Innovate UK

In association with:

PwC

Otley Energy

University of Leeds

Accelerating Net Zero Delivery: Unlocking the benefits of climate action in UK city-regions

Technical Annex: Economics Methodology

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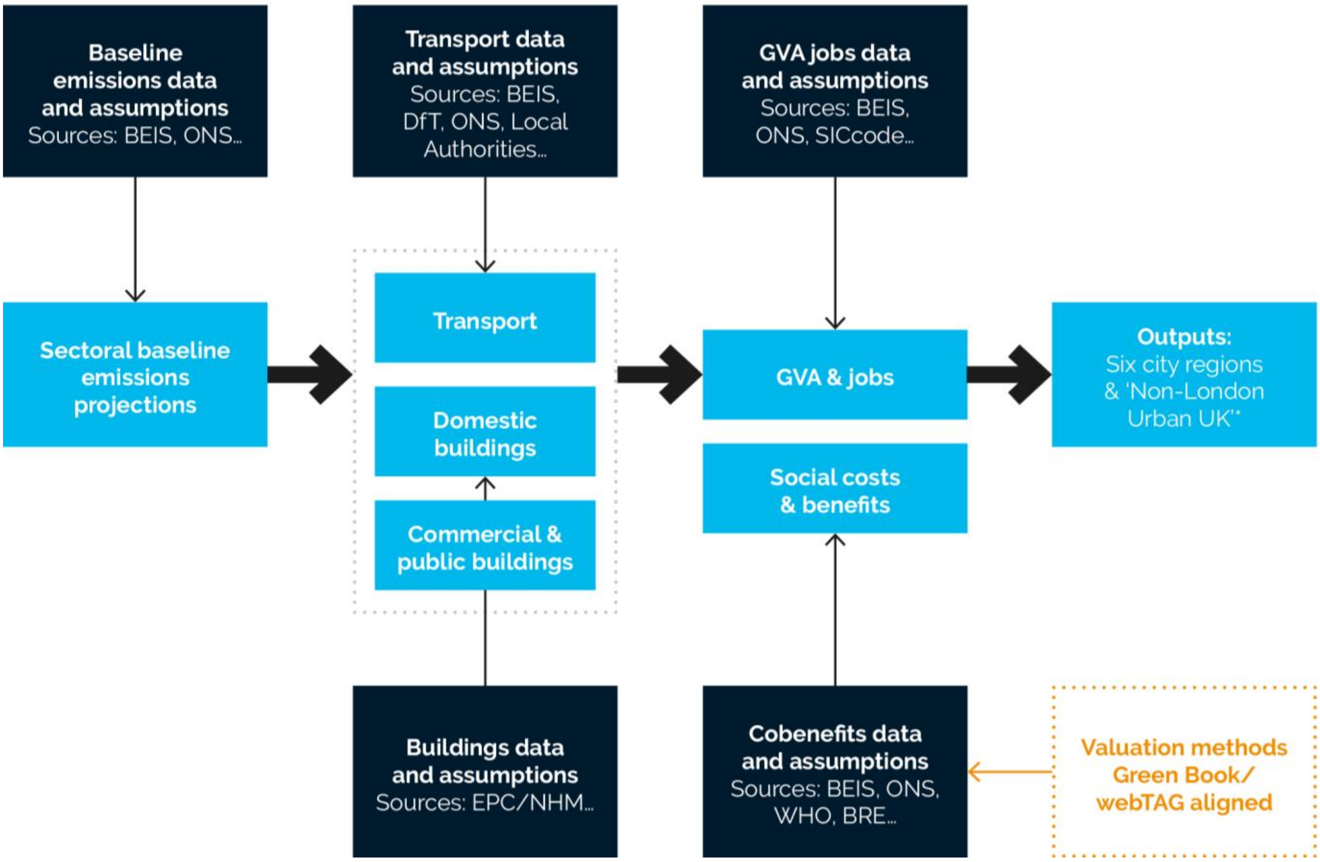
Contents

1 Purpose of this document

The purpose of this annex is to provide further details of the methodology which underpins the economic analysis and modelling undertaken to support the report: "Accelerating Net Zero Delivery: Unlocking the benefits of climate action in UK city-regions" and its accompanying Supplementary evidence.

The annex is structured into five main sections aligned to our modelling process as per Figure 1.

Figure 1: Full modelling process



The five sections are as follows:

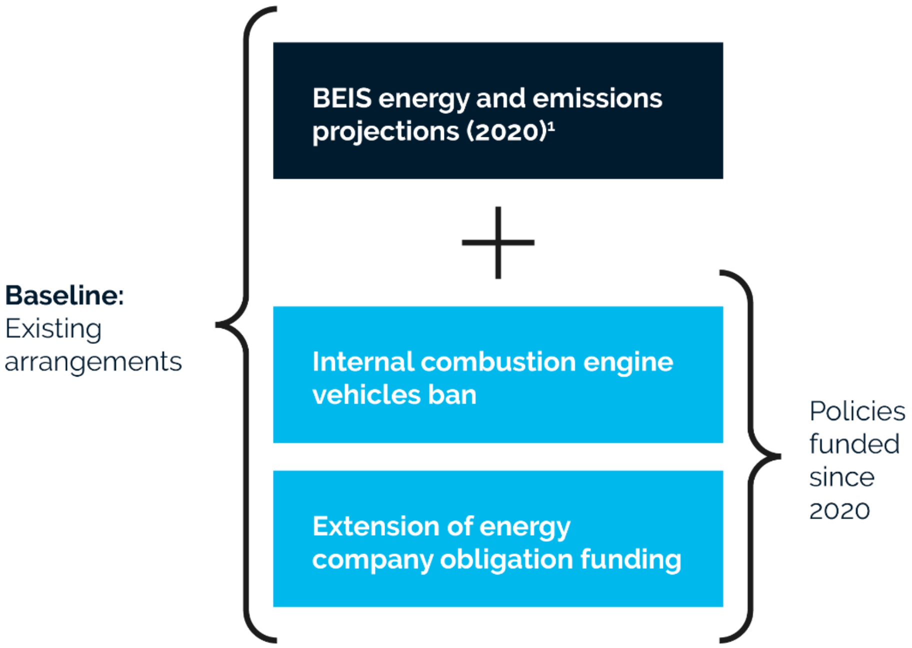
- We explain how we developed our baseline projections of carbon emissions in Section 2: Baseline carbon emissions
- We then explain how we have modelled the expected financial costs and benefits and potential reduction in carbon emissions for each of buildings & heat and surface transport covering the scope, inputs and assumptions underlying each of the models as well as their key outputs through Section 3: Financial costs and benefits and carbon reduction
- We explain how we have estimated each of the wider social costs and benefits associated with decarbonisation in Section 3.3 Social Costs and Benefits:
  - GHG emissions
  - Physical activity (from active travel) and bike journey quality (cycle lanes)
  - Warmer homes (and less excess cold deaths)
  - Quieter streets (lower noise pollution)

  - Faster journeys (lower congestion)
  - Safer streets (fewer motor vehicle accidents)
  - Cleaner air
  - Less wear and tear on roads
- Next, we explain the methodology we have used to assess the GVA and jobs associated with decarbonisation in Section 4: GVA and Jobs
- Finally, we explain the methodology we have used to build a picture of Urban UK in Section 5: Setting up non London Urban UK

2 Baseline carbon emissions

We set a baseline based on BEIS Energy and Emissions Projections (2020) being fully delivered under the existing arrangements, as well as policies that were published ahead of the release of the Government's Net Zero Strategy.

Figure 2: Baseline modelling assumptions



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.

2.1 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, and transport sectors and various sub sectors is available from The Department for Business, Energy and Industrial Strategy (BEIS) - Time period covered 2005-2018
- 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 CO2 and other GHGs and are disaggregated by nine sectors. Time period covered 1990 - 2040

2.2 Develop 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

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

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.

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)	2005-2018
	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 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
* passenger-kilometre

3 Financial costs & benefits and carbon reduction

3.1 Transport model

3.1.1 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

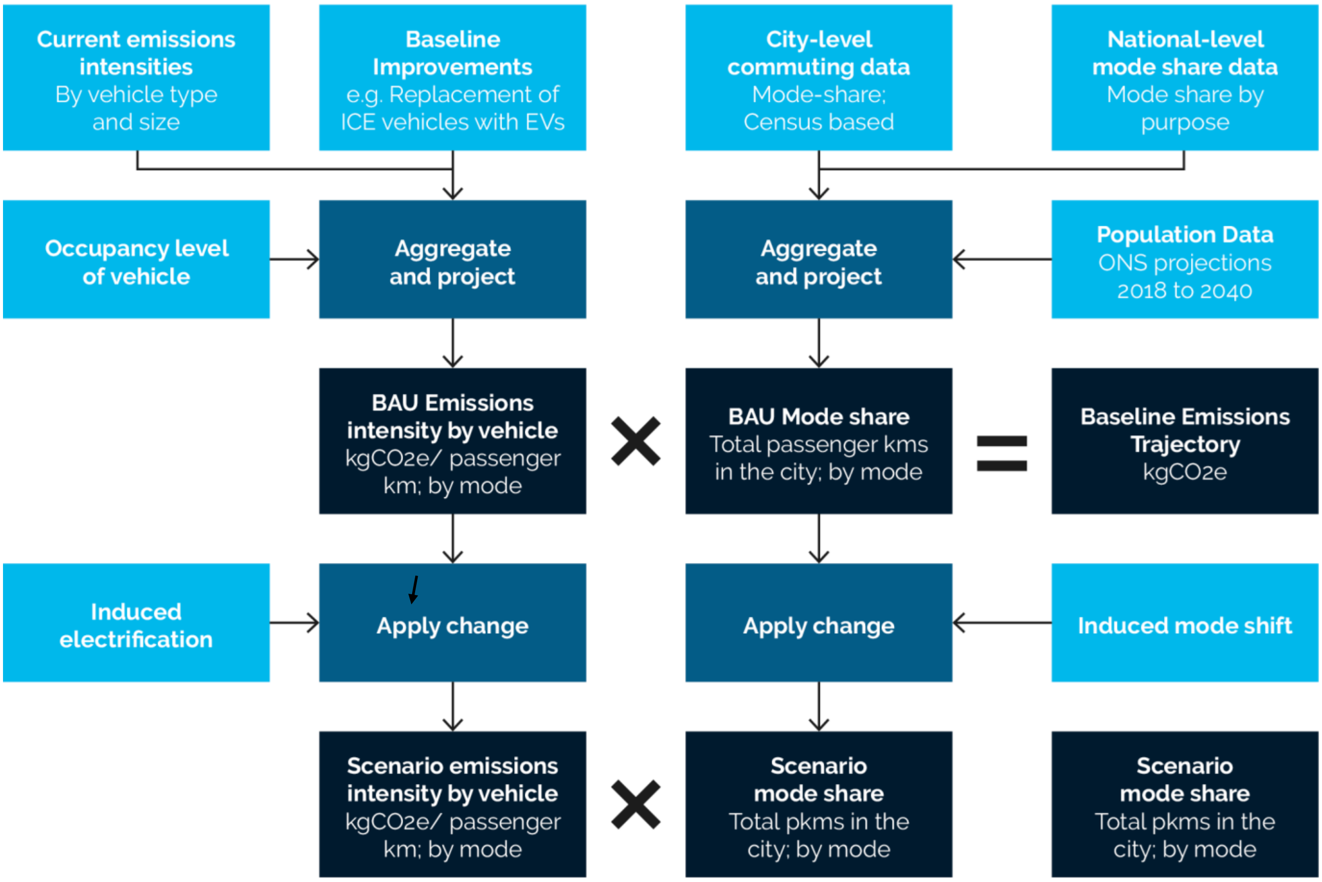
The transport model has been designed to estimate the costs, benefits and abatement potential of measures that change current travel patterns. Estimating total emissions in the transport sector involves compiling emissions intensities for each mode of transport (CO_2e/pkm) and city-region level mode share (pkms*) (see Figure 3).

First, we build a baseline 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 of trips for different trips (Shift)
- Efficiency gains due to electrification (Improve)
- Reduced number of trips due to network/logistical efficiencies (Avoid; only used for freight)

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. Therefore we do not consider scenarios such as temporary or permanent hybrid working.

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, rail, metro and tram travel are not considered. These make up 2% of journeys in most UK cities, (but 15% in London, which we have not modelled). We also exclude any changes to urban form because of the deployment of low carbon measures (e.g. decreased journey times leading to changes in trip lengths).

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

3.1.2 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% except for those related to logistics: because this would be a cost directly to the private sector, a discount rate of 7% is used[3]

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

[3]A survey of 177 firms found that the hurdle rate (required return on investment) was the main driver of uncertainty. Hurdle rates include a hurdle premium component which is related to the uncertainty of an investment. The average hurdle rate across all firms was 12%, with the average hurdle premium 8%, meaning that the required risk-free rate was closer to 4%. Given the fact that these numbers include a cross-section of industry and many of the investments this study is analysing are (a) not new ventures but in most cases low-risk upgrades to existing technology - e.g. heat pumps and electric vans and (b) will be mandated either by government (diesel HGV ban in 2040) or company policy - we have set the hurdle premium at a lower 3%, giving a total discount rate of 7%, double that of individuals and government. Because only a small proportion of low carbon measures are discounted at this higher rate, the overall level of investment required for each scenario is not significantly sensitive to this discount rate. Bank of England (2018) - Staff Working Paper No. 717 - Business investment, cost of capital and uncertainty in the United Kingdom — evidence from firm-level analysis - Marko Melolinna, Helen Miller and Srdan Tatomir

Cost or benefit	Title	Description
	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

3.1.3 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 running costs of an expanded bus network (bus capex costs are included)
- Any rail or metro shifts - buses are used as a proxy for all public transport
- 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)

Assumption	Description	Source
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.	Total 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 assumed to be the same across cities.	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)

Assumption	Description	Source
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
Measures that are large in scale and diverse in scope	– **Shared electric vehicles** - Assumed that 10 EVs are replaced by an EV that is part of a shared scheme. This is a modifier used in the integrated scenario. This modifies costs only. – **Shared bike scheme** - Shared bikes are assumed to be utilised ten times the amount of a private bicycle therefore the cost of a shared bike is 0.77 times the cost of a regular bike. This is a modifier used in the integrated scenario. This modifies costs only.	https://www.transportenvironment.org/sites/te/files/publications/Does-sharing-cars-really-reduce-car-use-June%202017.pdf https://inclusivev.eu/wp-content/uploads/2018/03/IncEV-Executive-Summary.pdf
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

Assumption	Description	Source
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. 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.	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
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 has a utilisation for work at 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)

Assumption	Description	Source
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

3.2 Building models

3.2.1 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

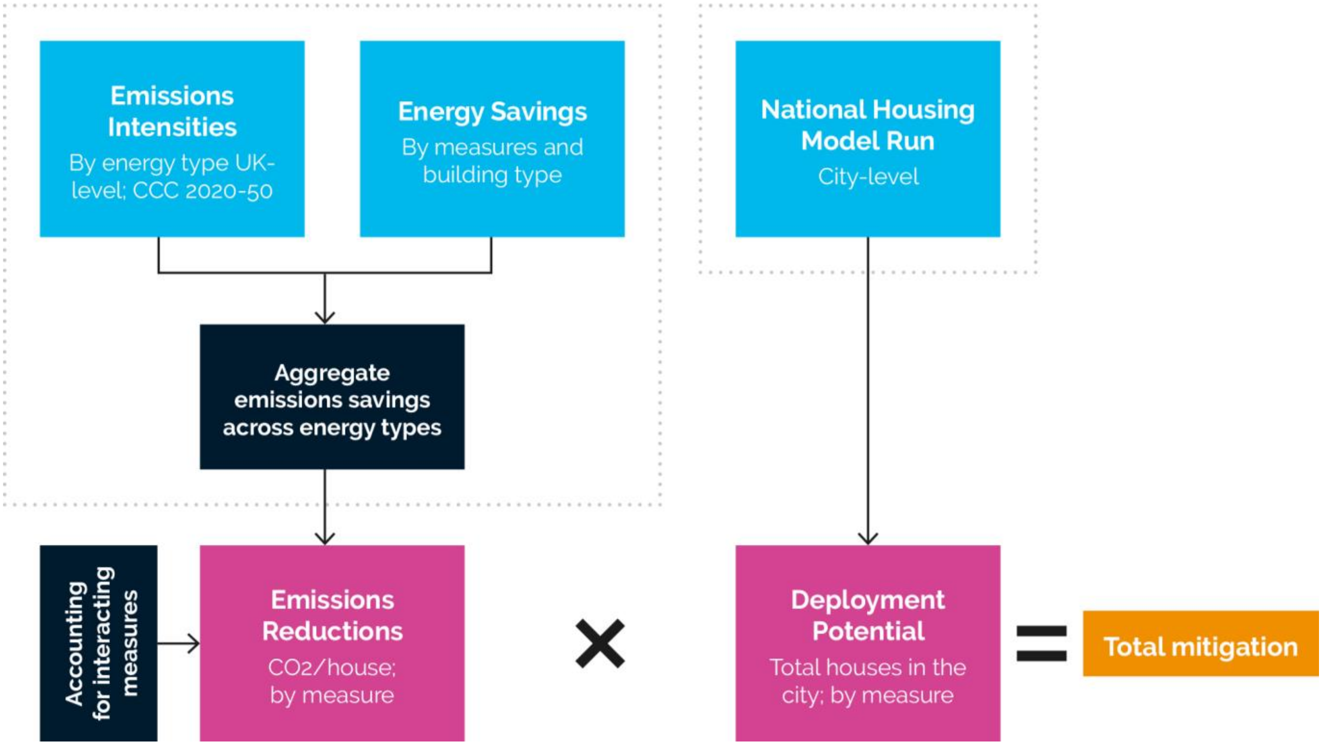
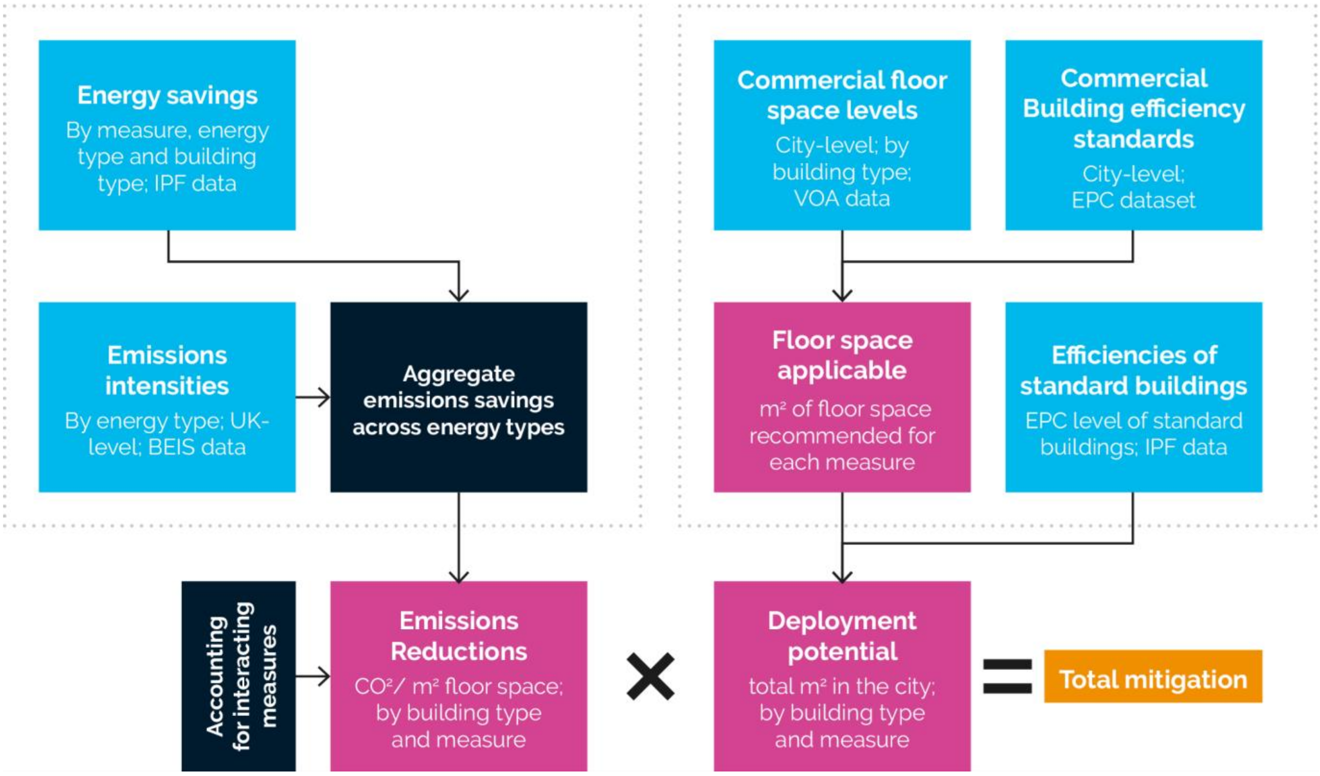


Figure 5: Flowchart outlining the commercial sector methodology



3.2.2 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.

3.2.2.1 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
Insulatin	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, installing a wind turbine
Scale and scope domestic Measures	Area based commercial PV installation, area-based commercial retrofit scheme.

3.2.2.2 Public and commercial buildings

In the domestic buildings sector, low carbon measures are deployed on a floor area basis across six 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 10C, reducing standby consumption, turning unnecessary lighting off
Microgeneration	Solar PV
Scale and scope commercial low carbon measures	Area based commercial PV installation, area-based commercial retrofit scheme.

3.2.3 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%. However, if a cost is directly applicable to the private sector (e.g. measures applied to retail units) a discount rate of 7% is used (see note 3 under Transport model)

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 fall to reach parity with ICE cars by 2035), 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. A sensitivity analysis in the economics supplementary evidence report considers a 25% rise in

buildings costs which is hypothesised as being due to an increase in labour costs - but could also be due to increases in materials such as timber, or microchips
- 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.

3.2.4 Key inputs and assumptions

3.2.4.1 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)*[4]. 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 is taken as static - i.e. we do not increase homes each year commensurate with likely house growth.

3.2.4.2 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.

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

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 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	https://www.gov.uk/government/publications/net-zero-strategy
Heat pump deployment in place agnostic scenario	Heat pump proportionality has been assigned per population in each city-region (based on the Government policy objective of 600,000 heat pumps provided each year from 2028 onwards), deployment starts in 2022 and exponentially increases to 2028 where the proportion of 600,000 heat pumps is deployed each year. The proportion of the original heat pump deployment across property types is calculated to split the updated deployment figure across property types	
District Heat Network deployment in place agnostic scenario	District heating networks currently supply 3% of the UK's heat supply: the aim is to increase the share to 20% by 2050. The Net Zero Strategy assumes that 6% of heating supply will be provided by district heating networks by 2035. To develop a deployment potential of district heat networks in the place agnostic scenario, proportionality is assigned per population in each city-region in the same manner as heat pump deployment. NB: this means that heat networks are assigned to cities based on population, but not based on the factors that will actually drive heat network deployment at the very local level: density, local heat sources and other local project feasibility factors	
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	

Assumption	Description	Source
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.	
Scale and scope low carbon measures	– District heating networks - The cost and benefits are based on figures from a case study in Tallaght. – Whole house retrofit - Measures that are replaced by a whole house retrofit are summed and compared with desk research values. It was found that this represented ~31% saving. This reduction is applied to other property types. The electricity, gas and other savings are reduced by approx 10% overall. – Low energy apartment retrofit - the same method is used and the same percentage reduction applied. – Area-Based Commercial Retrofit Scheme - Mean retrofit data comparing costs of typical schemes vs individual low carbon measures for a range of commercial typologies (5) is used as a cost reduction on the sum cost of low carbon measures. – Area-Based Commercial PV Installation - The average values of the three existing low carbon measures is used, and a costing improvement from economies of scale data for is used as a proxy for an area-based approach.	https://carbonneutralcities.org/wp-content/uploads/2018/05/1-London-Energiesprong-Transferability-Assessment.pdf , https://www.aecb.net/wp-content/uploads/2015/08/Going-Deep.pdf, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/656866/BEIS_Update_of_Domestic_Cost_Assumptions_031017.pdf , https://www.codema.ie/images/uploads/docs/TDHS_Marketing_Brochure_for_Developers.pdf https://www.hw.ac.uk/uk/schools/doc/egis/TARBASE_ND_REPORT.pdf , https://www.london.gov.uk/sites/default/files/appendix_a_solar_action_plan.pdf , https://www.theguardian.com/environment/2016/may/19/london-borough-installs-6000-solar-panels-on-market

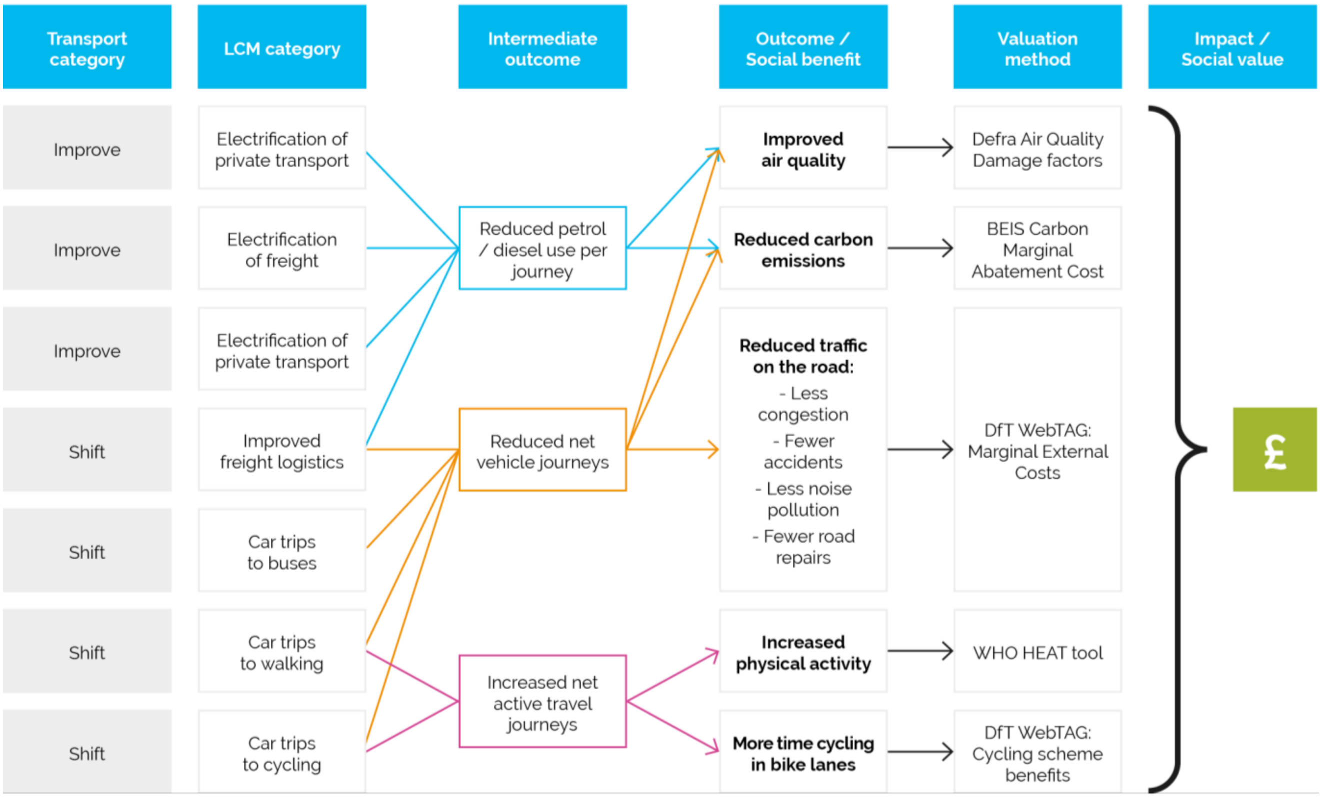
Assumption	Description	Source
Rebound effect	For some domestic LCMs, an increase in energy efficiency leads to increased use of energy to provide more comfort. We have assumed a rate of 15% rebound for certain measures and valued this using BEIS guidance - see 'Home Comfort' on pg 25	Committee for Climate 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%"

3.3 Social costs and benefits

Besides their financial costs and benefits, each low carbon measure creates various wider social costs and benefits. These have been identified and defined using impact pathways and drawing on the extensive existing literature that has considered the potential impacts of urban decarbonisation[5]. Taken together, the financial costs and benefits plus the wider social costs and benefits provide our estimates of the net present social value (NPSV) of each low carbon measure.

Figure 6 summarises the key impact pathways identified in relation to the low carbon measures relevant to surface transport and Figure 7 does the same for heat and buildings.

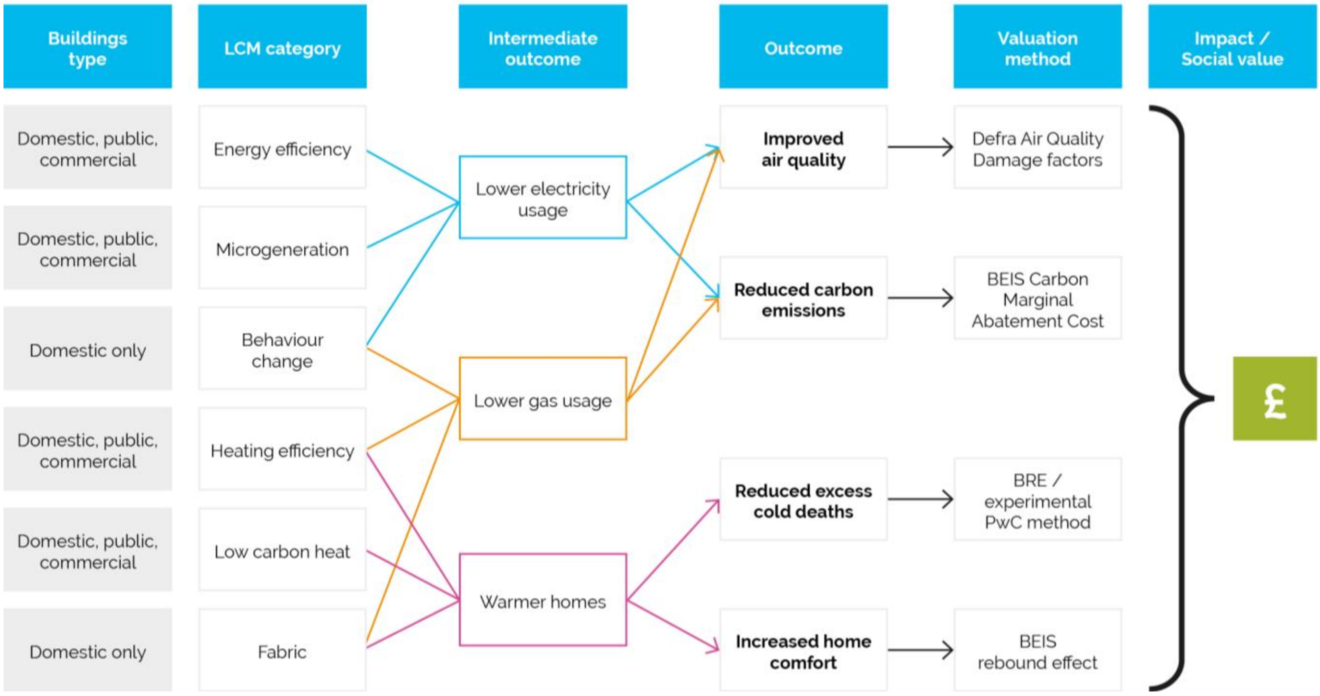
Figure 6: Simplified impact pathway for surface transport low carbon measures, by category



All social benefits are presented as positive benefits ('Improved air quality'). In aggregate, net benefits are generated under all scenarios but they comprise both costs and benefits. For example, switching car trips to buses results in a benefit of fewer cars on the road → *reduced* carbon emissions, congestion, accidents … but a cost of more buses on the road → *increased* carbon emissions, congestion, accidents.

[5] >100 studies were considered in our literature review. Of particular relevance was a meta-analysis by the Coalition for Urban Transitions and New Climate Economy (CUT/NCE, 2018) which reviewed >00 papers to create impact pathways for urban decarbonisation in cities across the developed and developing world

Figure 7: Simplified impact pathway for buildings low carbon measures by buildings type and category



Scale and scope low carbon measures are not shown; not all individual pathways shown e.g. some heating efficiency low carbon measures also reduce electricity usage, but they reduce gas usage far more as most UK homes have gas boilers

3.3.1.1 Social costs and benefits that are not measured

As a result of the literature review and the impact pathways, we also identified various social costs and benefits that are likely to be created by decarbonisation but were considered out of scope for this study because they are **immaterial, not directly relevant or unmeasurable:**

Table 9: Examples of wider social costs and benefits not measured in this study

Reason benefit not included	Example
Immaterial	– Light pollution – Indoor air pollution - this is relevant in the developing world where solid fuels are still used indoors, but negligible in the UK
Not directly relevant	– Heat stress - we only considered mitigation measures, so have not considered adaptation measures that would tackle heat stress and do not have a methodology to value it. The likelihood of heat stress may be increased by the addition of LCMs such as insulation in older homes – Odour - this may be relevant in the waste sector which we have not studied

Reason benefit not included	Example
Unmeasured or unmeasurable	– Distributional impacts are a significant factor in decarbonisation but this study was not designed to consider where the various costs and benefits would fall and would need further research – Other important social benefits similarly could not be measured, for example agglomeration effects, local attractiveness, biodiversity, and local safety – Triple glazing is likely to have an impact on noise pollution as well as warmth, but no studies we could find had considered this

Below, we explain the methodologies we have used to assess each type of social cost and benefit.

3.3.2 GHG emissions

Our approach to assessing the impact of reduced GHG emissions follows BEIS' latest guidance.

What benefit is being measured

As per BEIS guidance: "Greenhouse gas emissions values ("carbon values") are used across government for valuing impacts on GHG emissions resulting from policy interventions. They represent a monetary value that society places on one tonne of carbon dioxide equivalent (£/tCO2e). They differ from carbon prices, which represent the observed price of carbon in a relevant market (such as the UK Emissions Trading Scheme). The government uses these values to estimate a monetary value of the greenhouse gas impact of policy proposals during policy design, and after delivery."

Inputs

From both buildings and transport models: Emissions per low carbon measure per city-region/scenario

Source

- BEIS Valuation of greenhouse gas emissions: for policy appraisal and evaluation, updated Sep 2021, Annex 1

Valuation methodology

- Step 1: The annual net GHG emissions savings are key outputs from both the transport and buildings models
- Step 2: These are multiplied by the carbon price for the appropriate year
- Step 3: The estimated benefits are discounted at 3.5% to derive their net present value.

Sensitivity analysis

BEIS provide a high and low series for the carbon price, which increases or decreases the central price by 50%. This sensitivity is presented in our economics supplementary report.

Other inputs and assumptions

Note: Traded vs Non traded

By considering the change in use of different types of energy because of low carbon measures, it is possible to split the carbon values into traded and non-traded values. For example, as per BEIS guidance, electricity forms part of the traded sector, but domestic gas use is in the non-traded sector.

We do not present this analysis in our main findings or supplementary evidence. This is because reading of the updated guidance and further correspondence with BEIS GHG appraisal team suggests that (1) the usefulness of this disaggregation in a broad, hypothetical appraisal such as this study is limited and (2) the methodology is subject to change pending consultation on design of the UK ETS.

3.3.3 Decongestion benefits

Our assessment of the potential benefits of reduced congestion follows the approach recommended in the Department for Transport's WebTAG relating to Marginal External Costs, which builds on an academic paper from Samson et al (2001)[6]

What benefit is being measured

MECs measure the change in social value in having one less car on the road because of different factors:7

1. Less congestion → Improved journey time and quality, lower vehicle operating costs
2. Fewer accidents → lower mortality and morbidity
3. Fewer road repairs required → lower cost to the Exchequer
4. Lower levels of noise pollution → lower health and productivity burden
5. Fewer GHG emissions
6. Lower air pollution
7. Lower road / fuel duty to the Exchequer

Note that 5 and 6 are valued elsewhere in our analysis (so not used here) and 7 is a transfer from one group to another, so not measured in this study.

Inputs

From transport model: Change in vkms for each transport mode

Source

DfT WebTAG guidance A.5.4 - Marginal External Costs (MECs)

Valuation methodology

We use two sheets from the Tag MEC data - A5.4.1 (traffic data) and A5.4.2 (cost data)

3.3.3.1 A.5.4.1 - Traffic data

The output from the transport models is vkms for different vehicle types, per year, but these are not split by region or road type. Therefore, the first step required is to:

Step 1: Split total vkms in each city-region into different region and road type

This is done using DfT WebTAG Sheet 5.4.1: "Traffic by region, congestion band, area type & road type"

- Assumption: Regions are at the International Territorial (NUTS-1, i.e. Scotland, North-East, London); it is assumed that each city-region has the same transport road usage as the region it is located in. So, for example, Manchester and Liverpool both use North-West
- Assumption: There is no regional split for Northern Ireland, so Wales is used instead as Swansea-Bay and Belfast city-regions have similar levels of density
- Assumption: DfT's regional road-usage splits (5.4.1) change every 5 years but stay constant between them[8]

This allows us to say that, for example, if 100km is driven by a car in Glasgow city-region, X% of it will be on an A road in an Inner conurbation. So if 100km *less* is driven, it will disappear from this same road/region

3.3.3.2 A5.4.2 (cost data)

DfT gives values in pence per vehicle kilometre (vkm) avoided, split by the mode, place and time the vkm is avoided, by:

1. Vehicle type (Cars, LGVs, OGV, HGV and PSV)
2. Year (2015-2050)

[6] Sansom T, Nash CA, Mackie PJ, Shires J, Watkiss P (2001) Surface Transport Costs and Charges: Final Report. For the Department of the Environment, Transport and the Regions. Institute for Transport Studies, University of Leeds

[7] **DfT definition:** The primary method for estimating decongestion benefits in the absence of a multi-modal model is based on marginal external costs (MECs). The use of road vehicles incurs both private costs borne by the individual traveller (such as fuel costs and personal travel time) and external costs borne by others. These external costs include congestion, local & global air pollution, noise, infrastructure and accident costs. The MEC method is based on the change in these external costs arising from an additional (or removed) vehicle (or vehicle km) on the network. These costs have been estimated from the Department's National Transport Model and Surface Transport Costs and Charges: Great Britain 1998.

[8] The model does not straight-line these because the splits do not follow a linear pattern each 5 years but change erratically due to complex future transport modelling. DfT correspondence confirmed this approach.

3. Region (London, Inner and Outer Conurbations, Other Urban, Rural)
4. Road type (Motorways, A roads, Other Roads)
5. Congestion band (1 to 5; this describes what % of the time each road is expected to be in free-flowing traffic (band 1) or standstill (band 5))

1 and 2 are outputs from the transport model and 3, 4 and 5 are calculated using A5.4.1 above.

Step 2. Multiply the avoided vkms per mode, place and time by the pence/vkm value for the corresponding mode, place and time

Step 3. These benefits are discounted at 3.5%

Sensitivity analysis

Congestion band: Congestion band 5 represents the total breakdown of traffic which has large negative effects on journey time and productivity. As a result most of all congestion benefits are due to avoiding time in band 5. DfT correspondence noted that they urge caution when using band 5 and advised sensitivity analysis. We created 3 scenarios:

- Band 5 included at full values
- Band 5 reduced to the band 4 level
- Band 5 removed entirely

These are the high-medium-low sensitivities presented in our economics supplementary report.

Only the core scenario is used from WebTAG 5.4.2. DfT provides two other scenarios but these involve policy options (e.g. 'shift to ZEVs') rather than confidence intervals, so are ignored.

3.3.4 Air quality

We assess the value of the impacts on air quality using the damage cost guidance prepared by the Department for Environment, Food and Rural Affairs (Defra).

Inputs

- From transport model: Fuel usage by type, vehicle and year, split by local authority
- From buildings model: Fuel usage by type and year, split by local authority

Sources

Main method source

Defra: Air quality appraisal: damage cost guidance (2021)

Supplementary sources

- ONS density per LA
- Table 6 of the National Transport model

What benefit is being measured

The health costs of air pollution on people. The Defra approach considers different health impacts based on the latest advice from Public Health England and the Committee on the Medical Effects of Air Pollution (COMEAP). Three impact pathways are included in this valuation:

- public health
- the natural environment
- the economy

Detailed information on derivation of this methodology is available here

Valuation methodology

There are two Defra tables - one for air quality damage from transport emissions and one for fuel combustion from buildings. Both assume that damage is higher when fuel is consumed in more densely populated areas. They also require the user to calculate where each unit of fuel is used. However, the two tables use different "density areas", as shown:

Table 10: Density areas used to assess air quality damage in buildings and transport

Buildings
National Average
Domestic: Inner Conurbation
Domestic: Urban Big
Domestic: Urban Medium
Domestic: Urban Small
Domestic: Rural

Transport
Transport Average
Central London
Inner London
Outer London
Inner Conurbation
Outer Conurbation
Urban Big
Urban Large
Urban Medium
Urban Small
Transport Rural

Step 1: Split each local authority in each city-region into a transport and buildings density-area type.

Assumption: This is done, using either (depending on data availability):

- For buildings - The density of the LA is matched to ONS population stats, with each buildings density area being assigned to a different density quintile
- For transport - allocations from Table 6 of the National Transport model - and where these were not present for a place, ONS density is used as per (a)

* Note that neither of these methods have any relations to the splitting of vkms into road types in the section above

Step 2. Multiply the damage factors per fuel type, per year, per density area by the change in energy usage by fuel type per low carbon measure per year. For transport, vehicle type split is also required.

Step 3: These benefits are discounted at 3.5%. In addition, there is no annual data series for transport air quality damage, so damage costs are inflated to 2022 prices and then 2% p.a. as per the Defra guidance.

- Assumption: AQ damage includes both health benefits and non-health benefits (i.e. changes to productivity), therefore we use the discount rate of 3.5% and not the pure health benefits-rate of 1.5%

3.3.5 Physical activity

Our estimate of the health benefits associated with the change in levels of physical activity associated with adoption of different low carbon measures is based on the World Health Organisation's health economic assessment tool (HEAT).

Inputs

Transport model - extra vkms of cycling and walking per year

Sources

Main method

World Health Organisation - online Health Economic Assessment Tool (HEAT) for walking and cycling. Methodology was improved following correspondence with the authors, based on the academic paper that informs the methodology[9]

Supplementary sources

- ONS population data
- DfT transport frequency statistics
- Green Book supplementary guidance: Value of a Life Year (VOLY) - inflated from 2014

What benefit is being measured

Increased walking and cycling are associated with a decrease in all-cause mortality. The evidence for this is based on longitudinal studies of the reduced chance of dying of an average person with varying levels of walking / cycling per day. Each life not lost can then be valued statistically.

[9] Götschi, T et al (2020) Integrated Impact Assessment of Active Travel: Expanding the Scope of the Health Economic Assessment Tool (HEAT) for Walking and Cycling. Int. J. Environ. Res. Public Health

Valuation methodology

Assumption: The academic paper that underpins the methodology assumes that health benefits only accrue to people between 20-74 for walking and 20-64 for cycling since there is no evidence otherwise. We assume that all extra vkms travelled by active travel are completed by this age group. This is viewed as reasonable since:

- loss of life due to lack of physical exercise is very unlikely before 20
- frequency of exercise drops for those over 75, who are half as likely to walk regularly and for the over 65 who are three times less likely to cycle regularly than the population aged between 20 and 64/74 population[10]
- In addition, these age-groups are broken down further because the younger group (20-44) has a much lower risk of mortality - see step 5

Step 1: Our transport model estimates the extra vkms being walked and cycled per year

Step 2: Divide by the 20-64/74 populations, average walking/cycling speed (from HEAT; 14km/h) and 365 to give hours of exercise per person per year - assuming all people split the exercise evenly.

Step 3: Use HEAT calculation: Divide the extra exercise per person in each age group by the reference range given by HEAT, and then multiply by the total reduction in risk that is associated with the reference range (see HEAT tool).

Step 4: If volume of exercise exceeds the capped amount, cap. NB: this does not happen in any of the modelled scenarios, as it is equivalent to 450 minutes per week of cycling or walking

Step 5: Multiply the reduction in risk for each age group by the total all-cause mortality for each age group in a given city-region - *this gives the total number of mortalities per city-region per year that would be avoided by increased physical activity*

Step 6: Calculate the average number of life years remaining for each age group - e.g., older age groups are likely to live less long

Step 7: Multiply this by the number of expected mortalities (5) and the VOLY to give a total value of life lost per year

Step 8: Create a lag so that it takes 5 years to accrue total benefits, with 20% created in the first year, 40% in the second etc

Step 9: Discount by 1.5%: we use the Green Book recommended discount rate for health benefits as they are pure health benefits.

3.3.6 Excess cold

Our estimates of the social costs and benefits associated with the avoidance of excess cold follow an experimental method based on evidence from Building Research Establishment and Cambridgeshire County Council

What benefit is being measured

Savings to the NHS per annum if excess cold was eliminated.

Inputs

From the domestic buildings model, we consider only the deployment of those low carbon measures that have the potential to increase heat (e.g. insulation - 'heating low carbon measures').

Source

Main source

BRE: Cost of Poor Housing Briefing Paper v3 (Nicol, Roys & Garrett, 2015)

Supplementary sources

- The potential of each domestic 'heating low carbon measure' to increase heat in degrees C (using data from National Housing Model based on SAP scores[11])
- Excess winter deaths in each city-region, ONS

Key design assumptions

BRE[12] estimate the potential NHS savings if 25 different housing hazards were eliminated in the UK. The largest hazard is "excess cold" which was estimated to cost the NHS £848m in 2015 (£1.4bn in 2020 prices). The approach set out below allocates a proportion of these potential savings to the successful deployment of low carbon measures that increase domestic warmth.

This approach is experimental, was designed for this study and should be used with caution as the

[10] DfT statistics CW0305: Proportion of adults that walk or cycle, by frequency, purpose and demographic, England, 2018-2019

[11] Standard Assessment Procedure - BEIS 2013

[12] Gov.uk, updated by BRE: Cost of Poor Housing Briefing Paper v3 (Nicol, Roys & Garrett, 2015)

causal pathway from improved housing measures to lowered likelihood of morbidity or mortality from excess cold is complex and this study does not have sufficient data to draw a direct line from one to the other.

However, the assumptions used are conversative and the resulting benefits are not significant to the overall analysis (excess cold benefits represent ~1-5% of all social benefits in any given city-region/scenario).

- Assumption: The model does not contain information on income distribution so it is assumed that all low carbon measures generate the same level of benefits, even though, insulation in a poorer household would be more likely to eliminate excess cold
- Assumption: Excess cold creates wider social costs through lost productivity and reduced utility (it is unpleasant to live in a cold home). This study does not consider the former at all, which is likely to be significant, but the latter is included in "Home Comfort" benefits (see next section)
- Assumption: This method assumes a direct link between temperature increase and health benefits and makes no provision for other impacts of temperature e.g. (1) increased temperature may also decrease dampness which has health benefits (2) increased insulation may increase the likelihood of excess heat in summer which has health disbenefits not considered in this study

Valuation methodology

Step 1: Calculate the total value to the NHS of eliminating excess cold. Two datasets are combined:

- BRE show that 60% of total NHS costs are due to excess cold (£848m of £1.4bn)
- Cambridge Research Group show that the total cost to the NHS of ALL housing hazards is £2bn p.a13
- Therefore, we assume that a cost to the NHS of £1.2bn p.a. can be associated with cold-related housing hazards that can be tackled by warming low carbon measures (60% x £2bn)
- This is inflated to 2020 prices to give a figure of £1.43bn NHS costs14

[13] Gov.uk / Cambridgeshire County Council: The cost of poor housing to the NHS (2019)

Step 2: Allocate NHS costs to city-regions. Total NHS costs are split between city-regions on a population basis, but weighted for that city's experience of excess winter deaths in 2018/19[15] (i.e. pre-COVID)

- Assumption: Weighting NHS costs per city-region by observed excess winter deaths: Excess cold deaths depend on many factors including ambient winter temperature, housing stock and poverty levels of a city. In the absence of an analysis of these factors, it is assumed that observed excess winter deaths in a city-region could be considered indicative of them all
- Assumption: Excess cold baseline: Analysis of long-term trends show that excess winter deaths in the UK are falling by approx. 1% p.a. even as the population rises. This may be because of the factors mentioned above (warming temperature, improved housing) and it means that in the absence of low carbon measures, NHS costs would reduce over time. Therefore, this long-term trend is extrapolated and used to reduce the total amount of NHS savings available by ~1% p.a.

Step 3: Allocate NHS costs to each low carbon measure deployed

Domestic low carbon measures that increase heat are selected (67 out of 235).

- Assumption: only low carbon measures that increase temperature infer 'anti-excess cold' health benefits - therefore insulation is included, heat pumps are excluded

The temperature increase of each is used to calculate a warming factor per low carbon measure[16]

- Assumption: there is a direct, linear relationship between the extent to which a measure increases temperature and that measure's reduction in NHS costs
- Assumption: Measures that lower heat - thermostats, behaviour change - are assumed to not be deployed by households that are already cold, therefore there is no excess cold disbenefit applied to those measures

[14] Using an NHS inflation rate of 2% based on PwC research - available to discuss on request
[15] ONS - Excess winter deaths by Local authority - England and Wales only - 2018/19
[16] Using data from National Housing Model / SAP scores - See Standard Assessment Procedure - BEIS 2013

The warming factor is corrected by deployment potential so that 70% of max deployment = 100% of NHS cost savings

- Assumption: an assumption must be made about whether total excess cold is fully eliminated when all possible EPC measures are deployed or at a lower level. This analysis assumes a level of 70%. This is based on evidence showing that 37% of all homes surveyed in England have at least one significant hazard17, which means that the total NHS costs could be avoided if only those 37% of homes received warming low carbon measures. However, it is not possible to disaggregate at the household level so an assumption is made that once deployment reaches 70% of potential, all the at-risk 37% would be covered
- Note: A more means-tested rollout of warming low carbon measures would generate higher NHS savings faster, but a more market-based approach (incentives to install insulation that incentivise richer households first) would likely result in a slower reduction in excess cold

Use the corrected warming factor to assign a total £ value for each low carbon measure in each city. The total NHS costs can now be split between low carbon measures so that for example, in an average bungalow cavity wall insulation installed between 1976-83 is worth £140 p.a. in avoided NHS costs

Multiply these £ values by the number of each low carbon measure deployed in each city-region/scenario each year

Discount benefits at 1.5% (these are pure health benefits so discounted at reduced rate)

[17] Gov.uk / Cambridge Research Group: The cost of poor housing to the NHS (2019)

3.3.7 Home comfort

This benefit follows BEIS guidance[18] on how to value the additional comfort that households receive from being able to use domestic appliances (e.g. heating, lighting) more when the energy efficiency of the appliances improves.

What benefit is being measured

This benefit values the "rebound effect". This is the extent to which energy efficiency measures result in households saving money on their energy bills enabling them to afford to use these appliances more leading to an improved quality of life (i.e. warmer, more well-lit homes).

Inputs

From the domestic buildings model: the deployment of those low carbon measures where a reduction in energy usage (and therefore energy bills) may lead to higher usage (148 out of 235). For example a more efficient oven is included, lowering of a thermostat is excluded. Heat pumps are also excluded as they are more likely to increase fuel bills so there would be no rebound effect

Sources

Main source

- BEIS (2021) - guidance on how to value direct rebound effects19

Supplementary sources

- Committee for Climate Change (2013) 20 - 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)21 - extensive evidence of the size of the rebound

[18] Valuation of energy use and greenhouse gas: Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government (October 2021)
[19] Valuation of energy use and greenhouse gas: Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government (October 2021)
[20] CCC / EST (2013) - Review of potential for carbon savings from residential energy efficiency
[21] UK Energy Research Council (2007) - The Rebound Effect: an assessment of the evidence for economy-wide energy

effect in different settings, concluding that "The direct rebound effects were estimated to reduce overall energy savings by 15%"

- Assumption: in practice, the extent to which the rebound effect is present differs significantly but a central rate of 15% is chosen for all measures
- Assumption: 0% rebound effect is applied for public and commercial usage: the paper gives some evidence that offices, schools, hotels etc. are not constrained by energy prices to the same degree as households
- Assumption: indirect rebound effects are not considered at all - i.e. where money saved on energy is spent in the wider economy, increasing enjoyment
- Assumption: rebound rates remain at 15% throughout the study - there is no reduction over time thanks to exogenous changes to buildings standards or energy prices

Valuation methodology

Step 1: Select domestic buildings LCMs that are subject to a rebound effect

Step 2: Select which type of energy usage the rebound would be applied to: For example, triple glazing results in gas savings (boiler usage), but not electricity savings, so the rebound effect applies only to gas; low-energy lighting only affects electricity use; a gas combi-boiler saves both electricity and gas.

Step 3: Calculate 15% of the energy savings for each measure each year in kWhs

Step 4: Multiply this by the number of measures deployed each year and by the retail price of that measure

- Assumption: Analysis of costs in this study always use the long-run variable cost of energy, but the rebound effect uses the retail price. This follows BEIS guidance: because the retail price is the price households pay to increase their heating or lighting it is therefore a revealed preference of their willingness to pay for this experience

Step 5: Benefits are discounted at 3.5%

NB: in the buildings model (see pg 11), the rebound effect mirrors the approach taken here. i.e. the 15% increase in energy usage is applied to the same measures, which increases emissions accordingly

3.3.8 Bike lane ambience

We follow Department for Transport guidance on the extra journey quality a cyclist receives when cycling in a bus lane as opposed to an open road.

What benefit is being measured

When cycling in a bus lane cyclists feel safer and have less-interrupted journeys. Many cyclists would be willing to pay a small amount for this extra benefit and DfT have created a methodology that seeks to capture that value created.

Note that the total value of this measure is small (<1% of all social benefits) and in our main report and economic supplementary analysis we do not present it separately but as a part of physical activity benefits - but the methodology used is distinct.

Inputs

From transport model: extra vehicle kilometres (vkms) travelled by bike per city-region/scenario

Sources

DfT WebTAG A4.1.6: Value of journey ambience benefit of cycle facilities

Valuation methodology

Step 1: Translate bike vkms into minutes spent cycling each year by dividing by average cycling speed (14km/h)

Step 2: Create a constant (17%) to understand how much of this time iss spent in bike lanes by multiplying the assumed % of all kms spent in bike lanes by the assumed difference in speed in bike lanes versus the road

- Assumption: 20% of all kms travelled are in bike lanes. There is very little data on what % of time cyclists spend in bike lanes versus the open road in UK cities, but 20% is thought to be a reasonable level for non-London cities
- Assumption: Cyclists travel 15% faster in bike lanes because of fewer interruptions. There is very little data on difference in speeds in bike lanes, but this is thought to be reasonable

Step 3: Multiply total bike minutes p.a. by this constant to give bike lane minutes p.a. For each city-region/scenario

savings from improved energy efficiency / Barker and Foxon (2006)

Step 4: Calculate the average benefit generated per minute of cycle lane usage by averaging the 5 types of bike lane given in WebTAG

- Assumption: This study assumes that a given level of bike usage will create demand for more cycle lanes but not what type of lanes. DfT provides values for time spent in (1) Off-road segregated cycle track, (2) On-road segregated cycle lane (3) On-road non-segregated cycle lane (4) Wider lane (5) Shared bus lane. We assume that journeys are split evenly between all 5, and so use the mean value of 3.79 pence per minute

Step 5: Multiply bike lane minutes p.a. By this value to generate total benefits

Step 6: Benefits are discounted at a rate of 3.5%

4 GVA and jobs

This section explains how we have modelled the potential impact on GVA and jobs associated with decarbonisation.

What is being measured

Decarbonisation will require significant investment in many sectors of the economy, and it will also create significant cost savings. Each £ spent in a sector creates a degree of economic growth (gross value added, GVA) and job growth in that sector and other sectors. Each £ saved, conversely reduces growth. However, the relationship between investment and GVA/jobs differs significantly for each sector - i.e. a £ spent in retail creates more jobs than a £ spent in electricity transmission. So the way in which investment and savings are spread across different sectors will affect future GVA growth and job creation.

Input-Output (IO) modelling of this type is a good estimate of the potential growth and jobs that can be supported by a given level of investment, but it is subject to a series of assumptions:

- Assumption: UK IO table: We use a UK-level IO table for this analysis which means the analysis assumes that investment is made in an economy with the same structure as the UK economy and not each individual city-region. Although all our investments are made locally (purchase of heat pumps, EVs or construction of bike lanes), much of this investment will 'leak' into other parts of the UK. In some sectors this is not significant (most home retrofits are likely to be carried out by local tradespeople) but in others it is (increased EVs will not lead to local manufacturing jobs except in places like Oxford and Sunderland where EV factories are located)
- Assumption: International leakage: In addition, much of the investment will flow out of the UK and into other countries - foreign battery production. For each LCM, an assumption is made, based on evidence about what % of that product or service is likely to be produced in the UK
- Assumption: Static economic structure: economies change over time, but we use a static IO table that assumes the same structure to the UK economy over 30 years
- Assumption: No interactions: Investment of the scale required in this analysis would change the price of goods and labour and would also result in regional dynamics - i.e. labour prices might increase in those places with EV factories. It is possible to build in such interactions (CGE modelling), but this analysis does not
- Assumption: Type I multipliers. Direct economic spend creates indirect spend and induced spend. This study only uses type I multipliers (Direct + indirect) but we have also built in the option to include type II multipliers (Direct+indirect+induced). This has been ignored but would add approximately 20% to both GVA growth and jobs

Inputs

From the transport and buildings models: Expenditure by LCM

Sources

Main source

ONS, UK input-output analytical tables (2017)[22]

Supplementary sources

Various sources including trade magazines, government guidance and academic papers that describe:

- the various subcomponent splits in the costs of LCMs[23]
- The % of which sectoral spend per LCM is likely to take place in the UK

SIC Code.co.uk - database that matches economic goods and activities (i.e. LCMs) with their respective Standard Industrial Classification code, and therefore the part of the economy their expenditure stimulates

ONS productivity estimates to correct for jobs created in the future[24]

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[22] ONS, UK input-output analytical tables (2017)

[23] For example, BEIS (2020) Cost of installing heating measures in domestic properties

Overview of methodology

Step 1: Split LCMs by cost type: Most LCMs must be further split down from their headline cost into subcomponents. E.g. heat pumps cost £9-17,000 in this analysis but that comprises various costs which affect the economy in different ways. Various sources are used to split these costs

Step 2: Assign each LCM cost to a broad sector, e.g. Retail, Manufacturing

Step 3: Lookup detailed sectoral SIC codes by searching for each on SICcode.co.uk

Step 4: Split expenditure by what % of it takes place in the UK using various sources

Step 5: **Direct expenditure per LCM**: By multiplying the cost split per sector, with the UK split per LCM, create a value for each LCM which shows how many pence would stimulate each UK sector for £1 spent on that particular LCM

GVA

Step 6a: **Calculate direct GVA per LCM**: multiply direct expenditure per LCM by the *GVA to output ratio* for each sector to give Direct GVA per sector for every £1 expenditure on each LCM

Step 6b: Calculate indirect GVA per LCM: Multiply direct GVA by either Type I or Type II multiplier for each sector to give indirect GVA per £1 spent on each LCM

Step 6c: **Calculate total direct + indirect GVA per LCM**. Multiply the previous step by the total real £ expenditure per LCM per year to give GVA growth per sector, and overall

Jobs

Step 7: Repeat step 6b and 6c but instead of using Type I/II GVA multipliers, use Type I/II FTE effects. These calculate the number of jobs created by £1m spend in each sector

Step 7b: Correct for productivity. £1m (in real prices) spent in a sector now may create 10 jobs, but in 20 years' time, it is likely that that sector will have become more productive either because fewer people can do the same job better, or because of automation. To take these factors into account, we correct the job creation numbers using the ONS long-run productivity estimates. This data estimates that productivity will grow by ~1.4% p.a. (and therefore it will require 1.4% more investment in real terms to create the same number of jobs).

Assumption: We assume that all productivity gains are labour replacing.

[24] ONS, Supplementary forecast information, monthly profiles and long-term determinants (2021)

5 Setting up non-London Urban UK

To build a representation of Urban UK the first step was to define the population that we are representing. There is no set definition of "Urban Population" with variation between each of the four nations of the UK. The World Bank defines the urban population as representing 84% (2020, World Bank) of the total population of the UK. This has been defined using Output Areas, while our analysis has focused on Local Authorities, therefore, this was set as an initial target in Local Authority selection.

Step 1 - City-regions - Coverage up to 54% of UK population

It was decided that the project should focus on city-regions / combined authorities (these have a mix of dense and sparse built environment and a central political mandate). In Phase 1, 21 city-regions were defined using the following definitions:

Should be a wider city-region rather than just a city core

- Contains urban, suburban and peri-urban environments
- Coherent travel to work areas

City-region should be an official 'city-region' or combined authority

- Unambiguous boundaries
- Clear political mandate for place
- Ease of access to data

Step 2 - Primary Urban Areas - Coverage up to 67% of UK population

The analysis was extended to include Primary Urban Areas (PUAs) which weren't included in our city-regions - these are the "built up areas that provide a consistent measure to compare concentrations of economic activity across the UK. These are distinct from city-regions or combined authority geographies. Note all our city-regions include PUAs but extend the area to wider conurbations.

Step 3 - Further selection of Local authorities to catch those missed - Coverage up to 84% of UK population

We have used a definition of urban places using two main criteria:

- Population i.e. areas forming settlements with populations of over 10,000 (DEFRA); and
- Accessibility, commutable distances equating broadly to areas within a 30-minute drive of a settlement

Using this definition we can use a hybridised approach of the Scottish, Welsh, English and Northern Irish governments to categorise each local authority against a six-fold classification.

Table 11: Six-fold urban-rural classification

Class	Class Name	Description
1	Large Urban Areas	Settlements of over 125 000 people
2	Other Urban Areas	Settlements of 10 000 to 125 000 people
3	Accessible Small Towns	Settlements of between 3 000 and 10 000 people and within a 30 minute drive time of a Settlement of 10 000 or more
4	Remote Small Towns	Settlements of between 3 000 and 10 000 people and with a drive time of over 30 minutes to a Settlement of 10 000 or more
5	Accessible Rural	Areas with a population of less than 3 000 people and within a 30 minute drive time of a Settlement of 10 000 or more
6	Remote Rural	Areas with a population of less than 3 000 people and with a drive time of over 30 minutes to a Settlement of 10 000 or more

All local authorities for which either Class 1, 2 or 3 were selected and added to our analysis area.

Step 4 - Remove London - Coverage to 75% of UK population

In the transport sector modelling rail, metro or tram travel is not considered. These make up 2% of journeys in most UK cities, but 15% in London[25]. Given that London is a significant outlier. All 32 London Boroughs were removed from the analysis.

Step 5 - Data sources and deployment potential

To build a representative picture of Urban UK as defined above data for each Local Authority selected above gathered including population, number of homes, area of commercial space and energy consumption attributable to each mode of transport. This enabled the deployment potential of each low carbon measure to be estimated for each sector:

- Transport - using bottom-up aggregation of BEIS Tonnes Oil Equivalent data from all selected Local Authorities
- Domestic Buildings - Applying population and number of homes as a scaling factor to the calculated deployment potential of measures in the 6 analysed city-regions
- Commercial and Public Buildings - Applying area of commercial space and Gross Value Added as a scaling factor to the calculated deployment potential of measures in the 6 analysed city-regions.

[25] Source: NTS9903: Average number of trips (trip rates) by main mode, region and Rural-Urban Classification: England, 2018/19