRC's second-most ambitious strategy in terms of demand management. As the intention was still to represent a no policy baseline, albeit with a faster pathway of technological development, only the parameters relating to energy efficiency (appliances and boilers) which were deemed to be market driven and would not require further policy incentives were set to match the ITRC's LEB strategy.

Further details on the ITRC strategies are available in ITRC's book, The Future of National Infrastructure: A system-of-systems approach.

3.6.5 Energy scenarios

The climate change driver was also not varied for this sector.[10] Similarly to the waste sector the Commission chose not to explore spatial variations in the energy sector as energy can be generated in a different location to where it is consumed and the models used do not provide detailed representations of the distribution network. The number of modelled scenarios was therefore reduced accordingly.

Table 8 – Modelled scenarios in the energy sector

	scenario	economic growth	population growth	technological change
1	High population growth	central	high	central
4	Low economic growth	low	central	central
5	High technological development	central	central	high
6	High climate change	central	central	central
8	High population growth and technological development	central	high	high
12	Low economic growth and high technological development	low	central	high

Scenarios 1, 8 and 12 have been produced using UK TIMES and the ITRC energy demand and energy supply models. Scenario 4 has been produced using UK TIMES, and the remaining scenarios have been produced using the ITRC models only.

[10] Although BEIS' modelling takes into account future increases in average temperature driven by climate change, assumptions around future temperature were not linked to the climate change variants. All model runs produced by BEIS analysts for the Commission use the Met Office long term projections for temperature, which translates into a steady reduction in the number of winter degree days.

4

Findings

4.1 Scenario key

Table 9 shows the labelling used throughout this sector for each scenario. Drivers which do not affect particular sectors are left out of the code in the results charts and graphs.

Table 9 – Scenario labelling

	economic growth	population growth	climate change	technological change	scenario code	scenario colour
1	central	high	central	central	eC_pH_cC_tC	
2	central	low	central	central	eC_pL_cC_tC	
3	central	redistribution	central	central	eC_pR_cC_tC	
4	low	central	central	central	eL_pC_cC_tC	
5	central	central	central	high	eC_pC_cC_tH	
6	central	central	high	central	eC_pC_cH_tC	
7	central	central	low	central	eC_pC_cL_tC	
8	central	high	central	high	eC_pH_cC_tH	
9	central	central	high	high	eC_pC_cH_tH	
10	central	high	high	central	eC_pH_cH_tC	
11	modest	low	central	central	eM_pL_cC_tC	
12	low	central	central	high	eL_pC_cC_tH	

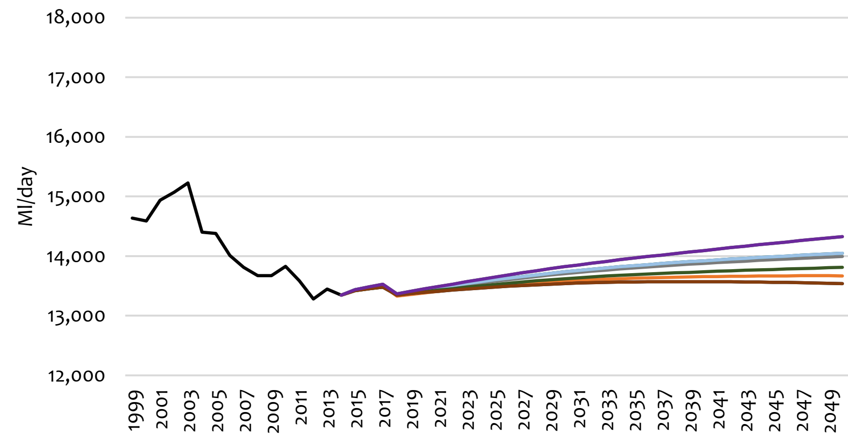
4.2 Water

4.2.1 Water demand and supply

Demand for water in the ITRC model is affected by **population growth** and **technological change**. Figure 17 indicates the range of potential outcomes for future demand for water between 2015 and 2050, as measured by demand from households, non-household demand and leakage. Historic demand figures correspond to 'distribution input' and were provided by the Environment Agency. The increase in demand over this period ranges from just 1% in the lowest scenario (low population growth and high technological change) to 7% in the highest scenario (high population growth and central technological change). Climate variability and change do not affect water demand in the model.

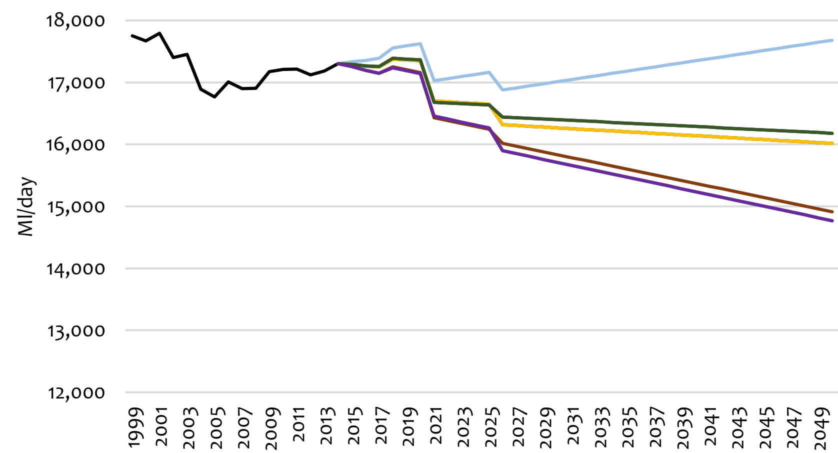
Water supply in the model is affected by future hydrological flows, which are driven by **climate variability and change**. Figure 18 indicates the range of potential outcomes for future available water supply ('deployable output') between 2015 and 2050. The change in deployable output between 2015 and 2050 ranges from a 2% increase in the low climate change scenario to a 15% reduction in the high climate change scenarios. When reporting water supply projections to the Environment Agency, water companies use the metric 'water available for use' rather than deployable output. Water available for use differs from deployable output as it also includes any losses in the water abstraction or treatment processes, and/or any allowance for regular water "outage" for asset maintenance.

Figure 17 – Average daily water demand, England – ITRC NISMOD

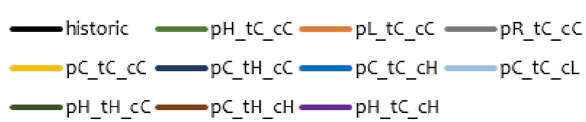


Source: historic figures provided by the EA; future scenarios produced by the Commission using NISMOD.

Figure 18 – Average daily water supply, England – ITRC NISMOD



Source: historic figures provided by the EA; future scenarios produced by the Commission using NISMOD.



It would be expected that the water supply results shown in Figure 18 would be 5-10% lower if water losses/outage were to be taken into account – in 2014 average deployable output in England was 1,175 Ml/day higher than water available for use.

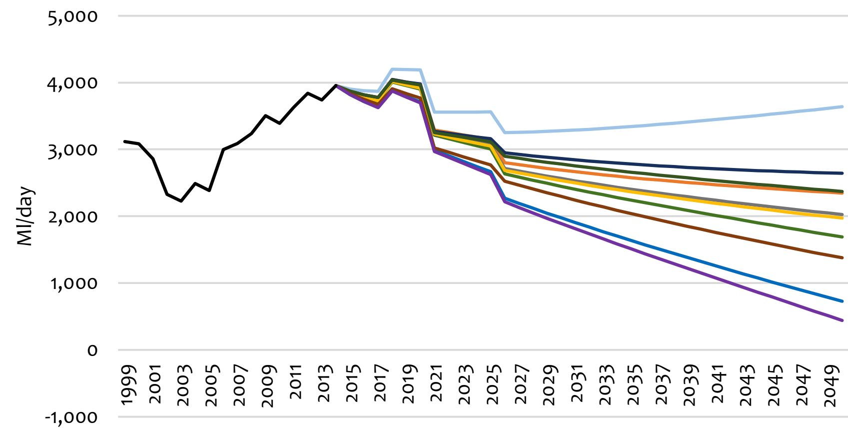
4.2.2 Water balance

Figure 19 indicates the range of potential outcomes for future **water balance** (the difference between supply, as measured by deployable output, and demand, as measured by distribution input) between 2015 and 2050. Aggregate water balance for England and Wales in 2050 ranges from an 89% reduction in the lowest balance scenario (high population growth, central technology and high climate change) to around 8% reduction in the highest balance scenario (central population growth, central technology and low climate change).

As was mentioned, the ITRC's water supply outputs do not take into account regular outages/losses experienced by water companies. They are also likely to be overestimating the overall water availability in the country. In order to better reflect water balance the figures below would need to be adjusted by the value of these outages. Figure 20 adjusts water balance to reflect these outages (using the difference between average daily deployable output and water available for use in 2014).

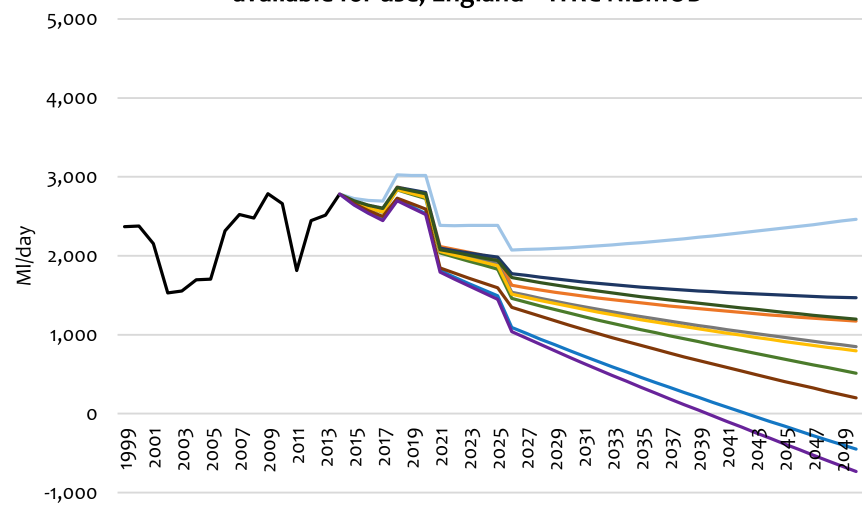
Although these results do not indicate a supply deficit in many of the scenarios they do not reflect spatial considerations of water balance, which cannot be ignored.

Figure 19 – Average daily water balance using deployable output, England – ITRC NISMOD

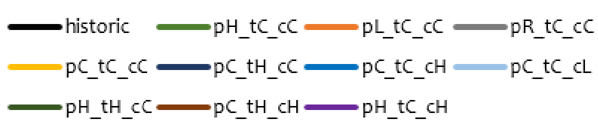


Source: historic figures provided by the EA; future scenarios produced by the Commission using NISMOD.

Figure 20 – Average daily water balance adjusted to reflect water available for use, England – ITRC NISMOD



Source: historic figures provided by the EA; future scenarios produced by the Commission using NISMOD.



By aggregating water supply and demand in all the English regions it is implicitly assumed that water can be transferred freely across regions, when in reality significant costs would be incurred in doing so, as there is no wide-scale water transfer infrastructure in place. The spatial element of water balance is further explored later in this section.

Water UK's Water resources long term planning framework is the first assessment for England and Wales of supply/demand vulnerability to more extreme drought events than those considered under the current planning framework. As a robustness check, the Commission has compared the scenario results obtained with NISMOD to Water UK's aggregate water balance results.

A few adjustments were made to the Commission's water balance outputs before these could be compared to Water UK's outputs:

Water supply definition

- The first was to adjust the Commission's supply metric, which is deployable output, to bring it in line with water available for use. This was done by subtracting the difference between deployable output and water available for use (taken from Water UK's report) from the ITRC modelling outputs. This brought water supply in 2016 down to 1,381 Ml/day, in line with initial water supply in the Water UK modelling results.

Water balance definition

- The second difference between the Water UK and Commission's modelling results is the definition of water balance. The Water UK report uses the standard Environment Agency definition, which subtracts Water Companies' 'target headroom' from the difference between supply (water available for use) and demand (distribution input) to generate water balance.[11]
- Target headroom is a risk-adjusted value which water companies use to account for uncertainty in all variable components of the supply/demand balance. The Water UK report subtracted 724 Ml/d from water balance in each year, which corresponds to the sum of the target headroom in all Water Resource Zones which companies put forward at WRMP14 for the start year of the Water UK analysis (2012). The 2012 value was used in order to only account for uncertainty in the starting balance and avoid double counting uncertainty going forward – it accounts for things such as uncertainty in reservoir and surface water yield, uncertain constraints to groundwater deployable output (water quality, drought), random asset failure, time limited licences, etc.

Geographic coverage

- Water UK's outputs cover England and Wales, so water balance outputs for Wales were added to the results shown in page 55.

[11] For a summary of Environment Agency water metrics referred to in this document see the Annex on page 75.

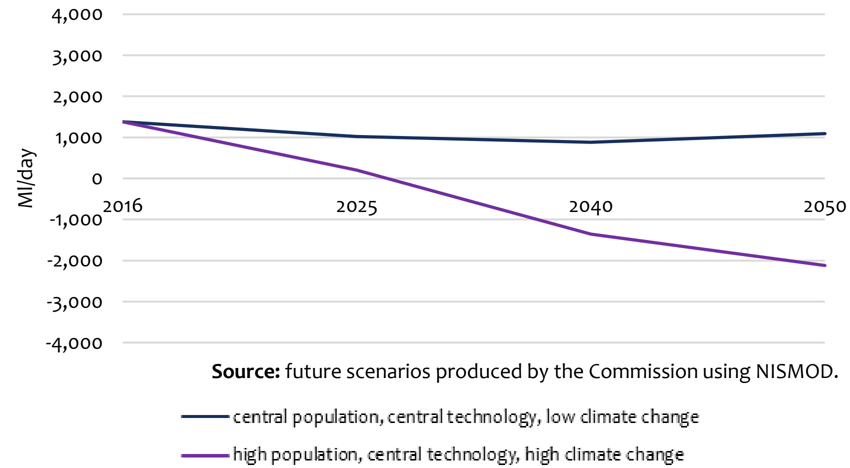
Figures 21 and 22 show the range of outcomes for average daily water balance in England and Wales in the Commission's scenarios and in the Water UK report. The range is significantly wider in the Water UK report, reflecting the different approach to scenario generation taken:

- Water UK's highest water balance scenario corresponds to similar population-driven demand but lower climate change and more ambitious demand management than the Commission's highest scenario. The demand management in the Water UK work is more ambitious as it is policy driven, which differs to the approach taken in the Commission's baseline.
- Water UK's lowest water balance scenario corresponds to similar population-driven demand, similar demand management (which has been treated as technological change in the Commission's scenarios) but significantly higher sustainability reductions (75% more than in the base scenario).

Supply-side spatial uncertainty

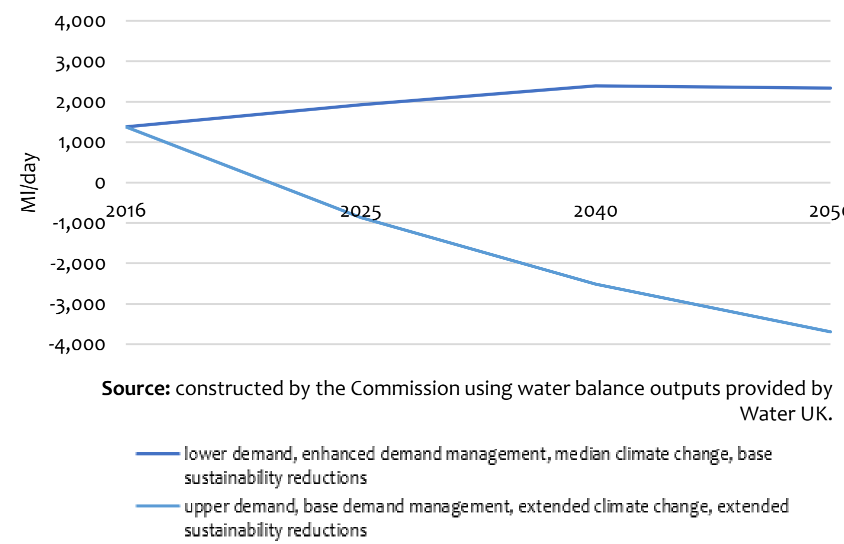
Figures average daily water balance (using deployable output, in Ml/day) across the UK in 2050. The South East faces significant supply deficits even in the scenario that puts the least pressure on national water balance. The maps also indicate how spatial variation in hydrological flows may lead to significant deficits in London.

Figure 21 – Average daily water balance adjusted to match Water UK definition, England and Wales – ITRC NISMOD



Source: future scenarios produced by the Commission using NISMOD.

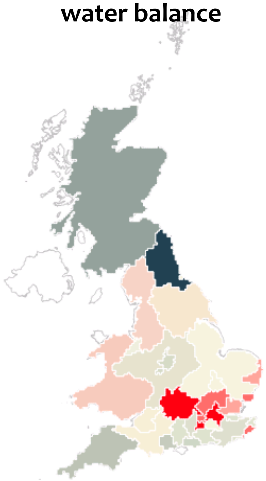
Figure 22 – Average daily water balance on Water UK definition, England and Wales – Water UK report



Source: constructed by the Commission using water balance outputs provided by Water UK.

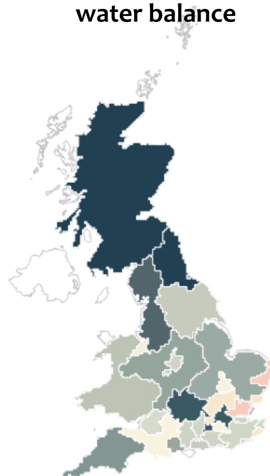
The balances shown here do not discount for regular outages/losses or target headroom and consequently **overestimate daily balance**, according to its standard definition. As they refer to average daily water balance, they may also be masking the magnitude of the problem, as there will be days with significantly lower balances than the average.

Figure 23 – Lowest aggregate water balance



pH_tC_cH

Figure 24 – Highest aggregate water balance

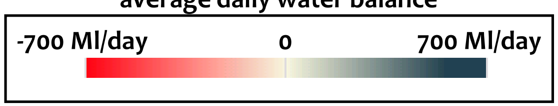


pL_tC_cC

Demand-side spatial uncertainty

Figures 25 and 26 show water balance (using deployable output, in Ml/year) across the UK in 2050 under two scenarios, which only differ in the geographical distribution of the population (total population is held constant).

average daily water balance



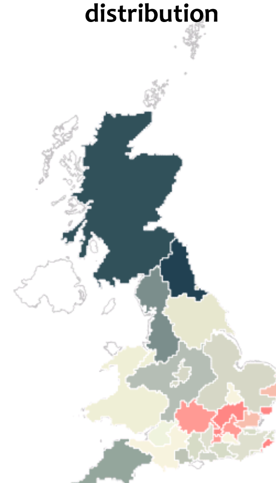
Source: maps produced by the ITRC NISMOD-LP reporting tool based on the Commission's scenario assumptions. Water company balances may not add up to national aggregates due to different calibration against historic figures.

Figure 25 uses the principal population projection which follows trend population growth in each region. In figure 26, population is constrained to grow in line with historic trends in housing construction in Local Authority Districts.

London and the South East face greater deficits in the trend population projection, as the redistribution variant leads to lower population growth in these regions. However, this comparison indicates that even if London's population were to grow by 12% less than the trend projection, the region would still face significant water deficits.

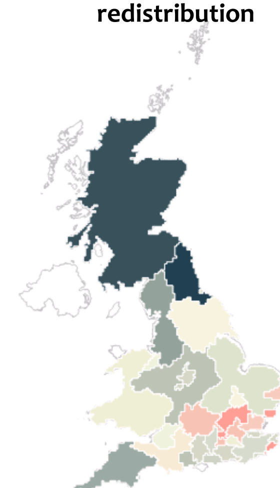
The redistribution of the population also leads to a water deficit in the West in the redistribution scenario, indicating how uncertainty in the distribution of the population could affect regions which may not expect to become water stressed.

Figure 25 – Central population distribution



pC_tC_cC

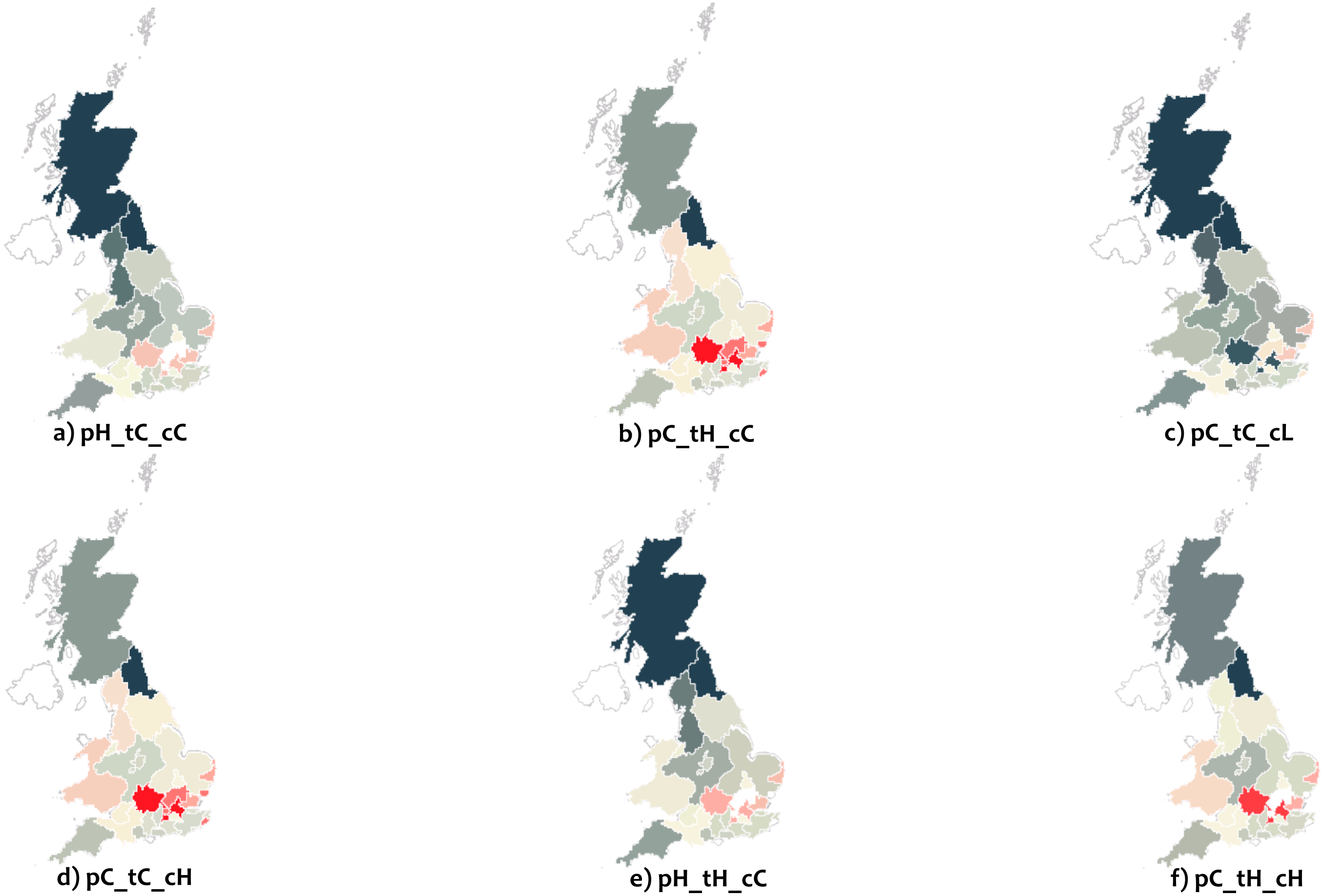
Figure 26 – Population redistribution

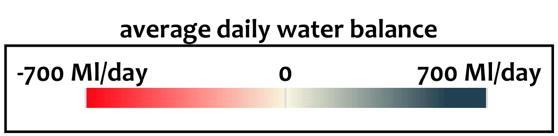


pR_tC_cC

Average daily water balance (using deployable output, in Ml/day) for the remaining six scenarios at the water company scale is shown below.

Figure 27 – Average daily water balance across six scenarios





Source: maps produced by the ITRC NISMOD-LP reporting tool based on the Commission's scenario assumptions. Water company balances may not add up to national aggregates due to different calibration against historic figures.

4.3 Transport

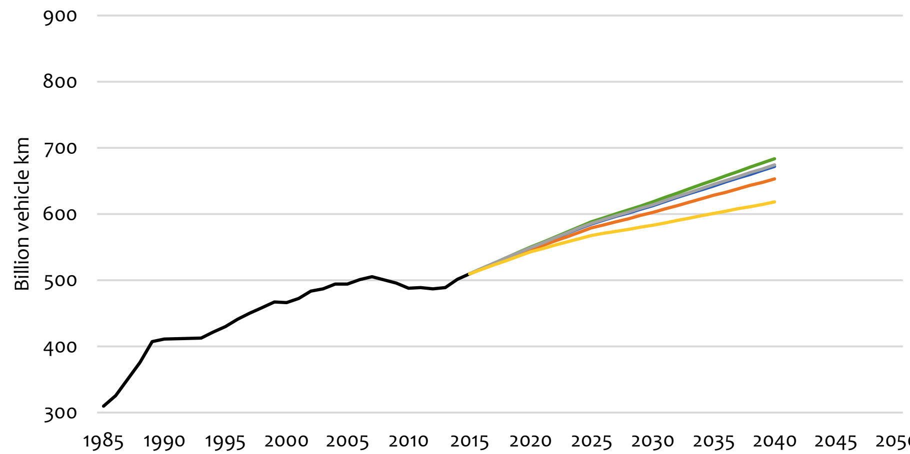
4.3.1 Road travel

Demand for travel is affected by **population growth, economic growth and employment, technological change** as well **as travel preferences.** Figures 28 and 29 show the range of potential outcomes for future demand for road travel between 2015 and 2050, modelled using the DfT's National Transport Model (NTM) and the ITRC's NISMOD model.

In the central technology case, the increase in road traffic in Great Britain between 2015 and 2040, as measured by road vehicle km travelled, ranges from 21% to 34% in the DfT's NTM, and from 30% to 54% in NISMOD. There is a significant increase in road traffic in the scenarios including the high technology variant post-2035, when the impact of CAVs is assumed to materialise. By 2050 CAVs lead to a 10% increase in road traffic on average , relative to the central technology scenarios. The sensitivity analysis scenario is represented by the red dashed line – it is still associated with demand growth of about 18% between 2015 and 2050 in NISMOD.

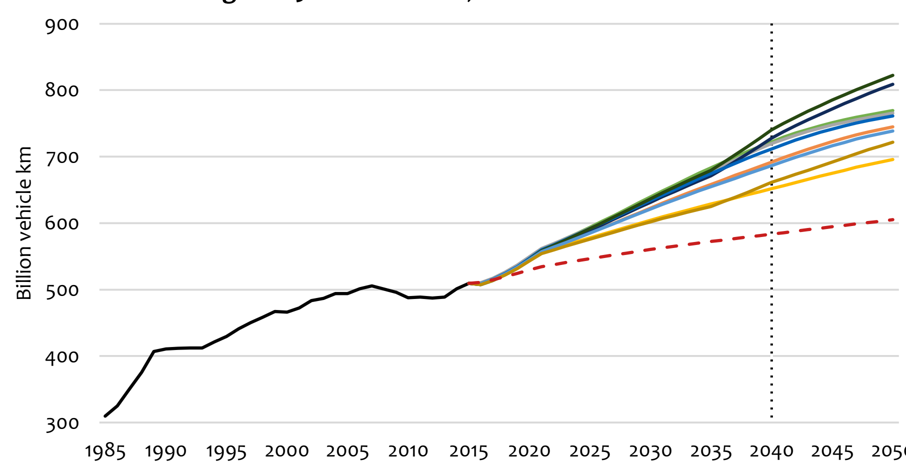
The Commission was interested in looking at the impacts of the demand outputs shown in Figures 28 and 29 on congestion in major roads. These results could not be obtained at the desired level of disaggregation. Although aggregate congestion metrics were available these were not considered to be insightful and were therefore not analysed in detail or included in this annex.

Figure 28 – Road traffic, Great Britain – DfT NTM

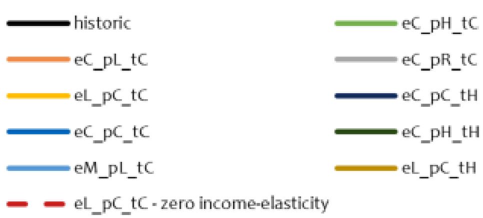


Source: historic figures published in DfT's Road traffic estimates in Great Britain; future scenarios produced by DfT analysts using the Commission's assumptions.

Figure 29 – Road traffic, Great Britain – ITRC NISMOD



Source: historic figures published in DfT's Road traffic estimates in Great Britain; future scenarios produced by the Commission using NISMOD.



4.3.2 Rail travel

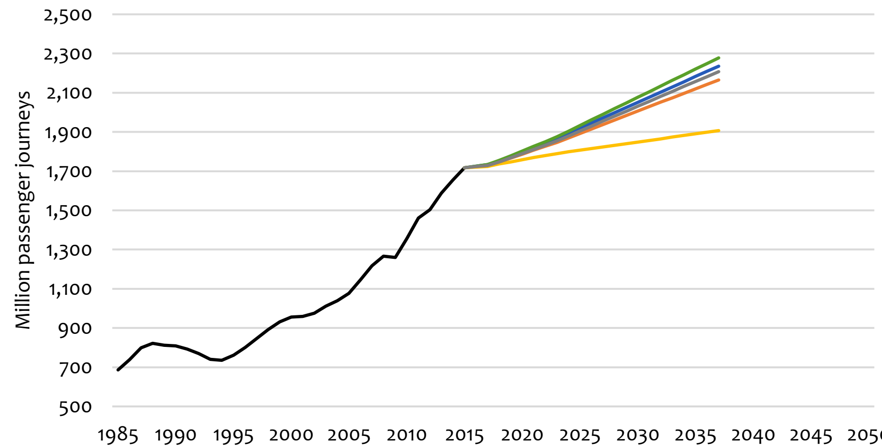
As is the case with road traffic, rail journeys are expected to increase between 2015 and 2050 in all scenarios considered. Figure 30 shows the range of outcomes for exogenous growth in rail journeys according to the DfT's EDGE model and Figure 31 shows the range of outcomes according to the ITRC's NISMOD. Rail demand in EDGE is calculated by applying unconstrained growth to constrained outturn data, which the DfT refer to as semi-constrained demand.

The EDGE model produces forecasts out to 2037, which is the length of time for which there is confidence in PDFH elasticities, according to the guidance. NISMOD produces outputs out to 2050, maintaining the same elasticities throughout the period.

The increase in rail travel in Great Britain between 2015 and 2037, as measured by rail passenger journeys, ranges from 11% to 33% in the DfT model, and from 11% to 27% in the ITRC model. A zero-income elasticity sensitivity test was not included for the rail model as unlike road travel, rail trip rates have been increasing in recent years.

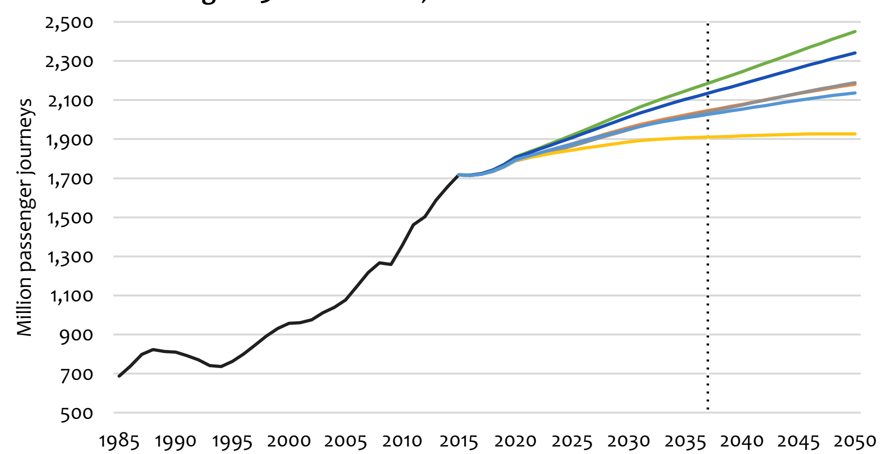
Although demand growth in both models looks very similar, different fare price assumptions were made in each model, as was mentioned in section 3.4.4. If similar assumptions had been used demand in NISMOD would be higher as DfT assumes slower growth in fare prices. Differences arise as NISMOD has a slightly higher fare elasticity, and links rail demand to fuel prices (which increase over time) whereas DfT use car costs (which decrease over time, due to efficiency improvements).

Figure 30 – Rail travel, Great Britain – DfT EDGE

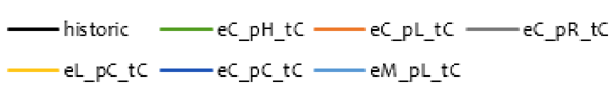


Source: historic figures published in DfT's Rail passenger numbers and crowding; future scenarios produced by DfT analysts using the Commission's assumptions.

Figure 31 – Rail travel, Great Britain – ITRC NISMOD



Source: historic figures published in DfT's Rail passenger numbers and crowding; future scenarios produced by the Commission using NISMOD.



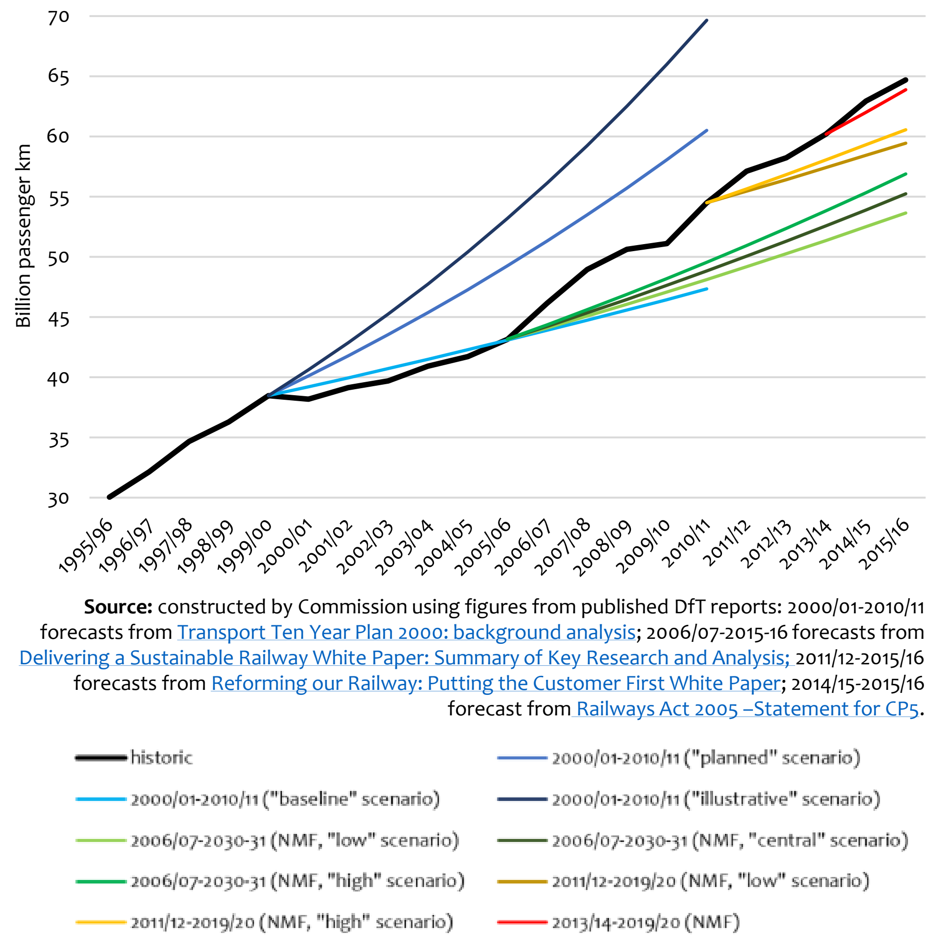
As has been mentioned, rail trips have been increasing significantly in recent years – the increase in rail journeys over the 23 year period preceding the modelled period (1993 to 2015), which saw investment in the railway, including timetable changes and new station and route openings, was 132%. In the recent Rail Demand Forecasting Estimation study prepared by ITS Leeds for the DfT, it is recognised that rail growth outputs derived from PDFH have not been performing well in explaining recent growth in rail demand. It is also noted that PDFH under-forecasts non-London demand, particularly for commuting into core cities.

Figure 32 shows past DfT forecasts of rail passenger kilometres alongside outturn data. It indicates that the "baseline" forecasts from the DfT's Transport Ten Year Plan (published 2000) were very close to actual demand up until around 2005/06. However, subsequent forecasts, such as the scenarios included in DfT's Delivering a Sustainable Railway White Paper (published 2008) and Reforming our Railways: Putting the Customer First White Paper (published 2012), have continuously under-forecast rail demand.

As both models used by the Commission are based on the PDFH methodology these outputs may also be underestimating rail demand growth.

The DfT and PDFC are going through a process of updating and improving the PDFH forecasting framework for PDFH 6.0. This process will update elasticities and may make significant changes to forecasts.

Figure 32 – DfT rail demand growth forecasts and outturn, Great Britain



Source: constructed by Commission using figures from published DfT reports: 2000/01-2010/11 forecasts from Transport Ten Year Plan 2000: background analysis; 2006/07-2015-16 forecasts from Delivering a Sustainable Railway White Paper: Summary of Key Research and Analysis; 2011/12-2015/16 forecasts from Reforming our Railway: Putting the Customer First White Paper; 2014/15-2015/16 forecast from Railways Act 2005 –Statement for CP5.

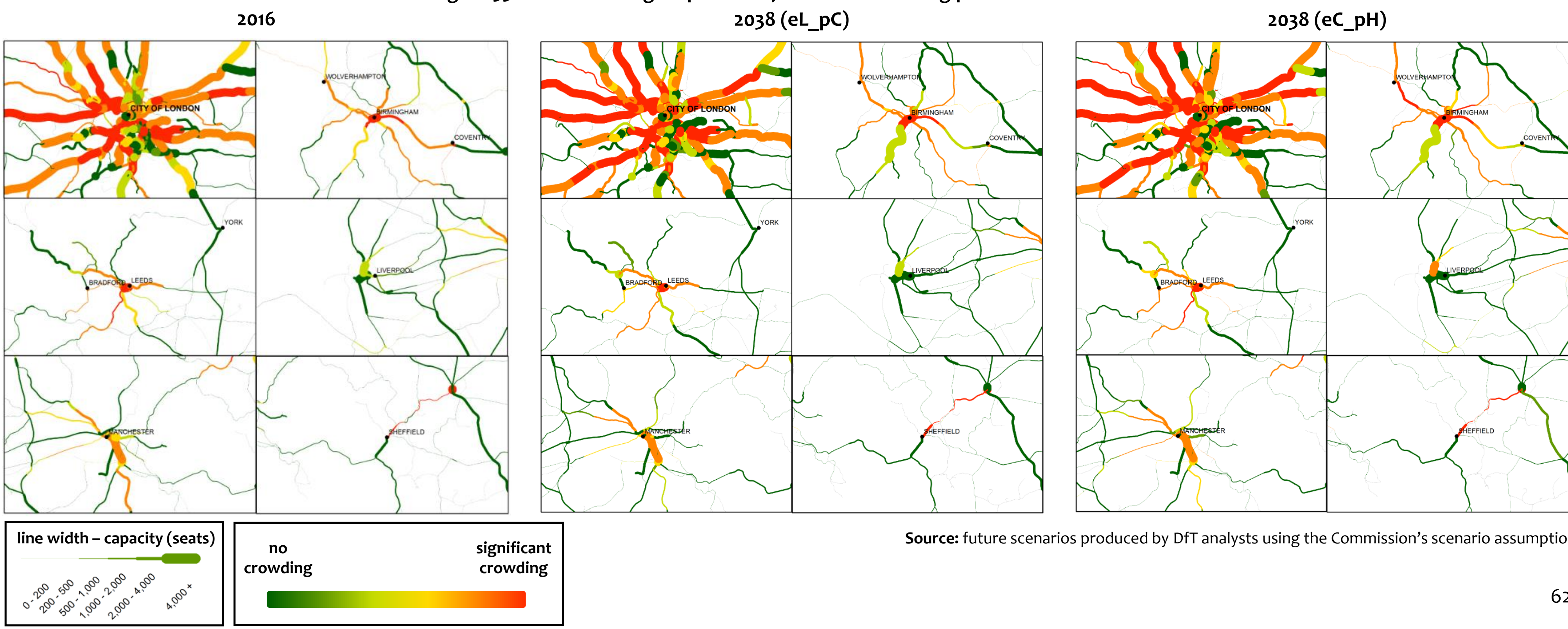
Figure 33 shows crowded minutes at morning peak hour across major English cities in 2016, as well as in 2038 for the scenarios with the lowest (eL_pC) and highest (eC_pH) demand growth, according to the DfT's NMF model.

There is already significant crowding in many of the lines in and out of London, which increases in both scenarios on some of these lines. The maps below do not include capacity enhancements brought about by HS2, which is expected to free up train paths on the West Coast and East Coast Main Lines as well as the Midland Main Line.

The inclusion of HS2 would be expected to reduce crowding on these lines in the maps below.

In the low demand growth scenario (eL_pC), crowding goes down on some lines in Leeds, Birmingham, Manchester and Liverpool. This is due to capacity enhancements around these cities, which are shown by the increased line width, and low growth in rail demand in this scenario. In the high demand growth scenario (eC_pH) crowding increases on many lines around these cities, despite these capacity enhancements.

Figure 33 – Rail crowding maps for major cities at morning peak hour – DfT NMF



Source: future scenarios produced by DfT analysts using the Commission's scenario assumptions.

4.4 Solid waste

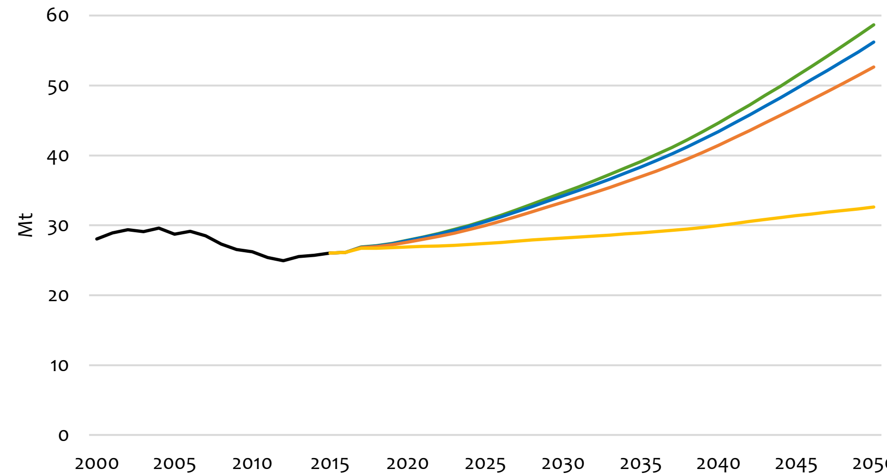
4.4.1 Local authority collected waste

Waste arisings are affected by the **population growth** and **economic growth** drivers. Figures 34 and 35 show the local authority collected waste (LACW) component of municipal solid waste (MSW) arisings.

LACW rises in all scenarios in Defra's waste arisings model, shown in Figure 34. The values in 2050 range from 33 Mt (in the scenario with low economic growth and central population growth) to 59 Mt (in the scenario with central economic growth and high population growth). Arisings forecasts in RouteMap do not account for any future decoupling of arisings from GDP and assume that growth in consumer expenditure is equal to growth in GDP – this will most likely lead to an overestimation of arisings growth. LACW arisings from ITRC's NISMOD are shown in Figure 35. A clear increase can be observed in four of the six scenarios tested, the largest of which is an increase to around 38 Mt in 2050, in the scenario with central economic growth and high population growth (eC_pH).

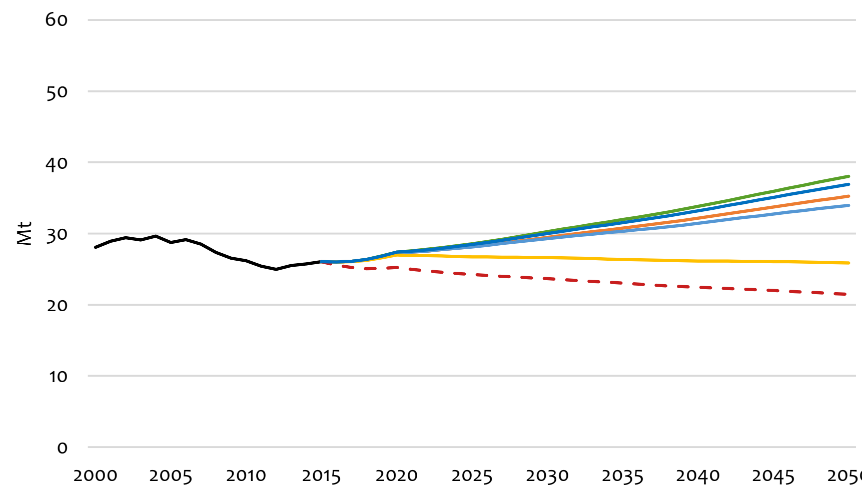
A sensitivity test of this scenario (eC_pH) was run with a negative income-elasticity to test the impact of future waste and economic growth decoupling, causing LACW arisings to fall by 19% between 2015 and 2050, to 21 Mt. Decoupling between waste arisings and economic growth could be associated with many things, such as a change in attitudes to throwing away waste or regulation around packaging reduction, which would lead to less waste produced per economic transaction.

Figure 34 – LACW arisings, England – Defra Waste Arisings Model



Source: historic figures published in Defra's Waste and recycling statistics; future scenarios produced by Defra analysts using the Commission's scenario assumptions.

Figure 35 – LACW arisings, England – ITRC NISMOD



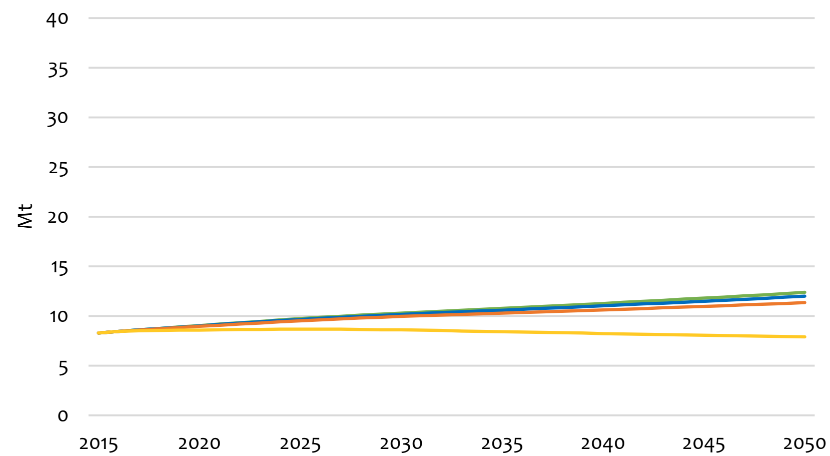
Source: historic figures published Defra's Waste and recycling statistics; future scenarios produced by the Commission using NISMOD.

4.4.2 Commercial and industrial waste

NISMOD produces estimates for all MSW, roughly half of which is assumed to be municipal-like commercial and industrial (C&I) waste, based on the observation that the reclassification of MSW to include the C&I component roughly doubled the target values in the landfill directive. Reliable data on historic C&I arisings is generally very scarce and subject to frequent revisions – Defra's most recent estimates of total C&I are 65% lower than the previous estimates. Defra are currently in the process of revising their C&I arisings estimates again. This renders C&I arisings estimates from both the Defra waste arisings model and NISMOD extremely uncertain, as the range of outcomes for C&I arisings shown in Figures 36 and 37 illustrates.

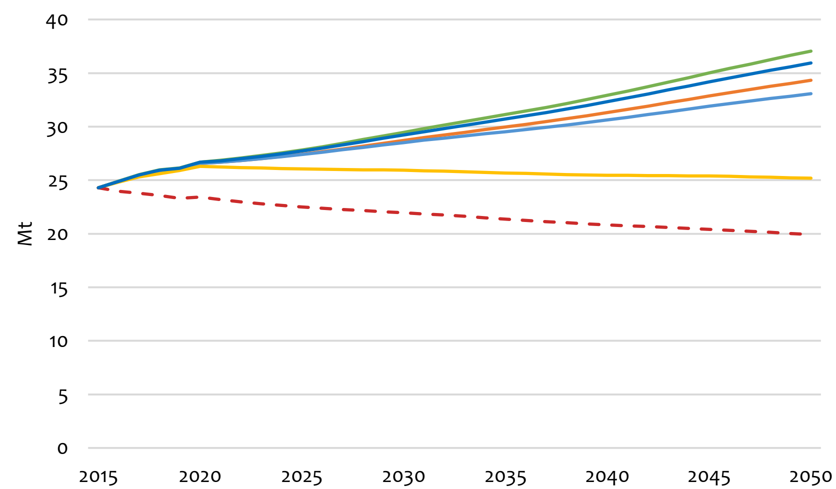
Figure 36 shows results from Defra's waste arisings model. MSW-like C&I rises very steadily on average, starting from around 8 Mt in 2014. The scenarios lead to MSW-like C&I arisings of between 8 and 12 Mt in 2050. Figure 37 shows MSW-like C&I arisings from NISMOD. The six scenarios lead to C&I arisings of between 20 and 37 Mt in 2050. The decoupling scenario sees a fall in MSW-like C&I arisings over the time period of 18%.

Figure 36 – MSW-like C&I arisings, England – Defra Waste Arisings Model



Source: future scenarios produced by Defra analysts using the Commission's scenario assumptions.

Figure 37 – MSW-like C&I arisings, England – ITRC NISMOD



Source: future scenarios produced by the Commission using NISMOD.

4.4.3 Municipal solid waste by destination

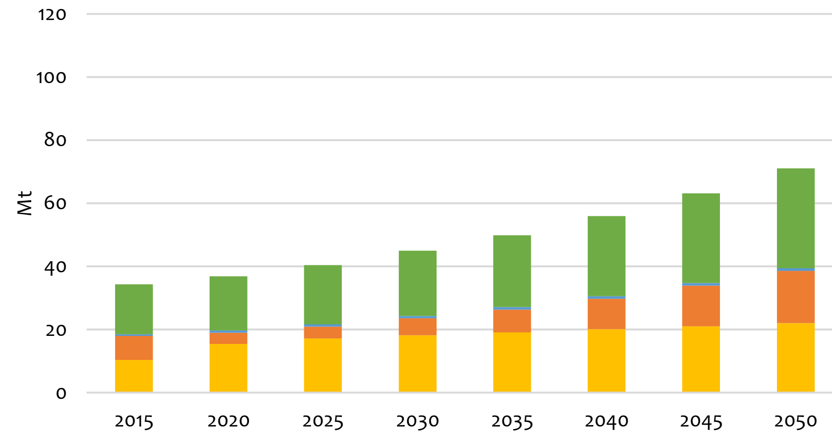
Figures 38 and 39 show outputs from Defra's RouteMap for waste arisings by final destination in the scenarios with the highest (eC_pH) and lowest (eL_pC) arisings.

Final waste destinations are grouped into four categories: recycling and composting; landfill; incineration (including exports); and other (non landfill), in line with breakdowns for LACW in Defra's [2015 Digest of Waste and Resource Statistics] publication. Anaerobic digestion (AD) has been classed under 'recycling and composting' in RouteMap – this is true for most anaerobic digestion, although a small amount will end up in energy from waste (EfW). As this amount is subject to frequent change it would be inaccurate to model a fixed proportion. Recycling and composting in the model may therefore be overestimated.

The proportion of waste which is recycled/composted as its final treatment is similar in both scenarios and between 45-46% throughout the period. A significantly larger proportion of waste is sent to landfill in 2050 in the high arisings scenario (23%) than in the low (9%) – this is to be expected as it is assumed that any waste exceeding capacity (which is represented by the pipeline of projects up 2025 and an extra 200kT of EfW capacity per year thereafter) is sent to landfill. This indicates that in a high population growth scenario and in the absence of waste decoupling the current infrastructure pipeline may not be sufficient to treat waste arisings without exceeding the 1999 Landfill Directive (depending on how much of the MSW is biodegradable), even assuming an additional 200kT per year of plant capacity.[12]

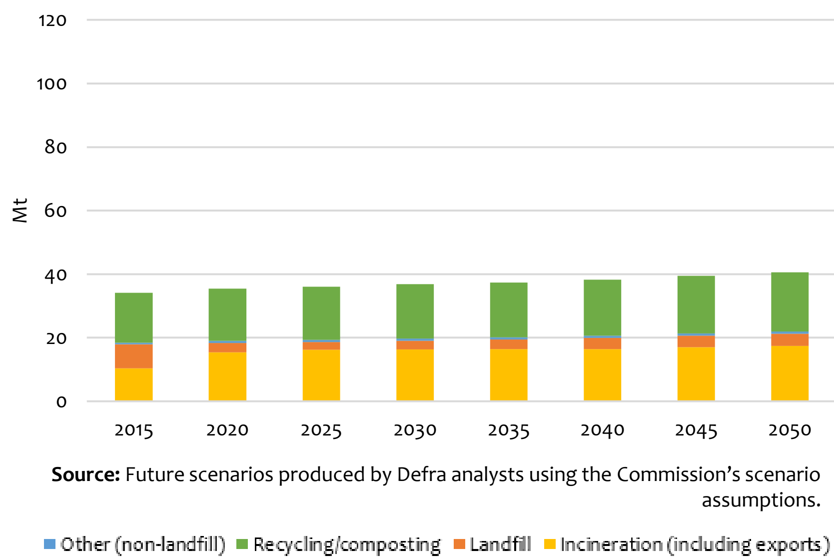
[12] The 1999 Landfill Directive states that no more than 10.16 Mt of biodegradable MSW should go to landfill by 2020.

Figure 38 – Final MSW destination (eC_pH), England – Defra RouteMap



Source: Future scenarios produced by Defra analysts using the Commission's scenario assumptions.

Figure 39 – Final MSW destination (eL_pC), England – Defra RouteMap



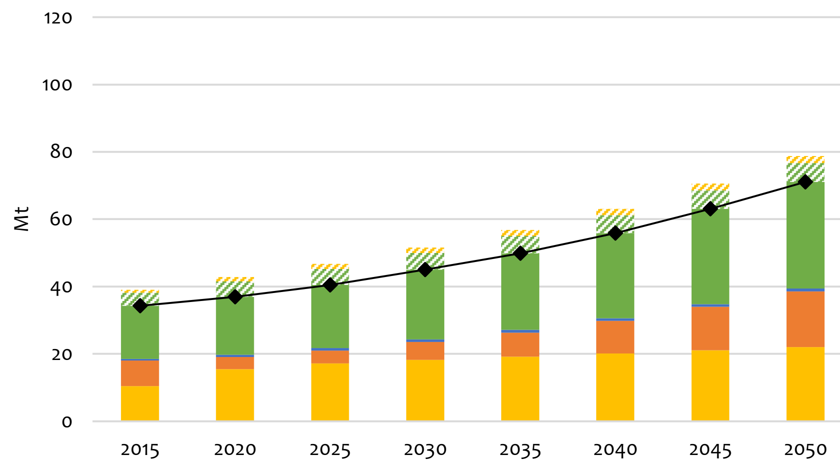
Source: Future scenarios produced by Defra analysts using the Commission's scenario assumptions.

4.4.4 Total waste treatment

Figures 40 and 41 show outputs from Defra's RouteMap for total treatment of municipal solid waste by treatment category. These results differ to those shown in Figures 38 and 39 as they include the amount of waste treated in **intermediate stages** – i.e. waste which goes to one type of facility before being sent to its final treatment/disposal destination. This is, however, still a useful metric to consider as it indicates the amount of waste which is actually going through the system – and the amount of treatment capacity required to treat that waste.

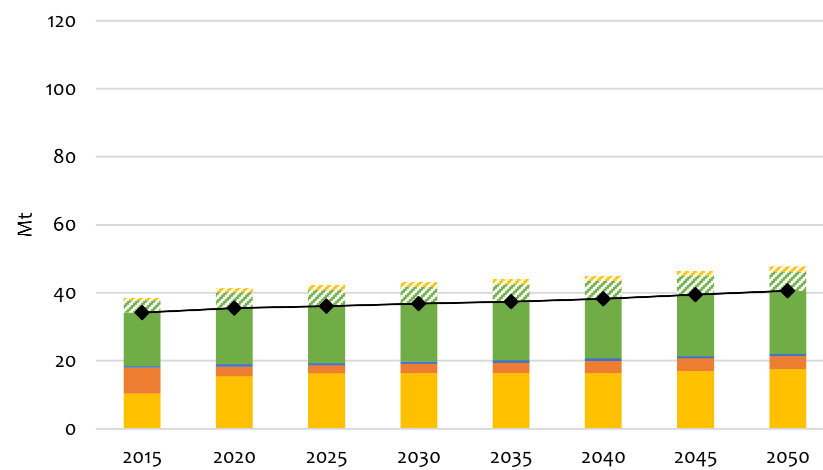
The figures below indicate that according to RouteMap almost 5 Mt of waste was treated through an intermediate process before reaching its final treatment destination in 2015. This figure increases to 8 Mt in 2050 in both scenarios with highest arisings (eC_pH) and lowest arisings (eL_pC).

Figure 40 – Total MSW treatment by type (eC_pH), England – Defra RouteMap



Source: future scenarios produced by Defra analysts using the Commission's scenario assumptions.

Figure 41 – Total MSW treatment by type (eL_pC), England – Defra RouteMap



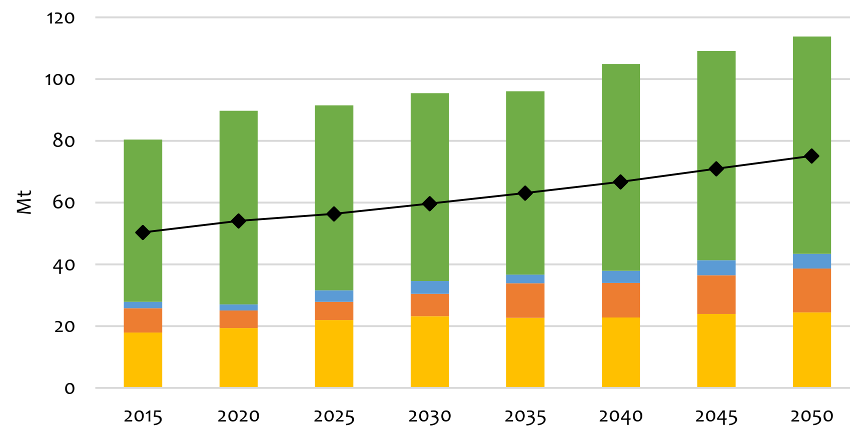
Source: future scenarios produced by Defra analysts using the Commission's scenario assumptions.

Figures 42 and 43 show total municipal solid waste treatment in ITRC's NISMOD. The model outputs do not distinguish between final and intermediate waste treatment, so outputs for waste arisings by final treatment destinations could not be produced.

There is more intermediate waste relative to the total amount of arisings in ITRC's NISMOD than in Defra's RouteMap. This is because NISMOD also models certain waste collection, disposal and sorting methods (e.g. kerbside sorting) which are not modelled by RouteMap and accounts for these alongside other treatment types. In addition, NISMOD's optimisation of waste treatment processes may lead some waste to take up additional treatment steps, which may not reflect reality, even if optimal in modelling terms. This means that intermediate waste treatment processes may be overestimated in the model.

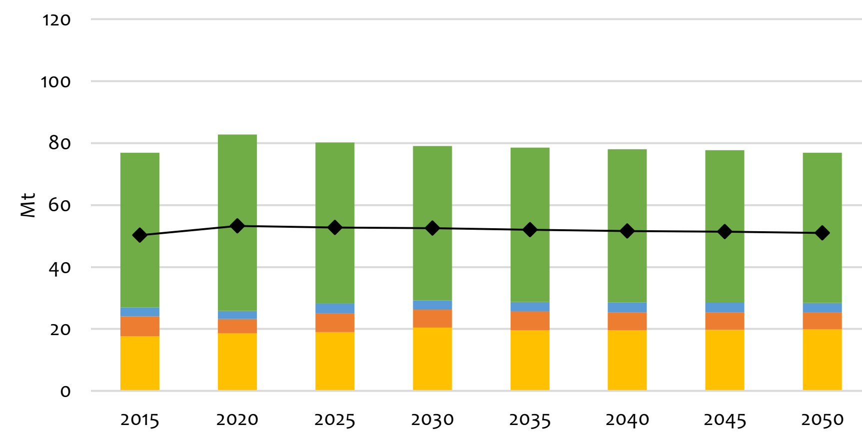
In addition to understanding requirements of waste treatment facilities in the future, the Commission is interested in assessing the availability of waste for generation of energy in the future – i.e. the energy from waste potential. This is determined by the amount of waste left over after recycling/composting, known as residual waste. Based on the findings in Figures 42 and 43, the estimates for residual MSW in 2050 would range from 25 Mt in the low economic growth and central population growth scenario to 38 Mt in the central economic growth and high population growth scenario.[13] In the waste decoupling scenario residual MSW would amount to 18 Mt in 2050. These figures may be overestimating residual MSW, and consequently the energy from waste potential, as some of the waste may be double counted (as the NISMOD treatment breakdowns include intermediate waste treatment).

Figure 42 – Total MSW treatment by type (eC_pH), England – ITRC NISMOD



Source: future scenarios produced by the Commission using NISMOD.

Figure 43 – Total MSW treatment by type (eL_pC), England – ITRC NISMOD



Source: future scenarios produced by the Commission using NISMOD.

[13] The sum of the landfill (which includes some anaerobic digestion) and incineration categories.

4.5 Energy

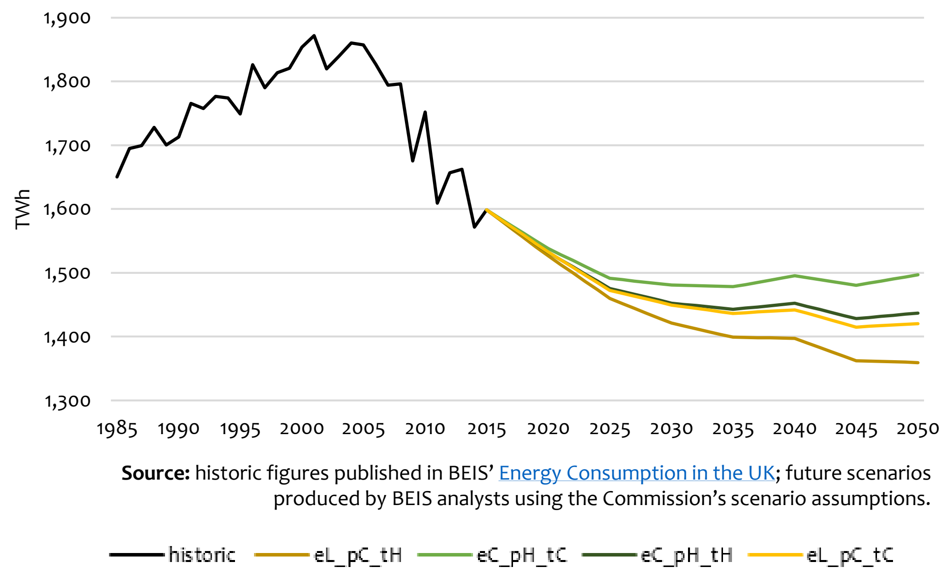
4.5.1 Energy demand

Demand for energy in UK TIMES is affected by **population growth, economic growth** and **technological development**.

Final energy consumption, shown in Figure 44, excludes energy losses from the transmission and distribution of electricity and the energy used to extract and transform to other energy forms. It also excludes energy consumption from international aviation and shipping. The results below indicate that the scenario with low socio-economic growth and high technological development leads to the lowest demand for energy, while the scenario with high socio-economic growth and low technology leads to the highest demand for energy.

However, even in the high demand scenario, energy demand is expected to fall by 4% compared to 2015 levels. This would continue the decline in final energy consumption in the UK observed since the early 2000s. Final energy consumption between 2000 and 2015 declined by around 14%, largely due to reductions in the industrial and domestic sectors. The fall in the industrial sector was driven by factors such as the shift from heavy industry towards a service-based economy as well as improvements in energy efficiency. Demand in the domestic sector peaked in 2005 but has been falling since, largely due to energy efficiency measures – i.e. the gradual replacement of older houses with newer, more energy efficient stock; retro-fitting of existing housing stock with insulation/double-glazing etc.; and general improvements in appliance efficiency.[14]

Figure 44 – Final energy consumption, UK – BEIS UK TIMES



Source: historic figures published in BEIS' Energy Consumption in the UK; future scenarios produced by BEIS analysts using the Commission's scenario assumptions.

[14] For a full discussion on the drivers of historic energy consumption see BEIS' Energy Consumption in the UK 2017.

4.5.2 Electricity demand

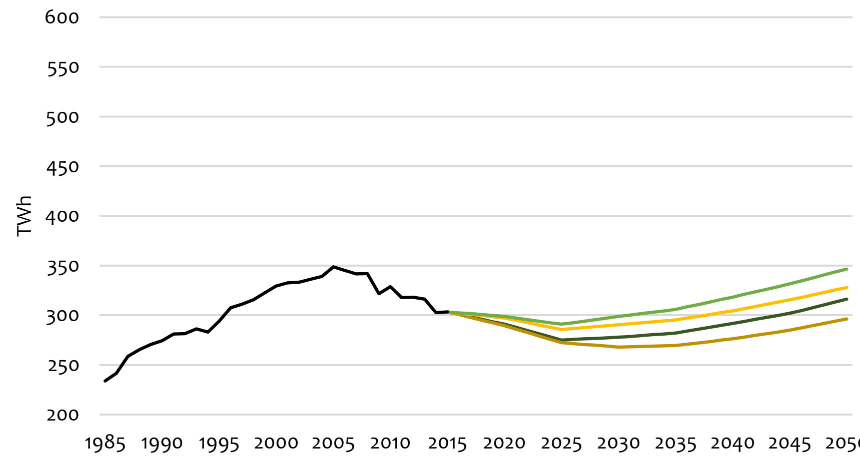
Electricity demand makes up a significant part of total energy demand – in 2015 electricity consumption was around 303 TWh, or 19% of energy consumption (1,598 TWh in 2015).

Figure 45 shows the range of outcomes for final electricity demand in UK TIMES – the change in electricity consumption between 2015 and 2050 ranges from a reduction of 7 TWh to an increase of 44 TWh.

Final electricity consumption is significantly higher in the ITRC model, as Figure 46 indicates. The increase in electricity consumption between 2015 and 2050 ranges from 125 to 246 TWh by 2050. The difference between the high and central technology scenarios in the ITRC model is negligible – this is because the reductions in electricity consumption brought about by energy efficiency in the high technology scenarios is offset by high consumption from electric vehicles. The cause for the large difference in electricity demand in both models is explored further in the rest of this section.

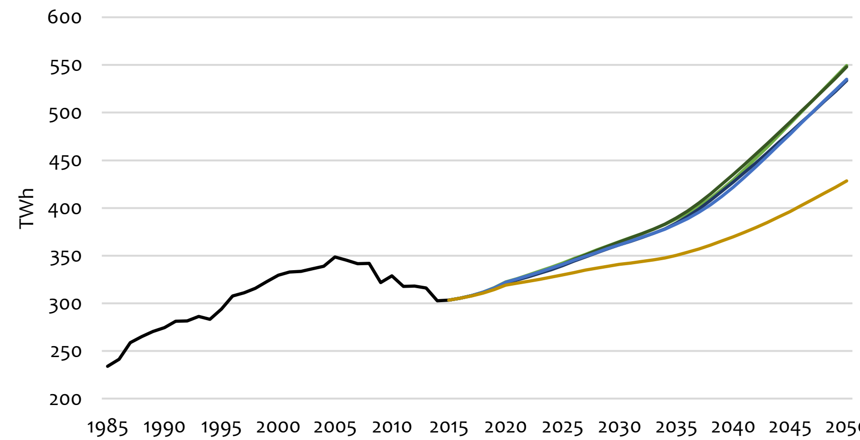
All scenarios assume that heat is not electrified – electrification of heat would significantly increase electricity demand.

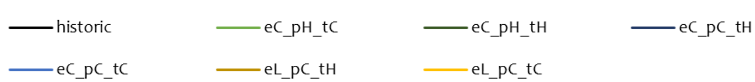
Figure 45 – Final electricity consumption, UK – BEIS UK TIMES



Source: historic figures published in BEIS' Energy Consumption in the UK; future scenarios produced by BEIS analysts using the Commission's scenario assumptions.

Figure 46 – Final electricity consumption, UK – ITRC NISMOD





Source: historic figures published in BEIS' Energy Consumption in the UK; future scenarios produced by the Commission using NISMOD.

Figures 47 and 48 show electricity consumption in the residential, transport and commercial/industrial sectors in UK TIMES and NISMOD in the scenario corresponding to the highest overall electricity consumption in both models (eC_pH_tC). Examining the electricity consumption in these three sectors, which account for the majority of electricity consumption, gives a better idea of where the differences in consumption between the two models lie.

Residential electricity demand

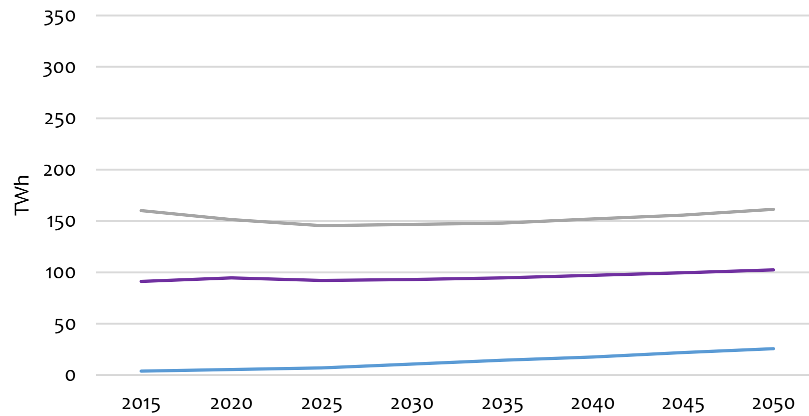
Domestic electricity demand in both models is closely aligned. The increase between 2015 and 2050 in this scenario is 11 TWh in UK TIMES and 13 TWh in NISMOD.

These results may include more electrical energy efficiency measures than would be taken up in the absence of demand side policies in the residential sector. This is because social research has found that there are substantial real world barriers to the take-up of privately cost-effective energy efficiency measures.

Electricity demand from transport

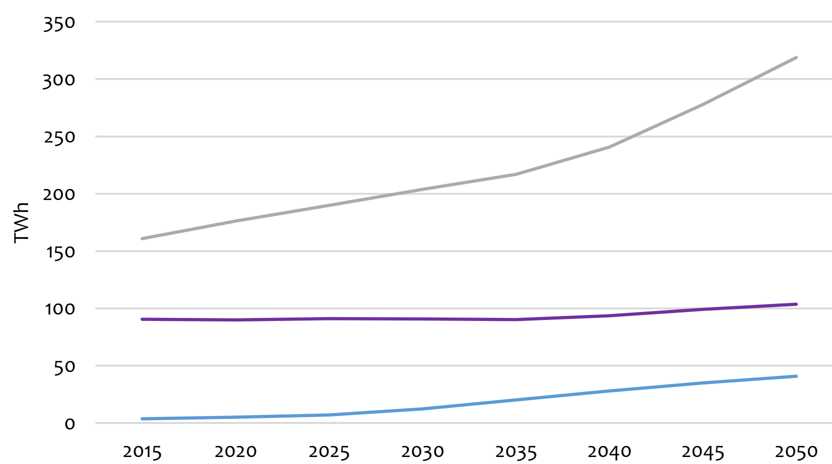
Electricity demand from transport increases significantly across both models due to the increase in electric vehicles. Average annual electricity demand from electric vehicles is projected to rise to 26 TWh by 2050 in UK TIMES. Electricity demand from the transport sector is projected to rise to 41 TWh in NISMOD. The NISMOD results include a small contribution from rail electrification, but most of transport electricity demand is driven by road transport.

Figure 47 – Electricity demand by sector (eC_pH_tC), UK – BEIS UK TIMES



Source: 2015 figures published in BEIS' Energy Consumption in the UK; future scenarios produced by BEIS analysts using the Commission's scenario assumptions.

Figure 48 – Electricity demand by sector (eC_pH_tC), UK – ITRC NISMOD



Source: 2015 figures published in BEIS' Energy Consumption in the UK; future scenarios produced by the Commission using NISMOD.

Residential
Industry and commercial/public
Transport

The UK TIMES model runs all project road travel to increase by 48% between 2015 and 2050, which is at the upper end of the outputs presented in the Commission's transport section.

The road travel inputs into the ITRC energy model depend on the socio-economic and technology variants chosen and growth in traffic is 51% between 2015 and 2050 in this scenario. Although traffic growth in this scenario is slightly higher in NISMOD, the model predicts higher electricity demand from transport than UK TIMES even in scenarios with lower traffic growth and equivalent EV take-up assumptions. This suggests that NISMOD assumes a higher electricity demand from EVs than UK TIMES.

Electricity demand in the industrial and services sectors

The choice of socio-economic variant had a much larger impact on electricity demand in these two sectors in NISMOD than in UK TIMES. The increase in electricity demand in NISMOD in the services and industry sectors almost doubled by 2050 compared to 2015 levels, increasing by 158 TWh. In UK TIMES, the change in electricity demand between 2015 and 2050 in the these sectors (what is characterised as industry plus commercial and public in the model) was a modest 1 TWh. Two likely reasons for this difference have been identified:

The sensitivity of NISMOD to socio-economic assumptions may be higher than in UK TIMES. Demand for electricity in these sectors is largely driven by increases in income (GVA) in both models.

As has been described in section 3.6.4, the approach taken to modelling energy efficiency in both models is different.

To get a sense of where the two sets of electricity demand outputs produced lie in relation to other forecasts, the Commission decided to compare these results to the National Grid's Future Energy Scenarios (FES) 2017. The two FES scenarios which most closely align with the Commission's no policy baseline are 'Steady State' and 'Consumer Power'. There are still significant differences in approach and assumptions between these scenarios and the Commission's – these differences, along with key similarities, are set out below and summarised in Table 10.

General

The FES scenarios have varying rates of economic growth but consistent population and household growth assumptions. The population growth and household growth assumptions match those in the Commission's central population growth variant.

The FES scenarios all assume a certain degree of policy intervention unlike the Commission's scenarios. Both Consumer Power and Steady State assume some heat electrification and a greater level of decentralised generation than currently.

Consumer Power

This scenario includes government policies that focus on indigenous energy supplies (support for North Sea gas and shale gas) which leads to low gas prices and some fuel switching from electricity to gas, which supresses electricity demand in the short run. Rapid rates of appliance replacement result in more innovation, some of which yield energy efficiency savings. This would lead to lower electricity demand relative to the Commission's scenarios.

Economic growth is assumed to be 1.8% pa, which is lower than the Commission's central and additional economic growth variants.

Steady State

This scenario assumes that innovation continues as it does today, in line with the rationale for the Commission's central technology variant. However, in the FES scenario this assumption leads to lower take-up of electric and plug-in hybrid vehicles, which only make up around 20% of the fleet by 2050. This figure for the Commission's central technology scenario is over 30%.

Economic growth is 1% pa, which is closest to, but lower than, the Commission's low economic growth variant.

Table 10 – Comparison of key assumptions

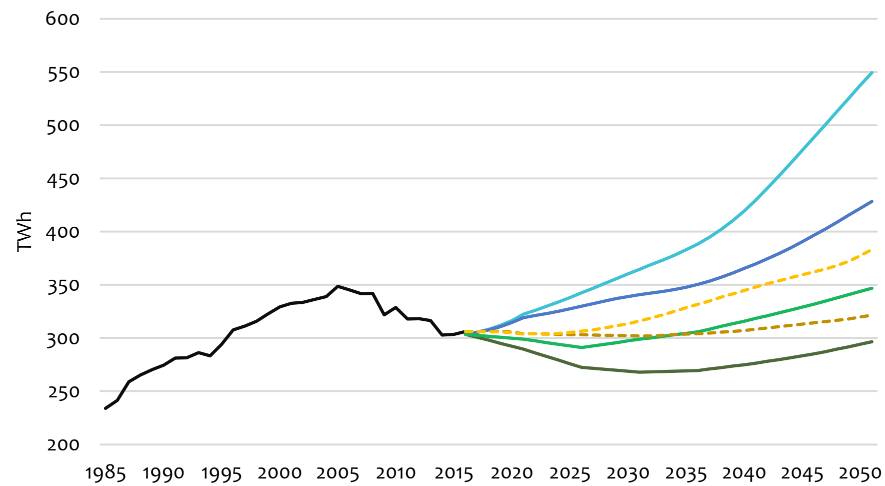
	scenario	economic growth	heat electrification	EV and PHEV take-up (% of fleet)
National Grid	Consumer Power	1.8% pa	1 million heat pumps by 2024	~70% by 2050
	Steady State	1.0% pa	1 million heat pumps by 2035	~20% by 2050
National Infrastructure Commission	eC_pH_tC	2.4% pa	-	~50% by 2050
	eL_pC_tH	1.2% pa	-	~35% by 2050

Source: constructed by the Commission using National Grid's Future Energy Scenarios 2017 data and the Commission's scenario data.

Figure 49 shows the Commission's highest and lowest electricity demand scenarios under UK TIMES and NISMOD, alongside the highest and lowest demand scenarios from National Grid's FES 2017.

Electricity demand in both of the NISMOD scenarios shown below is significantly higher than in the FES scenarios. Electricity demand in the low scenario under NISMOD (eL_pC_tH) is closest to demand in the highest National Grid scenario (Consumer Power) but still over 40 TWh higher in 2050. This is despite the fact that the National Grid scenario assumes a high degree of heat electrification and much higher economic growth.

Figure 49 – Final electricity consumption comparison, UK



Source: historic figures published in BEIS' Energy Consumption in the UK; future scenarios produced by the Commission using NISMOD or by BEIS analysts using the Commission's scenario assumptions; National Grid scenarios are published in Future Energy Scenarios 2017.

The lowest electricity demand scenario in UK TIMES (eL_pC_tH) is around 25 TWh lower in 2050 than National Grid's Steady State despite having higher economic growth and EV take-up assumptions. Part of this difference may be driven by heat electrification in National Grid's scenario.

The highest electricity demand scenario in UK TIMES (eC_pH_tC) is around 40 TWh lower than National Grid's Consumer Power scenario. The Consumer Power scenario assumes higher EV take-up and some electrification of heat, which would bring electricity demand up in relation to the Commission's scenario. However, the Commission's scenario assumes significantly higher economic growth.

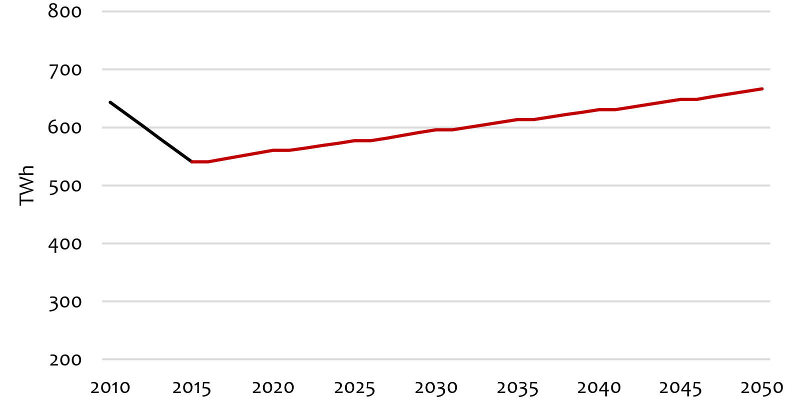
4.5.3 Heat demand

Heat demand makes up a large part of the overall energy demand in the domestic and services sectors. Figures 50 and 51 show the range of outcomes for heat demand in these sectors.

UK TIMES only produced one outcome for heat demand, as population growth is the biggest driver of heat demand and was not explicitly varied in the scenarios (it was only modelled through its impact on economic growth). Heat demand is expected to grow by 120 TWh between 2015 and 2050, as shown in Figure 50.

The NISMOD outputs shown in Figure 51 vary depending on the socio-economic variants chosen, as population growth (number of households) was explicitly taken into account. It also varies according to the technology variant in each scenario, as it is assumed that the technology variant leads to faster replacement of boilers with more efficient models.

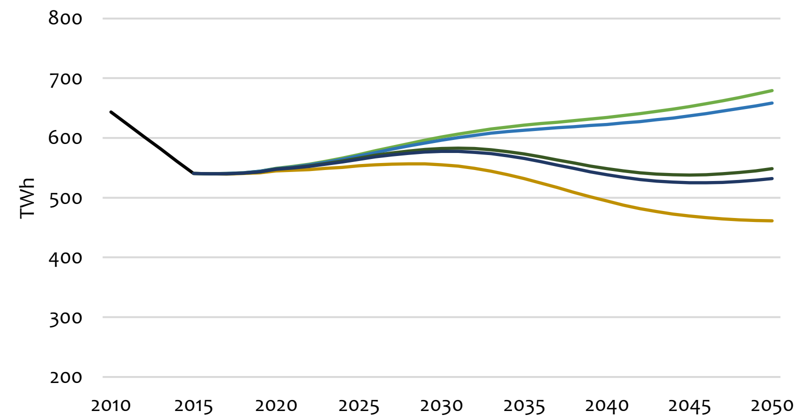
Figure 50 – Final domestic and commercial heat consumption, UK – BEIS UK TIMES



Source: historic figures published in BEIS' Energy Consumption in the UK future scenarios produced by BEIS analysts using the Commission's scenario assumptions.

historic BEIS UK Times

Figure 51 – Final domestic and commercial heat consumption, UK – ITRC NISMOD



Source: historic figures published in BEIS' Energy Consumption in the UK ; future scenarios produced by the Commission using NISMOD.

historic eL_pC_tH eC_pH_tC
eC_pC_tC eC_pH_tH eC_pC_tH

The change in heat demand between 2015 and 2050 ranges from a fall of 80 TWh to an increase of close to 150 TWh in NISMOD.

4.5.4 Greenhouse gas emissions

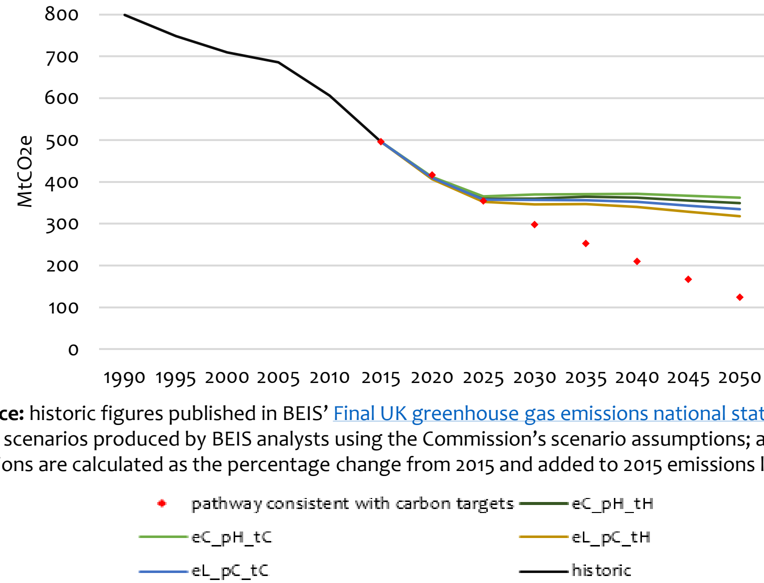
As can be seen in Figure 52 the UK is on track to make consistent progress in reducing its carbon emissions until 2020. Although it appears as though the UK will meet its fourth carbon budget (2025) under some of the scenarios, BEIS' most recent Energy and Emissions Projections suggest that the targets are not met without further action. Carbon targets would not be met from 2030 onwards in any of the baseline scenarios.

Carbon constraints have not been enforced, allowing the model to make energy generation and fuel choices based on least cost optimisation.

Figure 53 shows the proportion of total domestic emissions generated by the electricity, transport (excluding international aviation and shipping), waste and the remaining sectors, which are driving the highest emissions pathway shown in Figure 52 (corresponding to scenario eC_pH_tC).[15] Sectoral emissions breakdowns for other scenarios are not significantly different to those seen in scenario eC_pH_tC and are therefore not shown.

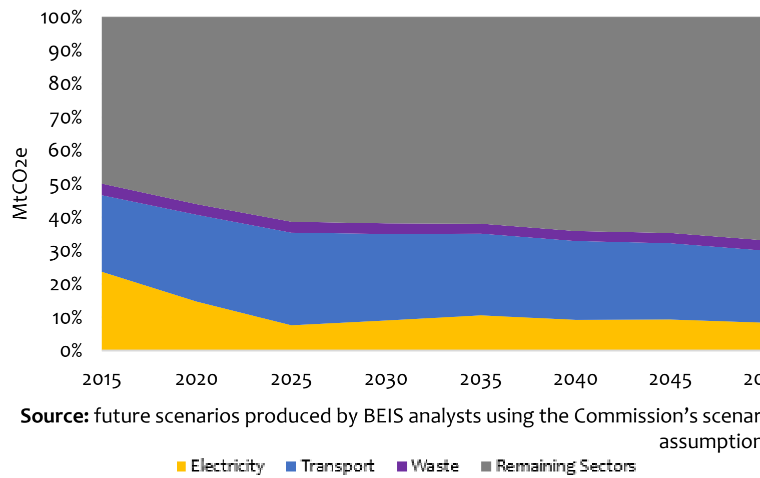
As Figure 53 indicates, electricity generation constitutes about 24% of total emissions in 2015 and falls to around 8% in 2050. In this scenario, by 2050, around 24% of electricity continues to be generated by fossil fuels, 47% by low carbon technologies (renewables and nuclear), 7% by combined heat and power (which is currently largely fossil fuel based, but may change in future) and 12% of electricity comes from interconnection.

Figure 52 – Annual total territorial emissions[16], UK – BEIS UK TIMES



Source: historic figures published in BEIS' Final UK greenhouse gas emissions national statistics; future scenarios produced by BEIS analysts using the Commission's scenario assumptions; annual emissions are calculated as the percentage change from 2015 and added to 2015 emissions levels.

Figure 53 – Annual total territorial emissions by sector, UK (eC_pH_tC) – BEIS UK TIMES



Source: future scenarios produced by BEIS analysts using the Commission's scenario assumptions.

[15] The remaining sectors consist of agriculture and LULUCF; industry; residential; commercial/public; refining and fuel manufacture and F-gas.
[16] Territorial emissions are those generated within national territory.

Appendix – Water metrics

NATIONAL INFRASTRUCTURE COMMISSION

	Environment Agency Metric	Description	Formula
Water supply	Deployable output	It is the total output from water sources or from bulk water supply for a water company. It is affected by factors such as: • The environment – hydrological flows, rainfall etc. • Licences – limiting water abstraction • Properties of pumping plants, wells and aquifers • Transfer and/or output main • Treatment • Water quality	
	Water available for use	Differs from deployable output as it deducts any losses in the water abstraction or treatment processes, and/or any allowance for regular water "outage" for asset maintenance. Outages are temporary losses in deployable output.	(deployable output) – (allowable outages and planning allowances)
Water demand	Distribution input	Used to assess water demand. It is the volume of water entering a water company's distribution system i.e. the system's demand for water. It will include water delivered to households and non-households as well as leakage.	(water delivered to non-households) + (water delivered to households) + (water taken unbilled) + (distribution system operational use) + (underground supply pipe leakage)
Water balance	Available headroom	The difference between water available for use (including imported water) and demand.	(water available for use) – (distribution input)
	Target headroom	Threshold of minimum acceptable headroom which would trigger the need for water management options. It is a risk-adjusted value which water companies use to account for uncertainty in all variable components of the supply/demand balance, including a climate change driven component.	
	Supply-demand balance	The difference between available headroom and target headroom.	(available headroom) – (target headroom)