Methodology Report

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Methodological Overview

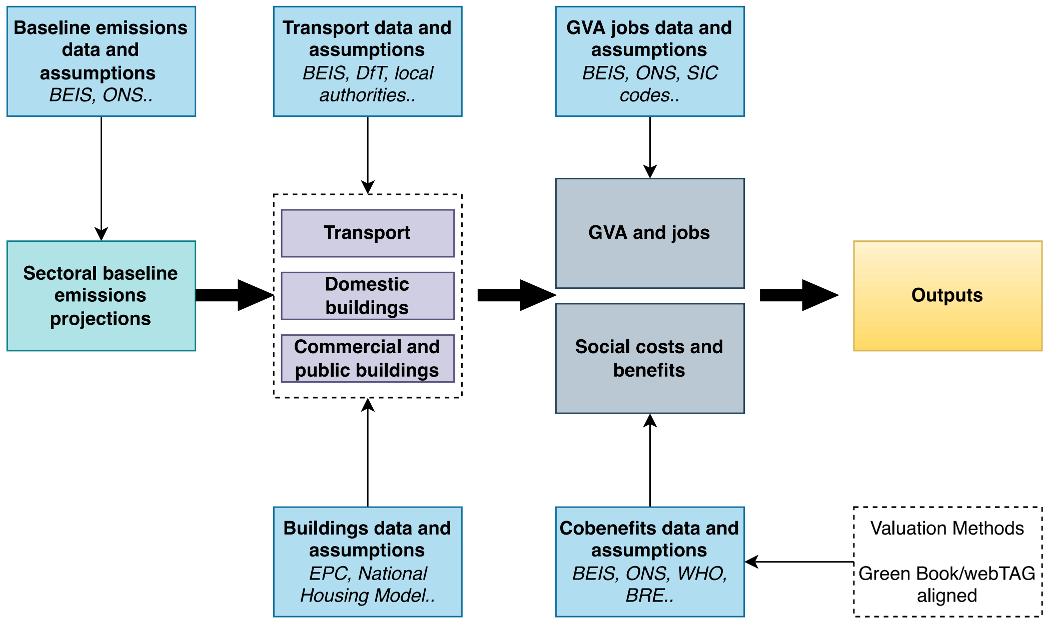

Figure 1: Overview of full methodological process

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

A baseline is set using BEIS Energy and Emissions Projections (2021) adjust to take into account policies that were published in the Net Zero Strategy and specific local actions where data is available.

The business-as-usual (BAU) trajectory for city-scale production-based (PB) emissions includes the carbon emitted directly within the city-region’s boundaries and indirectly via electricity use (Scope 1 and Scope 2 in GHG Protocol for Cities). Our focus is on all greenhouse gases measured in CO_2e.

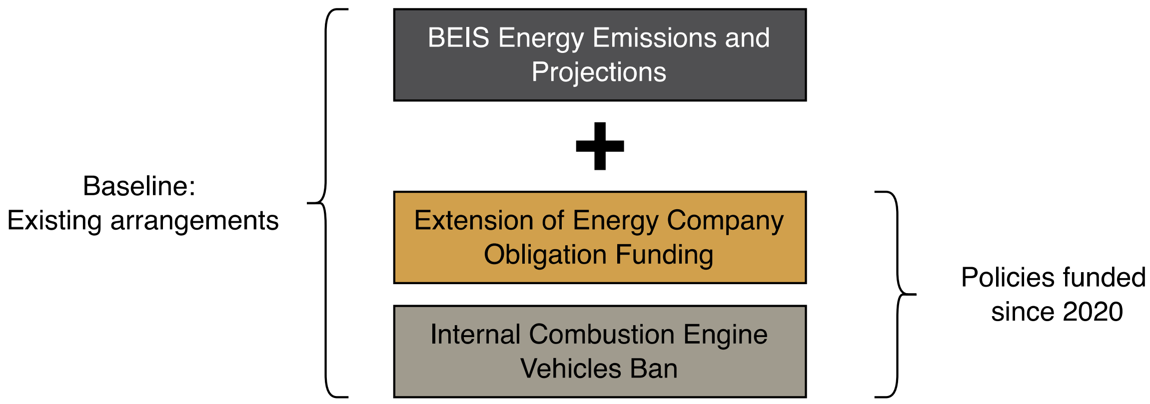

Figure 2: Baseline modelling assumptions

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.

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[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 Industrial processes Waste management Business Public	1990-2040	Ind' & Com' (other fuels)	2005-2019
	Energy supply		Ind' & Com' (electricity) 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 the transport most common in towns and cities across the UK:

- Cars and taxis
- Heavy and light commercial vehicles
- Buses and coaches
- Trains
- Walking and cycling

[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

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 emissions intensities for each mode of transport (CO_2e/pkm) and city-region level mode share (pkms) (see Figure 3).

First, we build a baseline built on existing travel patterns in person-km by mode on an annual basis. Next, to build a scenario we induce changes to the transport system by shifting the mode of trips (ie car to bicycle) or improving the technology employed by a trip (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.

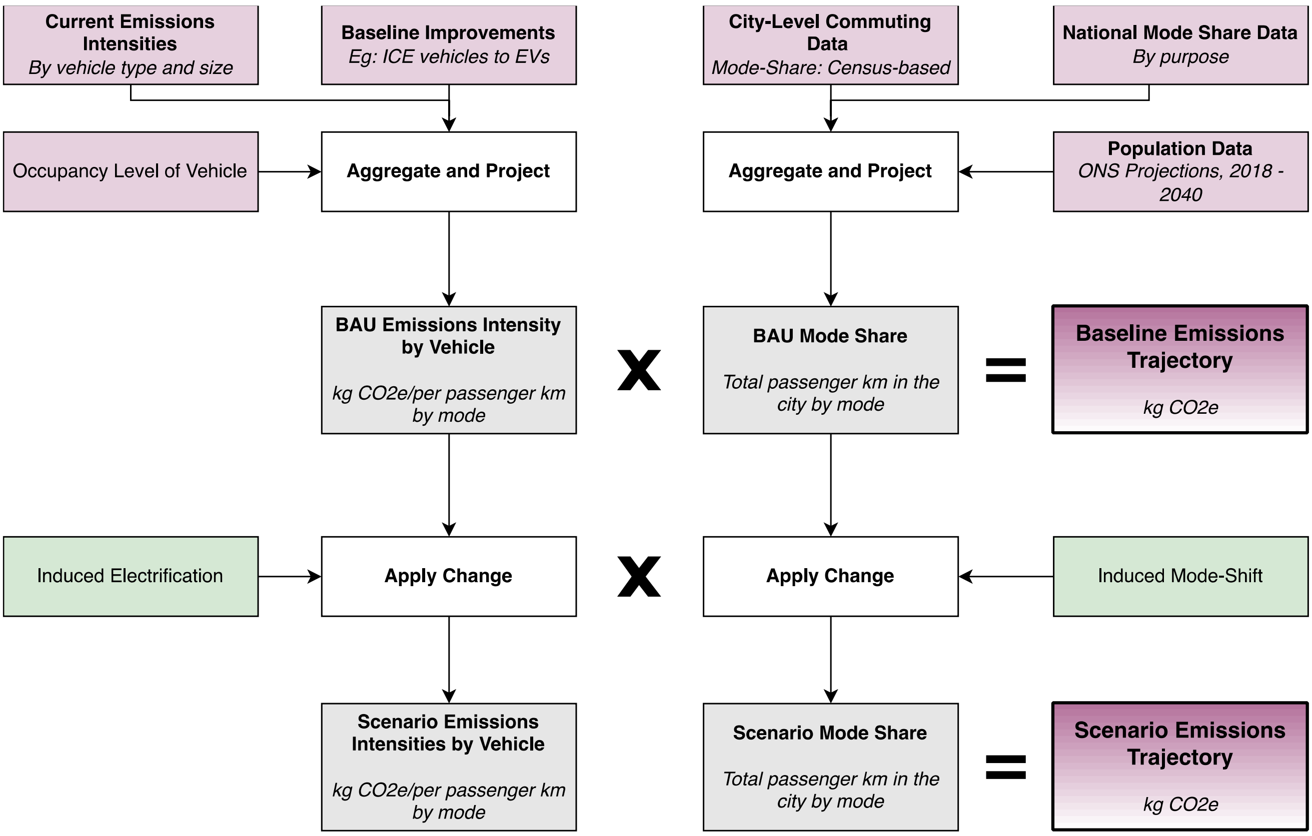

Figure 3: Flowchart outlining the transport sector methodology

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 numbers 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.

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 train	Trains generate emissions but lower energy consumption and higher occupancy mean emissions per passenger-km are lower than cars.
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. We do 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. 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 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 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.
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. Annex J: Total electricity generation by source 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). 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.	Table A 1.3.14: Non-Fuel Resource Vehicle Operating Costs https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.375.1581&rep=rep1&type=pdf

	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 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.

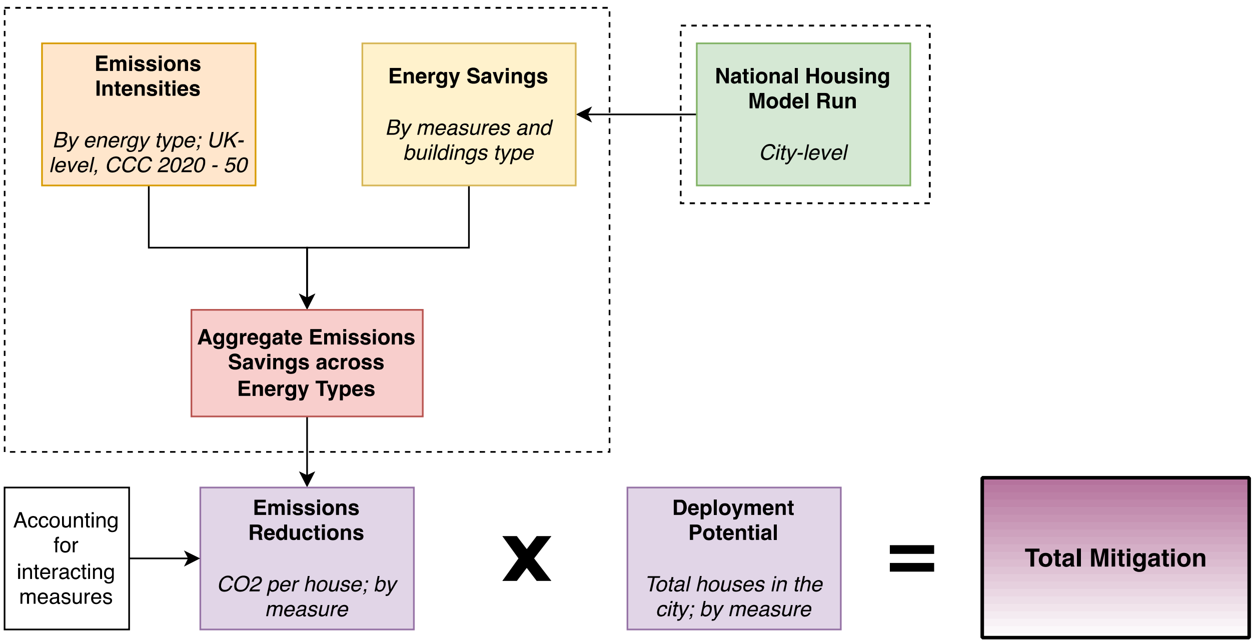

Figure 4: Flowchart outlining the domestic sector methodology

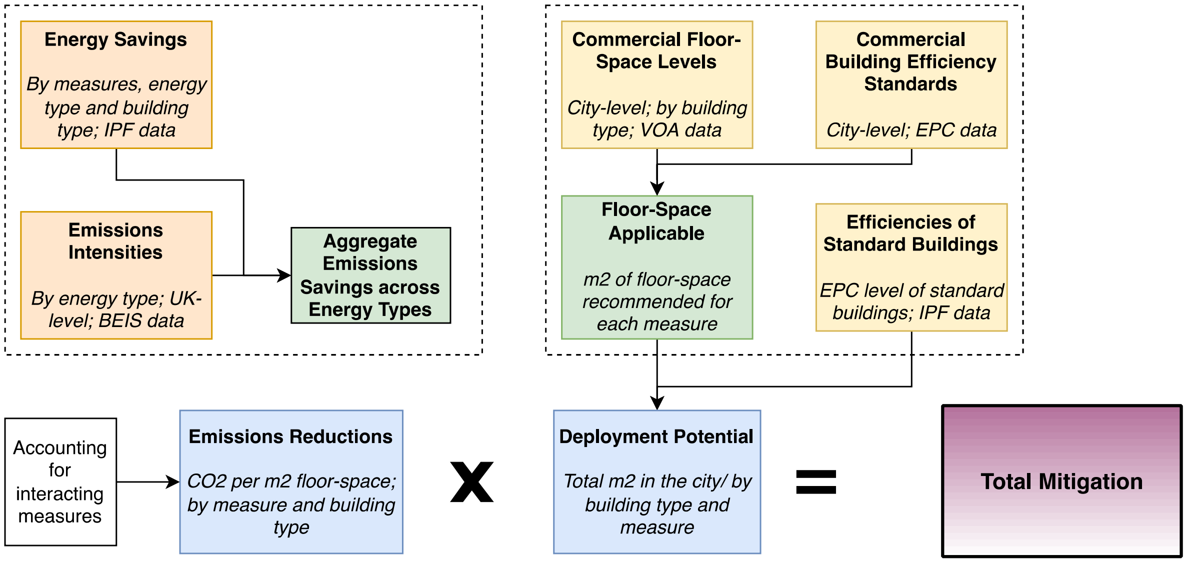

Figure 5: Flowchart outlining the commercial sector methodology

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 modelled 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 modelled 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: ● When the new low carbon measure is assumed to be deployed ● The expected length of life of the low carbon measure before it requires replacement. 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 As per BEIS Green Book guidance, we use long run variable costs, because energy prices include: ● Fixed costs that will not change in the long run with a small sustained change in energy use, ● Carbon costs, since these are valued separately, and ● 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 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 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: Corrected energy/carbon savings = original savings - original savings * (average house % savings w/o interactions - average house savings w/ interactions) Average house % savings w/o interactions = average number of interacting Low Carbon Measures per house * average % savings per measure Average house savings w/ interactions = average savings per measure ^ number of Low Carbon Measures 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 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%"

2.3 Land-Use Model

2.3.1 Overview of methodology

The aim of this model is to estimate land-use area breakdowns, current emissions, mitigation potential and associated costs/benefits in the UK at a local authority level. Many forms of land-use exist in the UK, with inherently variable emissions intensities. This model has been designed to estimate, as close as possible given existing data limitations, the different land-use types outside of the UK's urban areas. It is in keeping with UK reporting standards on land use categories and classification systems.

2.3.2 Baseline Area Estimates

Countryside Survey data form the basis of our analysis for land-use area breakdowns. This data covers the entirety of the UK and is representative at the national and habitat classification level, based on in-situ, high-resolution analysis. It provides data on land-use type, habitat type, habitat classification and flora/fauna species breakdown. Through spatial analysis, we can estimate these area breakdowns at an LA-level based on the specific habitat classification breakdowns of the local authority in question. This data does have limitations, but serves as the basis for the majority of this type of analysis in the UK, including emissions reporting by BEIS and DEFRA.

The area breakdowns are aggregated up to the habitat types of wetlands, forestry, urban, animal agriculture, cropland, grassland and other (including rock, sediment, standing water, etc). These area breakdowns are at a per-hectare level. Emissions originating from the 'other' category are not included due to negligible impact, hydrological intricacies, and lack of available data. Given the data limitations, bespoke validation from a range of sources is used, and if necessary, corrections are applied according to the confidence of these sources. This includes data provided by the local authority, GIS mapping, government datasets, and comparisons with reported emissions.

2.3.3 Baseline Emissions Estimates

Using these area breakdowns, alongside reported emissions from BEIS, we obtain per-hectare level emissions factors specific to the individual local authority. This data serves as our baseline, which is projected forward to 2050 using regional estimates from BEIS and DEFRA, under the central assumption scenario.

2.3.4 Scenarios

From this point, we build carbon-mitigation scenarios, starting with the most carbon-intensive subsectors. The deployment potential is informed by both the national estimates from the CCC and the specific area breakdowns of the local authority. We follow the Shift and Improve framework to estimate total abatement potential. The technical potential equals the projected baseline emissions minus the carbon abatement potential, which is aggregated across subsectors for final mitigation estimates across all land-use types in kt CO2e.

These scenarios currently differ from the buildings, industrial and transport sectors due to the economics of land-use carbon abatement. Land-use shifts and improvements are rarely cost-effective, as the benefits associated with direct carbon sequestration in most cases do not exceed the cost of actions. The scenarios imitate the CCC guidance of low, medium and high ambition scenarios. To improve the economic case of carbon mitigation in this sector, we have included economic benefits associated with the sale of carbon credits. These benefits include costs associated with accreditation and validation, increasing the feasibility of carbon mitigation measures in the land-use sector. The main areas of focus for this analysis are bog restoration and afforestation.

There is considerable scope to alter the types of shifts/improvements according to the wishes of the specific local authorities and their actors. We welcome input regarding assumptions and can accommodate specific policies regarding land-use. As the shifts/improvements are relatively malleable, specific sub-sectors such as wetlands or animal agriculture can be prioritised as needed.

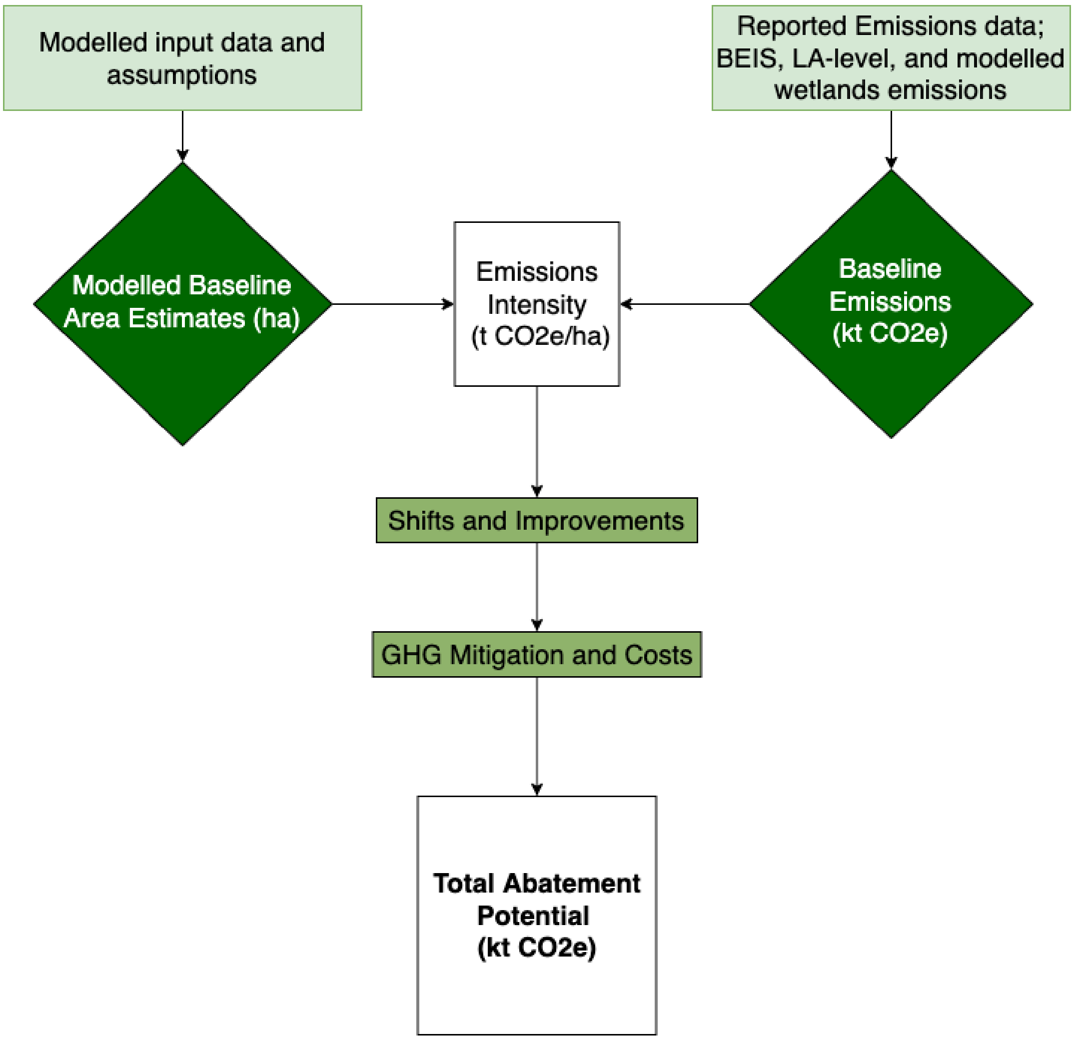

Figure 6: Key inputs into the Land-Use Model

2.3.5 Overview of peatland methodology

Emissions emanating from the Wetlands sub-sector have been modelled separately to estimate wetland areas, improve granularity and obtain higher-resolution data on land-use types.

2.3.6 Wetlands Area and Conditions Estimates

Spatial analysis and data from Evans et al. and Cruickshank et al. provide the base data for mapping peatlands across the UK. This data is extracted at the local authority level and validated against existing data sources. Regional-level estimates on peat conditions, and the type of land-use which exists in these areas are then applied to this data.

2.3.7 Emissions Baseline

This data, along with emissions intensities specific to the land-use type on these wetlands, provide our baseline data. These emissions include those associated with both industrial and domestic peat extraction (the cutting and removal of peat/turf for horticultural and industrial use). We project this baseline forward in tangent with BEIS forecasts at a regional level. However, it is important to keep in mind that wetlands are inherently variable. Depending on location, the type of wetland, and specific conditions, wetlands can be extremely sensitive to climatic changes – ie increases or decreases in precipitation levels and temperatures. Furthermore, complex feedback loops are predicted in the coming decades, where local climatic conditions can vary widely. Therefore, projecting these emissions into the future are solely indicative of current trends and are likely to be subject to considerable change.

2.3.8 Improvements

We use national estimates from the CCC for peat degradation to inform our maximum deployment potential, alongside our modelled data. We then apply specific improvements according to the land-use type. For example, if a specific peatland area is afforested, improvements for this land-use type include deforestation, scrub removal, seeding and monitoring. The associated economic costs and benefits, alongside abatement potential, are modelled on a per-hectare basis. This data is aggregated across conditions and land-use types to estimate maximum abatement potential.

2.3.9 Scenarios

From this abatement potential, we build three scenarios in line with CCC guidance of low, medium and high ambitions. These scenarios, again, are malleable and specific to each local authority. We follow policy guidance at a local or regional level where possible. In certain cases, for example Northern Ireland, there is no ratified legislation on wetlands policy. Under these circumstances we follow national policies.

Currently the scenarios are as follows, in line with guidance received by the NI Assembly and the CCC:

- **Low Ambition Scenario** – Immediate ban from 2023 on all peatland extraction, both industrial and domestic.
- **Medium Ambition Scenario** – Immediate ban on all peat extraction from 2023, rewetting 60% of lowland wetlands and 100% of upland wetlands by 2045.
- **High Ambition Scenario –** Immediate ban on all peat extraction from 2023 and shifting 100% of wetlands to near-natural condition.

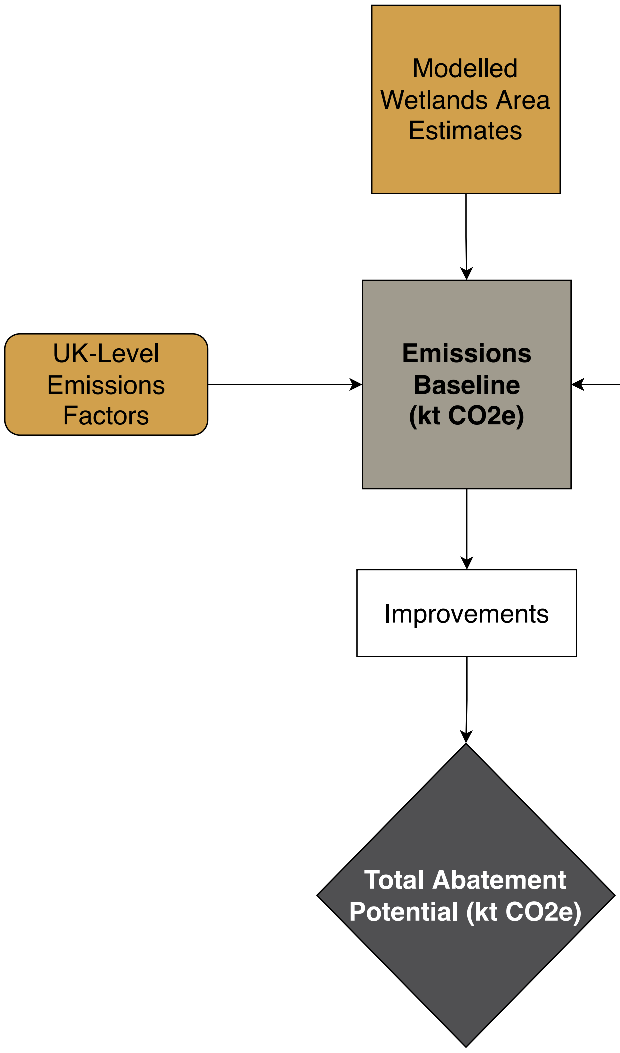

Figure 7: Key inputs into the peatland model

Table 9: Key Assumptions in the land-use models

Description	Source
Local Authority GHG Emissions	https://data.gov.uk/dataset/723c243d-2f1a-4d27-8b61-cdb93e5b10ff/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics-2005-to-2019
Habitat type and classification breakdowns	https://countrysidesurvey.org.uk/
Land-use abatement potential UK	Eory, V., MacLeod, M., Topp, C.F.E., Rees, R.M., Webb, J., McVittie, A., Wall, E., Borthwick, F., Watson, C., Waterhouse, A., Wiltshire, J., Bell, H., Moran, D., Dewhurst, R.
Implementation of an Emissions Inventory for UK Peatlands	Chris Evans, Rebekka Artz, Janet Moxley, Mary-Ann Smyth, Emily Taylor, Nicole Archer, Annette Burden, Jennifer Williamson, David Donnelly, Amanda Thomson, Gwen Buys, Heath Malcolm, David Wilson, Florence Renou-Wilson
Low-carbon measures for the land-use sector in the UK	Newell Price, J.P., Harris, D., Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D., Gooday, R.D., Lord, E.I. and Chambers, B.J. (ADAS), and Chadwick, D.R. and Misselbrook, T.H. (Rothamsted Research, North Wyke)
Economic Impacts of Land-Use Scenarios	https://www.theccc.org.uk/wp-content/uploads/2020/01/Economic-impacts-of-Net-Zero-land-use-scenarios-Vivid-Economics.pdf
Non-CO_2 abatement in the UK agricultural sector by 2050	Eory, V., Maire, J., MacLeod, M., Sykes, A., Barnes, A., Rees, R.M., Topp, C.F.E., Wall, E.
Quantifying the potential impact of Nature Based Solutions on GHG emissions from UK habitats	Thom and Doar, 2021
A Peatland Database for Northern Ireland: Methodology and Potential Resource	M. M. Cruickshank, R. W. Tomlinson, C. Dunwoody, D. Bond and P. M. Devine
UK Natural Capital for Peatlands	Hazel Trenbirth and Adam Dutton ONS, UK
NI Peatland Policy Recommendations	NI Assembly, Josh Pike, 2021