# Methodology Report

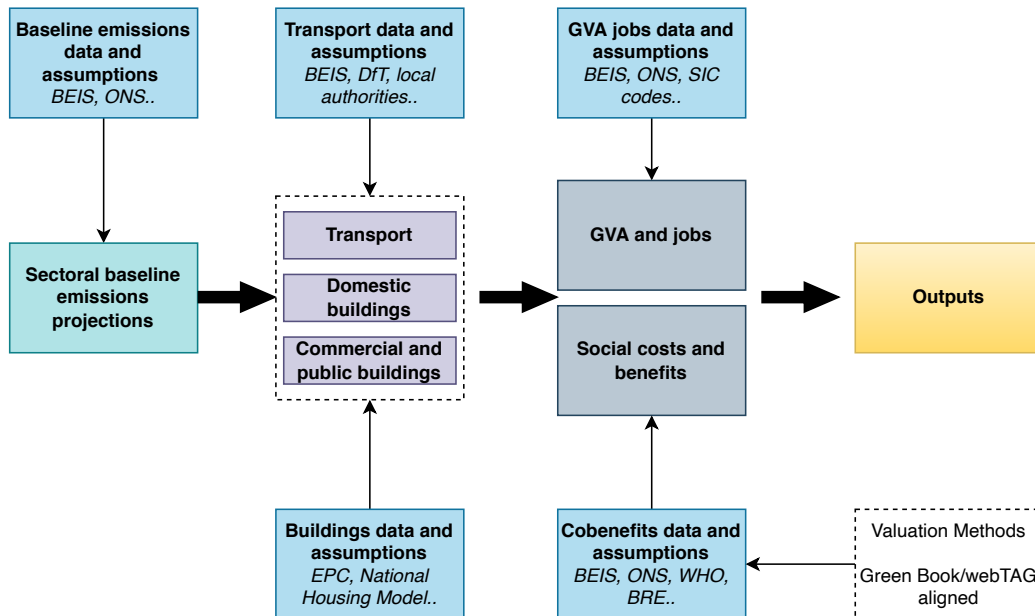*Table of Contents*

# Methodological Overview



*Figure 1: Overview of full methodological process*

An overview of our start-to-finish modelling process, beginning with our baseline analysis, sectoral emissions modelling, associated costs, direct benefits and co-benefits, and final outputs. We use a range of publicly available data from government sources, including BEIS and ONS, and EPC data for the buildings stock, following best-practice modelling guidance from the Green Book and TAG.

# 1   Baseline carbon emissions

We set a baseline based on BEIS Energy and Emissions Projections (2021) being fully delivered under the existing arrangements, as well as policies that were published ahead of the release of the Net Zero Strategy.

The business-as-usual (BAU) trajectory for city-scale production-based (PB) emissions, i.e. the carbon emitted either directly within the city-region's boundaries or indirectly via electricity use (Scope 1 and Scope 2 in GHG Protocol for Cities). Our focus is on all greenhouse gases measured as the mass of $CO_2e$.
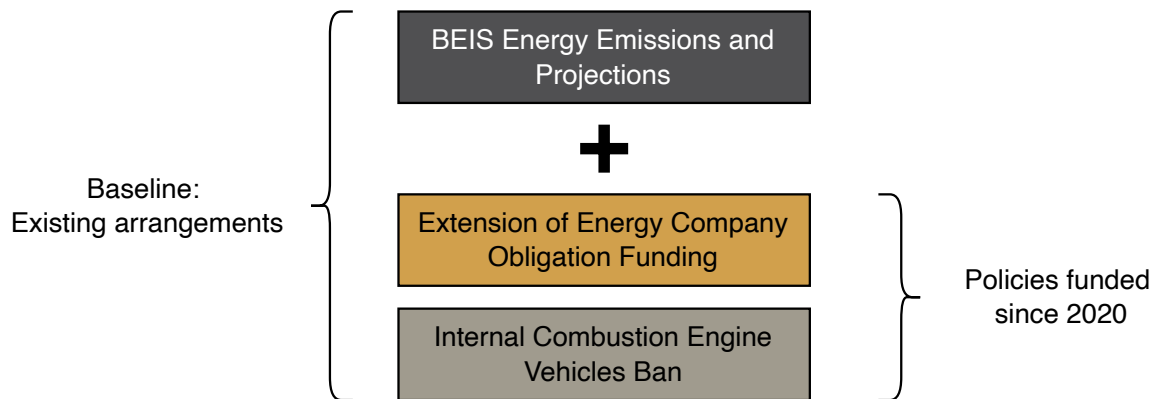
*Figure 2: Baseline modelling assumptions*

## 1.1  Emissions data sources

Our starting point is historical local authority carbon emissions data. To develop a BAU trajectory, we project emissions forward by utilising city-region level population forecasts and national-level emissions scenarios[1]:

- Local authority level carbon emissions data disaggregated between *domestic*, *industrial and commercial*, *public* and *transport* sectors and various sub sectors is available from The Department for Business Energy and Industrial Strategy (BEIS) - Time period covered 2005-2019
- Both UK- and LA-level population projections are regularly updated by the Office for National Statistics (ONS)
- UK-level projections of emissions and the carbon intensity of electricity supply are also available from BEIS covering both $CO_2$ and other GHGs and are disaggregated by nine sectors. Time period covered 1990 – 2040

## 1.2  Developing emissions projections

To develop a forecast of BAU, we first match the BEIS national-level emitting sectors to the city-region level sectors, aggregating into clusters where necessary (see Table 1). We then convert the local emissions to all GHGs by using the ratio of $CO_2e$ to $CO_2$ for each national-level sector. We then calculate the growth rate in *per-capita* emissions for each national-level sector. Using these growth rates, we use the latest city-region level, per-capita emissions for each sector and project them forward to 2050. We, therefore, assume that the per-capita growth rates in emissions at the city-region and national-levels are the same for each sector/cluster.

To this standard approach adjustments are made for policies from national and local governments. In the transport sector the ban on internal combustion engine vehicles (ICE) from 2035 is included with data from Cambridge Economics used to estimate the impact on ICE and electric vehicle proportions in advance on 2035. At the local level planned and funded policies and programs are included where data is available.

---

[1] All these data sources are freely available through the government's open data site (https://data.gov.uk)

*Table 1: National-level sectors from the BEIS emissions scenarios matched to the city-region level, local authority emissions sectors (aggregating where necessary, as indicated by the shading)[2]*

| | National-level | | City-region level | |
| --- | --- | --- | --- | --- |
| | Disaggregation | Time frame | Disaggregation | Time frame |
| Emitting sector | Agriculture<br>Industrial processes<br>Waste management<br>Business<br>Public | 1990-2040 | Ind' & Com' (other fuels) | 2005-2019 |
| | Energy supply | | Ind' & Com' (electricity)<br>Domestic (electricity) | |
| | Residential | | Domestic (other fuels) | |
| | Transport | | Transport | |
| | LULUCF | | LULUCF | |

We then explored city-region level mitigation scenarios for emissions across the domestic, commercial and transport sectors. For each sector, we:

- Identify a range of applicable Low Carbon Measures
- Assess their per-unit investment costs and energy savings
- Estimate their city-wide deployment potentials.

# 2    Financial costs & benefits and carbon reduction

## 2.1    Transport model
### 2.1.1 Overview of methodology

Many forms of transport exist, and each generates emissions in different ways and to varying degrees. The analysis focuses on intra-city transport most prevalent in towns and cities across the UK:

- Cars and taxis
- Heavy and light commercial vehicles
- Buses and coaches

The transport model has been designed to estimate the costs, benefits and abatement potential of measures that change current travel patterns. Estimating total emissions in the transport sector involves compiling

---

[2] Note that emissions from Land Use and Land Use Change and Forestry (LULUCF) are negligible, at less than 0.3% of total city-region level emissions

emissions intensities for each mode of transport (CO$_2$e/pkm) and city-region level mode share (pkms) (see Figure 3).

First, we build a baseline based on existing travel patterns. Next to build a scenario we induce changes to the transport system be it shifts in mode or improvements (i.e. electrification). The mitigation achieved by a scenario is the difference between the scenario and the baseline emissions trajectory. Then we isolate the change in the energy used (emissions intensities) and distance travelled (mode share) that is attributable to:

● Substitution (shift)
● Efficiency gains (improve).

Comparing the changes in distance travelled and energy used from the baseline, based on what influenced the change, we can attribute costs and benefits to each Low Carbon Measure such as shifting journeys from small petrol cars to walking or electrification of public buses.
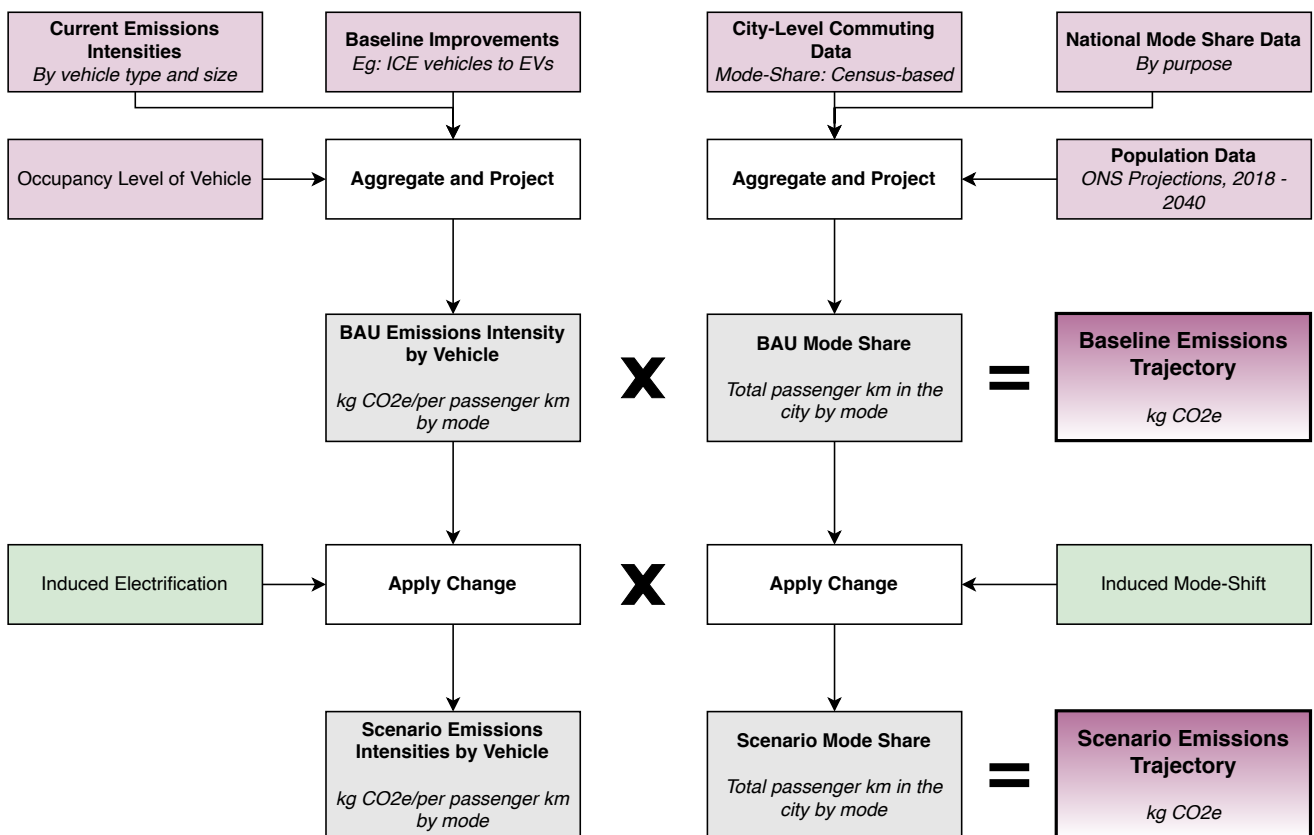


*Figure 3: Flowchart outlining the transport sector methodology*

The options for decarbonising these forms of transport are assessed using the Avoid, Shift, and Improve framework. The modelling focuses on Shift and Improve, with one Avoid measure added in one scenario.

In all scenarios, overall journey volumes do not change except to account for population growth. So if a passenger shifts from a petrol car, a new journey has to be created, in an EV, bus, bike or walking, and a journey in the petrol car is lost.

A key principle in the development of each scenario is that while the order of cost effectiveness drives the order of deployment this is within the bounds of 'Shift then Improve'. This means that the Low Carbon Measures categorised as Shift are deployed in order of cost effectiveness followed by Low Carbon Measures categorised as Improve.

In this study we exclude any changes to urban form due to the challenges of modelling changes in urban form without extensive local travel information. Metro trips are also not considered where metro is applicable, a limitation of our existing modelling capabilities.

*Table 2: Categories of Low Carbon Measures in transport sector*

| Category of Low Carbon Measure | Description |
| --- | --- |
| Avoid | Improving the efficiency of the transport system, including integrated land-use planning and transport to reduce trip length |
| More efficient logistics | Improving efficiency of the logistics system by better route planning or combining trips for multiple purposes |
| Shift | Moving from the most energy consuming urban transport modes towards more environmentally friendly modes |
| Car trips to walking | Walking generates no emissions so shifting reduces carbon emissions from trips otherwise taken by car |
| Car trips to cycling | Cycling generates no emissions so shifting reduces carbon emissions from trips otherwise taken by car |
| Car trips to buses | Buses generate emissions but lower energy consumption and higher occupancy mean emissions per passenger-km are lower than cars. |
| Improve | Enhancing the energy efficiency of transport modes, taking advantage alternative energy use |
| Electrification of private petrol and diesel vehicles | Petrol and diesel vehicles generate emissions on every journey and electrification provides an opportunity for the energy used to be generated via renewable sources |
| Electrification of distribution vehicles (HGV, OGV1 and OGV2) | Electrifying vehicles typically run on petrol or diesel provides an opportunity for the energy used to be generated via renewable sources |
| Electrification of buses and coaches | Electrifying buses and coaches previously run on petrol or diesel provides an opportunity for some the energy used to be generated via renewable sources |

## 2.1.2 Financial costs and benefits

The costs and benefits are attributed to each Low Carbon Measure by comparing the difference between the scenario and the baseline model runs to allow for system interactions. This difference in energy usage and/ or distance travelled which is used to attribute costs and benefits means that they are calculated as net. Table 3 lists the costs and benefits included in our analysis. All costs are discounted at a rate of 3.5%.

*Table 3: Financial costs and benefits in transport sector*

| Cost or benefit | Title | Description |
|---|---|---|
| Cost | Discounted Capital Cost - Charging Infrastructure | The cost of chargers is worked out based on the number of extra EV kilometres driven in each scenario |
| | Discounted Capital Cost - Vehicle Purchase | The net cost of: electric vehicles over ICE vehicles; extra buses required; and bike purchases |
| | Discounted Capital cost - Infrastructure | The cost of extra bike lanes and bus lanes required, based on a proportion of the extra bus riders and cyclists added |
| | Discounted non-fuel operating costs (buses) | The extra operating costs associated with running buses - chiefly drivers' salaries. This is a cost in most city-region/scenarios since more bus journeys are required. |
| Benefit | Discounted non-fuel operating costs (all vehicles) | Maintenance, oil, and tyres for all vehicles. This is a benefit in most city-region/scenarios since higher maintenance of buses is offset by much lower maintenance costs for cars, both because there are fewer cars and because EVs are cheaper to maintain. |
| | Discounted energy savings | The net cost of energy required to power the new journey patterns. This is a benefit in all city-region/scenarios since electricity is cheaper than petrol/diesel and walking/cycling is free |

## 2.1.3 Key inputs and assumptions

To estimate a city's residents' travel activity we use a combination of city- and region-level data. Trips per person by mode and region are derived from the National Travel Survey (2017-2019) and average miles by mode from the 2011 census. These are adjusted for the local region, where city-region level mode share data is available. Population data are derived from ONS projections. Data from the Department of Transport 'Transport Analysis Guidance' are used for vehicle occupancy and proportion of work and non-work trips. Following the process outlined in the flowchart in Figure 3 these inputs provide pkm by mode over the period 2021-2050.

The GHG emission intensity and cost of different travel modes are estimated using national datasets. The proportion of cars by fuel source and fuel and non-fuel operating costs by vehicle type are drawn from the Department of Transport 'Transport Analysis Guidance'. Energy prices are drawn from BEIS 2020 Updated Energy and Emissions Projections and vehicle emission factors are derived from the UK Government Emissions Factors for Company Reporting, excluding electricity grid emissions factor projections which are derived from BEIS 2018 Updated Energy & Emissions Projections.

A notable assumption is that we assume that it is possible to simply shift ~40% of car users onto buses or bikes under the current system. It does not exhaustively model secondary effects of this on the transport system, i.e.

- Rebound (other users taking up cars as the roads are now quiet)
- The only enabling infrastructure costed in the mode is EV charging infrastructure, and this may be under-counted since it is likely that range anxiety and home charging will lead to a higher ratio of chargers to cars than we see under the current petrol station model

The assumptions used to estimate a city's residents' travel activity are provided in Table 4.

*Table 4: Key assumptions in buildings model*

| Assumption | Description | Source |
|---|---|---|
| Trips per year per person | Average number of trips taken per person per year by mode for that region | Department for Transport Statistics - National Travel Survey - England: 2018/2019 (2 survey years combined) |
| Distance travelled by mode annually | Average distance in miles travelled by mode annually across that region | Department for Transport Statistics - Average miles travelled by mode, region and Rural-Urban Classification: England - All areas |
| Total Oil Equivalent (TOE) | Total oil equivalent by transport mode is used to develop a baseline for motorised transport energy use in each local authority. | 9Total final energy consumption at regional and local authority level: 2005 to 2018. BEIS. |
| Maximum distance km cycling per person per day | 2.7 km per person per day is assumed to be an upper limit for achievable mode shift based on levels achieved in Denmark. | https://www.regionh.dk/english/traffic/cycling/Documents/17751Cykelregnskab_UK.pdf |
| Maximum distance km walking per person per day | 2.5 km per person per day assumed to be an upper limit for achievable most shift based on literature review. | https://www.nhsinform.scot/healthy-living/keeping-active/activities/walking |
| Distance per year per vehicle | Kilometres per vehicle (and by vehicle type) per year is held constant across cities and across time. If a scenario shifts trips to motorised transport the number of new vehicles is determined using the number of additional kilometres by that vehicle type divided by the average annual kilometres by that vehicle type. | Transport Statistics for Great Britain. Department for Transport |
| Fast chargers per BEV | One fast charger for 80 battery electric vehicles and one for every 5 goods and/or transit vehicles. | Nicholas, M. and Hall, D., 2018. Lessons learned on early electric vehicle fast-charging deployments. International Council on Clean Transportation, Washington. |
| % trips by mode (2018 post only) | Total final energy consumption at regional and local authority level: 2005 to 2018 (BEIS) is used to determine travel by motorised vehicles. To estimate travel by non-motorised modes NTS0103 is used to estimate the number of per person trips by bicycle and on foot. These values are regional and available only for English regions, as a consequence assumptions are made for cities in Wales, Scotland and Northern Ireland. | NTS0103: Average number of trips by main modes - index: England |
| Average trip distance | Average trip distances are determined by the region of the local authority. | NTS0105: Average distance travelled by main modes - index: England |
| Changes to urban form | We have assumed that the urban form of a city-region stays static, meaning that average trip lengths by mode remains constant.<br><br>This means that any major infrastructure projects which could drastically change the way we travel are not accounted for. | |
| Occupancy | Car and vehicle occupancies through 2036. Values held constant from 2036 through 2050. | TAG Table A 1.3.3 |
| Occupancy - buses | Alteration from TAG source. Increased occupancy of buses from 14 to 17. This is based on research undertaken by University of Leeds | Source: University of Leeds research (unpublished) |

| | | |
|---|---|---|
| Proportion of car, LGV & other vehicle kilometres using petrol, diesel or electricity | The proportions drawn from this dataset are assumed to hold for all cities. | TAG Table A 1.3.9<br><br>Special consideration for Petrol/Diesel (set at 1%) |
| Vehicle energy use | Vehicle efficiencies are assumed to be the same across cities. | TAG Table A 1.3.11 |
| Vehicle efficiencies | Data from the TAG is used in conjunction with academic literature to provide values for different vehicle sizes. | TAG Data Table A 1.3.11<br><br>And<br><br>Chkaiban, R., Hajj, E.Y., Bailey, G., Sime, M., Xu, H. and Sebaaly, P.E., 2020. Fuel and non-fuel vehicle operating costs comparison of select vehicle types and fuel sources: A parametric study. In Pavement, Roadway, and Bridge Life Cycle Assessment 2020 (pp. 284-293). CRC Press. |
| Share of kilometres by vehicle size | This includes data to split heavy goods vehicles into types and passenger vehicles into large, medium and small | VEH0124: Licensed vehicles by make and model and year of first registration: United Kingdom |
| GHG emission factors | Scope 1 emissions factors are drawn from BEIS conversion factors. For Scope 2 emissions the reference scenarios for electricity production and generation sources are used to generate a baseline and annual conversion factors | Conversion factors 2021: full set (for advanced users). BEIS.<br><br>Annex J: Total electricity generation by source<br><br>Annex G: Major power producers' generation by source |
| Marginal capital cost per vehicle | The marginal cost of electric vehicle relative to ICE equivalent e.g. electric car to ICE car | TAG Table A1.3.14 |
| Cost per fast charger | Faster chargers are assumed to cost £75,000 based on literature and consultation. This cost is the same for all vehicle types. | Mathieu, L. "Roll-out of public EV charging infrastructure in the EU." Transport & Environment 7 (2018). |
| Cost per bicycle | £505 - Accounting for both the average cost of a bike alongside new entrant hard accessories | http://eprints.lse.ac.uk/38063/1/BritishCyclingEconomy.pdf |
| Non-Fuel Resource Vehicle Operating Costs (NFOC) | The elements making up non-fuel vehicle operating costs include oil, tyres, maintenance, depreciation and vehicle capital saving (only for vehicles in working time).<br><br>Following discussion with DfT, it was noted that NFOC contains a large depreciation component. DfT guidance can be found in the link below and the original document (1988) that NFOC is derived for is "Review of Operating Costs in COBA, EEA division of transport, 1990-91". This shows that NFOC parameter a is made up of 36% oil, tyres and maintenance and 64% depreciation, and that parameter b is 100% depreciation. Depreciation is a way of expressing capital costs on an annualised basis. Because our methodology is net, we only consider the additional capital costs of Low Carbon Measures - e.g. an EV is X more expensive than an | Table A 1.3.14: Non-Fuel Resource Vehicle Operating Costs<br><br>https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.375.1581&rep=rep1&type=pdf |

| | | |
|---|---|---|
| | ICE car. This surplus is included in our capex calculations as an upfront cost and constitutes the only relevant capex for vehicles. Therefore, there should be no depreciation contained in any of our calculations. Therefore, for our calculations we use parameter a * 0.36 and do not use parameter b. | |
| NFOC of electric vehicles | E-PSV, e-OGV1, and e-OGV are assumed to have half the operating costs of their ICE equivalent. Data from academic literature are used to provide values for different vehicle sizes. | TAG Table A 1.3.14 And Chkaiban, R., Hajj, E.Y., Bailey, G., Sime, M., Xu, H. and Sebaaly, P.E., 2020. Fuel and non-fuel vehicle operating costs comparison of select vehicle types and fuel sources: A parametric study. In Pavement, Roadway, and Bridge Life Cycle Assessment 2020 (pp. 284-293). CRC Press. |
| NFOC for cars - share of cars | It has been assumed that all private vehicles have a utilisation for work of 18.2% | Table NTS0409 from DfT (2019 table) |
| Additional NFOC for buses | Further NFOC to account for additional costs based upon the CPT index. It has been assumed that for every £1 spent on fuel, £4.88 is spent on DRIVERS' wages, other labour and staff costs and insurance claims. | https://www.cpt-uk.org/media/ca2iuq21/change-in-bus-coach-industry-costs-for-the-12-months-to-31-december-2019.pdf |
| Reference energy prices | Retail prices are assumed for all vehicles. | BEIS 2018 Updated Energy & Emissions Projections (Retail prices table) |
| Cost of buses lanes per km | Assumed cost of additional bus lane capacity at £250,000 per km. | Greener Journeys/KPMG (2017) |
| Capacity of a bus lane | A reasonable planning-level capacity for a dedicated transit lane is 80 buses per hour | https://nacto.org/publication/transit-street-design-guide/introduction/why/designing-move-people/#:~:text=A%20reasonable%20planning%2Dlevel%20capacity,through%20a%20single%20transit%20lane. |
| Cost of cycling interventions | Assumption of £0.98m per additional km of additional cycling infrastructure based upon a mixture of schemes such as cycle superhighway, mixed strategic cycle routes and resurfaced cycle routes. | https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/742451/typical-costings-for-ambitious-cycling-schemes.pdf |
| Additional capacity of cycling infrastructure | Assumed that major shifts to cycling will require additional dedicated infrastructure to (a) handle additional bikes on the road (b) generate the interest and shift necessary. Given the high capacity of cycling infrastructure, as well as the option for cyclists to use roads and alternative infrastructure there is a high degree of elasticity between the shift to cycling and additional infrastructure required. | Link |

## 2.2 Building models
### 2.2.1 Overview of methodology

The purpose of these models is to estimate the financial costs, benefits and abatement potential of applying a variety of Low Carbon Measures across 13 building archetypes in city-regions across the UK.

The building's models have been separated into domestic and commercial sectors. This is primarily because Low Carbon Measures although similar are applied in different ways i.e. on a per house basis in domestic buildings and on a floor space basis in public and commercial buildings.

The methodologies for estimating annual carbon savings in the domestic and commercial sectors are outlined in Figures 4 and 5. Annual carbon savings per-unit of each measure are multiplied by the number of units deployed in the mitigation scenario (houses or m$^2$ of floor-space).

Per-unit carbon savings are obtained from the energy savings data we describe below and the associated emissions intensities. We also account for the interactions that occur when multiple Low Carbon Measures are deployed within the same building, which can reduce the savings achieved in the case of, for example, solar photovoltaics and efficient lighting.
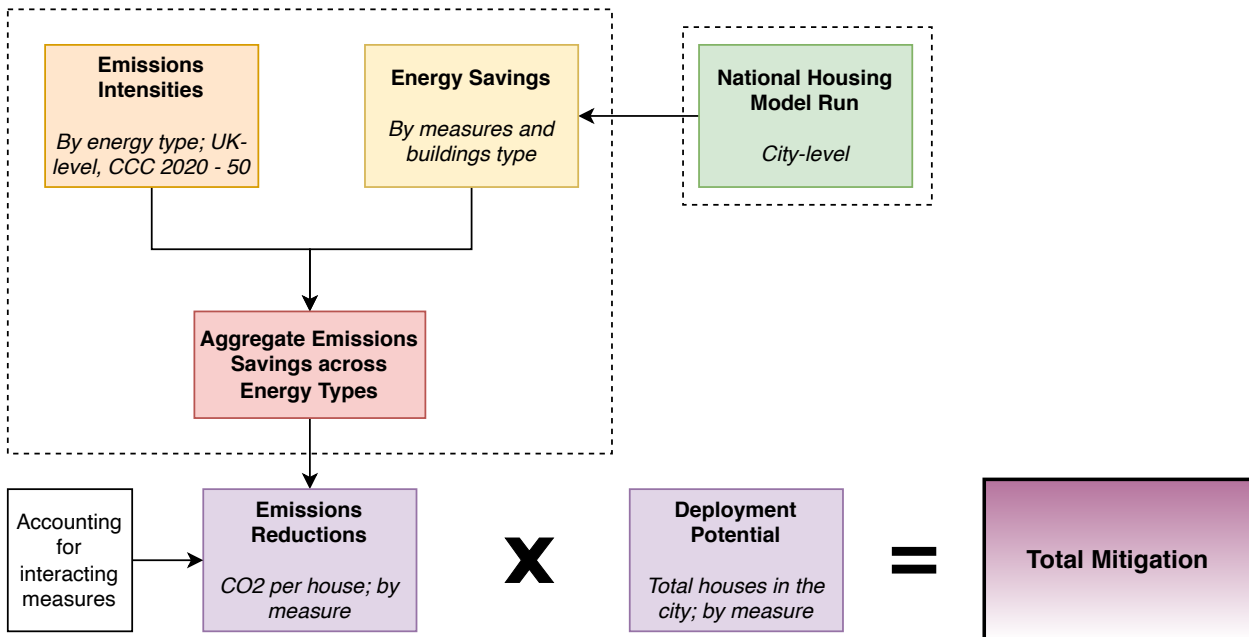


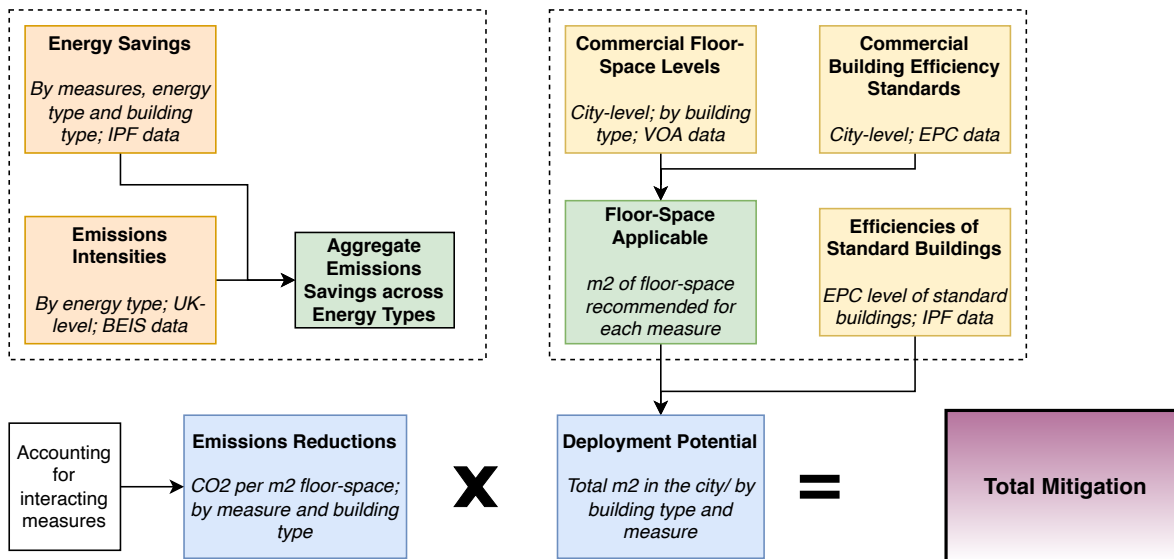Figure 4: Flowchart outlining the domestic sector methodology

*Figure 5: Flowchart outlining the commercial sector methodology*

## 2.2.2 Low Carbon Measures by category

The options for decarbonising domestic and public and commercial buildings are broadly similar. Table 5 and Table 6 detail the categories of Low Carbon Measures applied in the building sector.

## 2.2.1.1    Domestic buildings

In the domestic buildings sector, Low Carbon Measures are deployed on a per home basis across seven archetypes:

- Bungalows
- Converted built flats
- Houses (detached, semi-detached, end of terrace, mid-terrace)
- Purpose built flats (high rise and low rise).

*Table 5: Categories of Low Carbon Measures applied to domestic buildings*

| Category of Low Carbon Measure | Description |
|---|---|
| Energy efficiency | Upgrading gas ovens and appliances to energy efficient alternatives, gas hobs and ovens to induction alternatives, analogue to digital TVs, filament light bulbs to low energy lighting |
| Insulation | Increasing air tightness, replacing single with double glazing, external shading, improving insulation |
| Heating efficiency | Upgrading boilers to 95% efficiency, using heating controls, heat recovery, increasing efficiency of technology (e.g. DC drive fan coils, chilled beams) |
| Low carbon heat | Installing solar thermal or replacing gas boilers with air source heat pumps |
| Microgeneration | Solar PV |
| Whole-house retrofit | Deep retrofits where the costs and nature of the retrofit are informed by the typology and EPC rating of a dwelling, and the heating system is shifted to a heat pump. |
| New-builds | New housing stock is calculated according to projected population changes and occupancy rates. All new builds are estimated to conform to PassiveHaus energy-efficiency building standards |

## 2.2.1.2 Public and commercial buildings

In the commercial buildings sector, Low Carbon Measures are deployed on a floor area basis across seven archetypes:

- Offices
- Retail space
- Industrial/warehouse units
- Community centres›
- Education
- Healthcare spaces
- Hotels

*Table 6: Categories of Low Carbon Measures applied to public and commercial buildings*

| Category of Low Carbon Measure | Description |
|---|---|
| Energy efficiency | Increasing energy efficiency of light bulbs, daylight and movement sensors, increasing efficiency of technology (e.g. variable speed pumps, chillers) |
| Insulation | Installing insulation (cavity wall, external wall, floor, internal wall, loft), draught-proofing, top up loft, triple glazing |
| Heating efficiency | Upgrading storage tanks and conventional boilers to gas combi-boilers, tank insulation, thermostats, radiator valves |
| Low carbon heat | Replacing storage tanks and conventional boilers with heat pumps, use of solar thermal |
| Behaviour change | Lowering thermostats, reducing heating for washing machines, reducing household heating by 1C, reducing standby consumption, turning unnecessary lighting off |
| Microgeneration | Solar PV |

| Whole-building retrofits | Deep retrofits where the costs and nature of the retrofit are informed by the typology and EPC rating of a dwelling, and the heating system is shifted to a heat pump. |
|---|---|
| New-Builds | New housing stock is calculated according to projected population changes and occupancy rates. All new builds are estimated to conform to PassiveHaus energy-efficiency building standards |

## 2.2.2 Financial costs and benefits

The costs and benefits are calculated based on the deployment of each Low Carbon Measure which means that they are calculated as net. Table 7 lists the costs and benefits included in our analysis. Costs are discounted at a rate of 3.5%.

*Table 7: Calculated financial costs and benefits in buildings sector*

| Title | Description |
|---|---|
| Capital cost | The capital costs of low carbon measures are estimated in net present value terms over the period from 2022 to 2050 taking into account:<br><br>● When the new low carbon measure is assumed to be deployed<br>● The expected length of life of the low carbon measure before it requires replacement.<br><br>Note - The total net present investment cost is applied on deployment between 2022 and 2030. This means that the cost of replacement is not realistically spread across the study period. |
| Energy savings | The deployment of each measure between 2022 and 2050 is multiplied by the estimated energy saving (for electricity, gas and other) associated with each Low Carbon Measure, multiplied by the discounted energy cost forecast from BEIS<br><br>As per BEIS Green Book guidance, we use long run variable costs, because energy prices include:<br><br>● Fixed costs that will not change in the long run with a small sustained change in energy use,<br>● Carbon costs, since these are valued separately, and<br>● Taxes, margins, and other components which reflect transfers between groups in society |

Unlike in the transport model (where it is assumed that the price of EVs is likely to reach parity with ICE cars by 2025), the cost of all buildings measures in this study stays the same in real terms. This is because most buildings measures, such as insulation and boilers, are very mature technologies and unlikely to be subject to significant innovation. There are exceptions:

● Heat pumps are a key technology in the net zero transition and the Government's Net Zero Strategy
● Retrofit labour costs may rise over and above headline inflation due to significant demand.
● Solar prices are already low but will continue to fall - this was ignored in the analysis because even when deployed to their full potential, domestic and commercial solar combined make up only 3% of all buildings Low Carbon Measures.

## 2.2.3 Key inputs and assumptions
### 2.2.3.1    Domestic

For the domestic sector the list of Low Carbon Measures, their lifetimes, and their costs and energy savings (electricity, gas, and other fuels) are consistent with the UK's National Housing Model (NHM), which was

developed by the *Centre for Sustainable Energy (CSE)*[3]. It is worth noting that these costs have been tested and updated each time the models have been used at local authorities, most recently in 2020.

The EPC data sets represent the full housing stock by local authority including information on current insulation levels, heating systems, etc. on a per property basis. Using EPC datasets in conjunction with these NHM outputs, we assess what Low Carbon Measures are appropriate for a particular city's domestic sector, how many houses each measure would be suitable for, we call this the deployment potential. Using a s-curve deployment profile, each measure is deployed to its potential within the constraints set by the scenario. Therefore we can calculate what energy and emissions savings would be expected assuming the household maintains the same heating regime post-installation of each measure. The buildings stock grows with population growth.

## 2.2.3.2    Public and commercial

The Public & Commercial buildings sector operates in largely the same manner as the domestic sector, where the basic unit of analysis is changed from individual homes to $m^2$ area of applicable non-domestic floorspace. For the commercial sector we obtain lists of Low Carbon Measures and their lifetimes, costs, and energy savings (electricity and gas) from the review of the Investment Property Forum (IPF), which are appropriate throughout the UK. Measures are grouped into different building types with (marginal) costs and (multi-vectoral) energy savings detailed on a measure-by-measure basis. To calculate city-region level deployment potentials we utilise LA-level data describing:

● Existing commercial floor-space by building type from the Valuation Office Agency (VOA)
● EPC assessments reported for commercial building stock across LA.

We use these datasets together to estimate the floor-space in a city-region across each archetype. We assume that the area of commercial floor-space remains static across each of these archetypes. This appears reasonable as for the periods within which data are available there are only negligible changes in the distributions of EPCs of commercial buildings and existing commercial floor-space. We use the proportion of floorspace surveyed in EPC assessments that recommends a particular intervention and apply this to the total floorspace in a city.

*Table 8: Key Assumptions in buildings models*

| Assumption | Description | Source |
|---|---|---|
| Heat pump costs | Conducted brief review of the Centre for Sustainable Energy (CSE) measures and inflated all to 2020 prices<br><br>All looked reasonable except for heat pumps - these are potentially central to the transition and likely to be in high demand and - subsequently - high supply<br><br>We found accurate up to date costs from the UK Government (see link) and used these to update the cost of heat pumps | https://www.gov.uk/government/publications/cost-of-installing-heating-measures-in-domestic-properties |
| Heat pump cost reduction | Heat pump cost reduction has been applied in all scenarios in line with the NZS: The Net Zero Strategy stated that there is ambition to reduce the cost of heat pumps by at least 25-50% by 2025 and that price parity with gas boilers is | https://www.gov.uk/government/publications/net-zero-strategy |

---

[3] CSE (2014) National Household Model: A computer model of the whole GB housing. stock

| | | |
|---|---|---|
| | reached by 2030. Therefore, the price of an average heat pumps used in the analysis falls each year to 2030 when it reaches the same real price as an average gas boiler | |
| Deployment potential figures | The deployment potential for each Low Carbon Measure for each property type is calculated for each city-region based on EPC data, data is gathered on whether the Low Carbon Measure could be deployed within a household and then aggregated up to the relevant Low Carbon Measure group | https://epc.opendatacommunities.org / |
| S-curve deployment of buildings measures | In all scenarios, it is assumed that deployment of building measures starts slowly in 2022 and builds to a peak in the late 2020s before tapering off. An S-curve is applied here rather than a linear growth rate | |
| Interactions methodology | We assume that measures that impact the heating of a home will interact. Given a household will use a certain amount of energy for heating, each Low Carbon Measure will reduce the savings available for other measures. The following equations are applied to account for this:<br><br>Corrected energy/carbon savings = original savings - original savings * (average house % savings w/o interactions - average house savings w/ interactions)<br><br>Average house % savings w/o interactions = average number of interacting Low Carbon Measures per house * average % savings per measure<br><br>Average house savings w/ interactions = average savings per measure ^ number of Low Carbon Measures<br><br>Although cooling measures would also interact, there isn't enough and so the impact is negligible. | |
| Rebound effect | For some domestic LCMs, an increase in energy efficiency leads to increased use of energy to provide more comfort. We have assumed a rate of 15% rebound for certain measures and valued this using BEIS guidance - see 'Home Comfort' on pg 25 | Committee for Climate Change (2013) - discussion of how the energy savings potential of Low Carbon Measures is rarely reached because of in-use, comfort and inaccessibility factors. This analysis only considers comfort factors, but the context may be useful for further analysis<br><br>UK Energy Research Council (2007) - extensive evidence of the size of the rebound effect in different settings, concluding that "The direct rebound effects were estimated to reduce overall energy savings by 15%" |