frontier economics

NET ZERO DISTRIBUTIONAL MODEL

Methodology

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Executive Summary

Frontier Economics has been commissioned by the CCC to develop an Excel-based model, the Net Zero Distributional Model ('NZDM'), that can be used to assess the distribution of costs to households under different low-carbon heat and transport policy to deliver Net Zero. The box below provides a high-level overview of the model.

High-level summary of the Net Zero Distributional Model

The model calculates the **distributional effect on household costs of selected policies for decarbonisation** in residential buildings and surface transport on a set of **15 representative customer archetypes**, as well as the impact on **Exchequer spending and revenue**.

The model estimates household costs under a **'baseline' scenario** and a scenario in which households take-up low-carbon technologies in line with the CCC's Sixth Carbon Budget pathways. In the baseline scenario, no further policy action to incentivise decarbonisation beyond today or significant take-up of low-carbon technologies is taken. The societal costs of climate inaction (for example costs driven by more frequent extreme weather events) are not factored into the baseline.

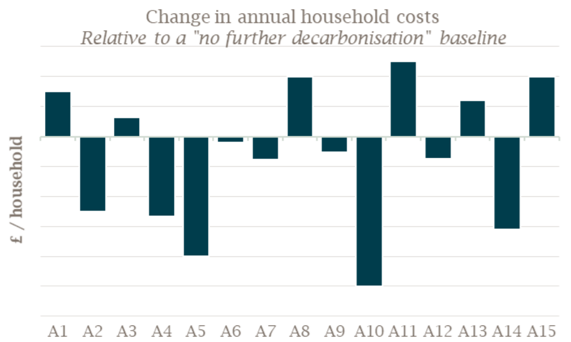
The **starting point in the model** (i.e. if the user does not select to apply any policies) is that the user of the technologies bears the cost / benefits of taking up and using that technology under the CCC's uptake scenario. **Distributional policies can then be 'layered on'** by the model user to assess the consequences for distribution, relative to the 'user pays/user benefits' starting point. Users can select different combinations of policy instruments that will drive a decarbonisation measure for selected households (e.g. grants targeted at low-income households).

The model calculates the **total costs (or revenues)** associated with providing these policies to all households and distributes these across the 15 archetypes. The model calculates **the change in household-level costs** for each archetype and snapshot year, relative to the CCC's baseline. The change in costs includes: i) upfront capital costs of technologies and retrofits; ii) ongoing (non-fuel) costs (e.g. maintenance), iii) energy costs (e.g. electricity / gas costs or petrol / diesel costs); and iv) additional costs / benefits such as changes in grants or general taxation (due to policies).

Example inputs for users to adjust

Aim	Policy instrument	Apply the policy instrument?	Who does the policy instrument target?	How should the cost (revenue) be funded (spent)?
Incentivise switching to heat pumps	Grants for heat pumps	Yes	Low-income households	Electricity charges
	Boiler manufacturer obligation	No		
	Gas boiler phase-outs	Yes	Applies by default	n/a
Increase energy efficiency	Grants for wall insulation	Yes	Low efficiency homes	Gas charges
	Home efficiency standards	Yes	Applies by default	n/a
Incentivise uptake of electric vehicles	Grants for EVs	Yes	No targeting	Road pricing
	Phase out petrol / diesel cars	Yes	Applies by default	n/a

Example output



1 Net Zero Distributional Model

1.1 Purpose of this work

A major transformation of residential buildings and surface transport is required to meet the Sixth Carbon Budget and to ensure that the UK is on track to meet Net Zero. This transformation will significantly affect household energy and transport costs. For example, there is likely to be an increase in costs from the required investment in energy efficiency of buildings and low-carbon heating, but in other areas, such as the shift in transport to EVs, large savings are available for households[1].

The CCC has identified that a key challenge in meeting Net Zero will be ensuring a fair and efficient distribution of these costs and benefits of the transition and that further research on this issue is required. In addition, the CCC has also identified scope to increase the efficiency of the energy transition by removing distortions that are in place under the current system (e.g. higher policy on electricity costs compared to gas, despite the potential to decarbonise through electrification).

We have been commissioned by the CCC to develop a model that can estimate the impact on households and the Exchequer of different policies to incentivise and fund the energy transition in the residential buildings and surface transport sectors. Our work will feed into the CCC's wider research on the relative merits of different decarbonisation delivery mechanisms and into its contribution to the debate on how these measures should be funded.

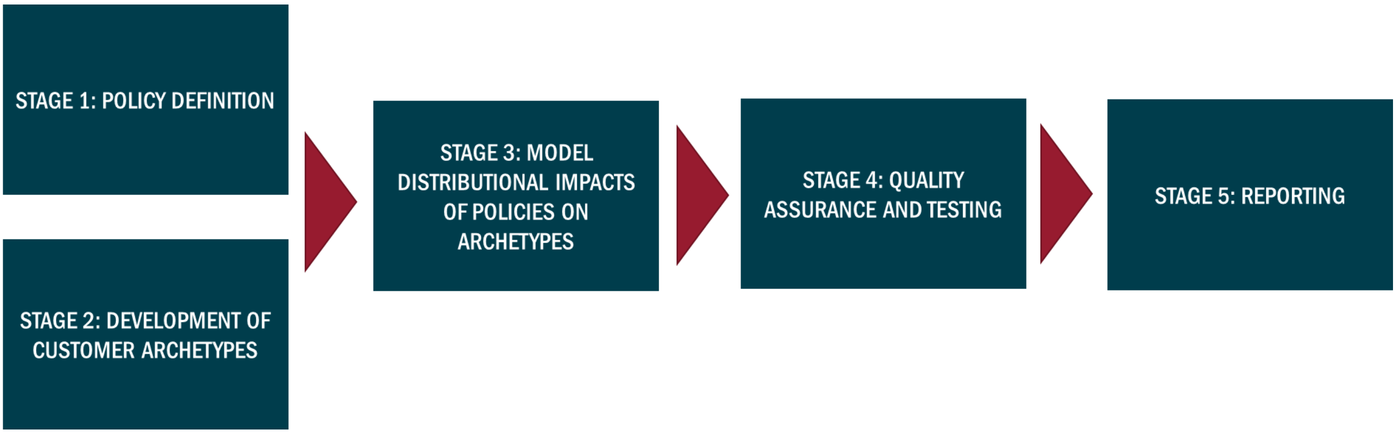
The key aim of this project has been to develop, populate and test an Excel-based model, the 'Net Zero Distributional Model' that facilitates the testing of the impact of different policy combinations on different household archetypes and on the Exchequer. The aim of the model is to enable users from the policy community and beyond to explore questions around the distributional impacts of Net Zero policies.

1.2 Overview of project stages

We have undertaken this work in five stages, as shown in Figure 1. We provide an overview of each stage below.

[1] CCC (2020), The Sixth Carbon Budget- the UK's path to Net Zero, https://www.theccc.org.uk/publication/sixth-carbon-budget/

Figure 1 Overview of project stages



1.2.1 Stage 1: Policy definition

We first defined a set of 24 policies that have the potential to support decarbonisation of the residential buildings and transport sectors, as well as a set of potential funding mechanisms. We describe the process for defining this list of policies in Section 3.

1.2.2 Stage 2: Development of customer archetypes

We have built on Ofgem's household archetypes[2] to develop a set of archetypes that differentiate according to household building energy and transport usage, and for which we estimate the impact of different distributional policies. The 15 archetypes we have developed represent district groups in the UK population that differ by key drivers of energy and transport costs. These archetypes were developed in two steps:

- **Archetype clusters:** We carried out a clustering analysis in STATA to develop a set of 15 archetype 'clusters'.
- **Representative archetypes:** We then applied a set of systematic rules to allocate characteristics to the 'representative household' in each cluster. For example, clusters with the highest proportion of households off the gas grid are allocated as 'off-gas grid' until the total number of households off the gas grid across the clusters, is in line with the UK-wide figure. This allowed us to develop a set of representative archetypes in an Excel-based model. Throughout this report, we use the term 'archetypes model' to refer to this model. The process for developing archetypes is set out in Section 4.

The representative archetypes are then entered into the NZDM in the next step.

1.2.3 Stage 3: Model distributional impacts of policies on representative archetypes

The main output of this project is an Excel-based model that can be used to assess the distribution of costs to household archetypes (as defined in stage 2) under different low-carbon heat and transport policies (as

[2] CSE (2020), *Ofgem energy consumer archetypes*, https://www.ofgem.gov.uk/sites/default/files/docs/2020/05/ofgem_energy_consumer_archetypes_-_final_report_0.pdf

defined in stage one) for reaching Net Zero. Throughout this report, we use the term 'Net Zero Distributional Model' ('NZDM') to refer to this model. We summarise our model methodology in Section 5.

1.2.4 Stage 4: Quality assurance and testing

We have followed our quality assurance processes to ensure that the model is robust and accurate, including user testing by Frontier staff and the CCC. This process included:

- Before any model was developed, we assessed the potential risks and develop a register of tests that will need to be carried out before the model can be considered final. These tests cover checking the input assumptions, validation of the model (i.e., whether what we are modelling is sufficiently representative of the real world) and verification of the model (i.e., whether this has been implemented correctly). Before signing off the model, all tests specified in the QM register were carried out;

- We have carried out sensitivity testing where key inputs are adjusted up and down to verify that the model reacts in the expected way;

- We have sense-checked outputs to other external sources, where these are available;

- We have used specialist auditing software[3] to ensure the spreadsheet is consistent and facilitate a detailed formula-by-formula audit;

- The model methodology has been reviewed by a subject matter expert, and user experience testing has been carried out by a user unfamiliar with the model;

- All quality assurance checks have been carried out by a team member not directly involved in producing the analysis; and

- Assumptions have been recorded in a log as they are introduced to the model, following the BEIS guidance.[4]

1.2.5 Stage 5: Reporting

The final stage of the project involved the preparation of the model report, including a step-by-step model user guide.

1.3 Structure of this report

The rest of this document is structured in the following way:

- In Section 2, we summarise the scope and aims of the project.

[3] In line with Frontier's standard QA practice, we have used the 'Rainbow Analyst' auditing software in Excel.

[4] BEIS (2016), *BEIS Quality Assurance (QA) modelling: Assumptions log template*, https://www.gov.uk/government/publications/assumptions-log-template

- In Section 3, we describe our approach to modelling policies.
- In Section 4, we describe our approach to modelling archetypes.
- In Section 5, we describe our model methodology.
- In Section 6 we set out potential areas of future work.

Further Annexes below also provide more detail on the assumptions and background analysis. A detailed assumptions log can be found within the NZDM and a detailed model user guide can also be found in the supplementary document titled 'NZDM User Guide'.

2 Scope and aims of this project

In this section, we summarise the scope of this work and the methodology we have followed.

The overall aim of the project is to develop the NZDM to allows users to assess the impact on households and the Exchequer of different policy packages for low-carbon residential buildings and surface transport.

2.1 Scope and key assumptions

To balance the validity and accuracy of the model while ensuring that model is transparent and tractable, we have focussed the scope of our work as follows.

- **Uptake and use of low-carbon technologies**. The model is based around a set of fixed (or exogenous) uptake and use scenarios, based on CCC Sixth Carbon Budget analysis. This means that adjusting policies will not change the level of emissions reductions and the technology mix in the NZDM. Instead, it will change how the costs of a given uptake and use scenario are distributed across households and the Exchequer. The purpose of this model is to understand the distributional impact of different policy instruments (or combinations of instruments) on household costs, for a given set of assumptions relating to the uptake and use of technologies. The project does not aim to model how policies may change the uptake and use of low-carbon technologies by households; it looks only at how the financial costs and benefits of the policies will be distributed under alternative policy instruments.

  Throughout this document, we use 'policy instruments' to refer to interventions that change the distribution of the financial costs and benefits associated with a given uptake and use scenario. We also use the term 'low-carbon technologies' to refer to heating technologies such as heat pump and transport technologies such as electric vehicles as well as retrofit options such as insulation.

- **Policy effectiveness**. This project does not assess the potential effectiveness of policies. We assume that any policy instrument (or combinations of instruments) can be associated with the exogenous uptake and use scenarios. Model users will therefore need to exercise some judgement to assess whether the selected policy (or combinations of policies), and the associated values of those policies, could deliver the uptake scenario. Where policy instruments that redistribute costs and benefits are not selected by the user, the model distributes the costs and benefits of the uptake and use of low-carbon technologies according to the 'user pays' principle, i.e. assuming the user of the technology pays or benefits from it. For example, if no low-carbon heating policy is selected, archetypes that take up heat pumps will cover the full upfront and ongoing costs of those heat pumps.

- **Snapshot years**. The NZDM focuses in on snapshot years, starting in 2021, 2025, and then at five yearly intervals out to 2050. Household costs and benefits are presented for these snapshot years. The user can also consider the average across all snapshot years.

- **Annualised costs**. Lump sum costs and benefits to households (e.g. technology costs or grants) are annualised (i.e. converted to an annual equivalent figure, taking into account the household discount rate)[5], and technology lifetimes (for technology costs) and length of time between snapshot years (for grants). This ensures that lump sum figures do not bias costs or benefits in a specific snapshot year and is in line with a situation where households can smooth expenditure over time (e.g. via financing options).

- **Costs and benefits relative to a baseline**. All household costs and benefits are estimated relative to the CCC's 'baseline' scenario. The CCC's baseline scenario reflects one in which there is no further policy action to incentivise decarbonisation beyond today. It is included as a reference only: the baseline is not in line with the UK's international or domestic commitments on climate change mitigation. It takes into account currently funded low-carbon policies (for example, existing policy costs captured in electricity retail prices), but does not take into account unfunded policies or proposals, or significant uptake of low-carbon technologies from today.[6] These estimates encompass cost and benefits associated with capital investments (e.g. in heating technologies, vehicles) as well as associated operating and fuel costs. However, the costs of climate inaction (for example, associated with increased extreme weather events) are not included in the baseline costs in the NZDM.

- **Absolute costs**. Alongside the estimates of costs and benefits costs relative to a baseline, the model also estimates total fuel costs across buildings and transport for each household archetype. These total fuel costs exclude the capital costs of technologies and are expressed in absolute terms, rather than relative to the baseline scenario. This output allows the user to understand what energy bills (including energy for transport) may look like for different household archetypes under different policy instruments.

- **Representative households**. The model calculates the impact of selected policy instruments on the household costs of a set of 15 representative archetypal households with particular characteristics and uptake. Each archetype represents a distinct group of households in the UK population, differentiated by key drivers in energy and transport costs, such as housing type, and mileage, and demographic characteristics, such as income. We do not estimate the cost and benefits for 'average' households for each archetype, as this would limit the distributional analysis by reducing the diversity between archetypes[7]. The focus on representative rather than average households means that multiplying up the costs for each archetype by the number of households in each group will not allow total UK-wide household costs to be estimated.

- **Empty archetype**. In addition to the 15 representative archetypes we developed, the model also includes a 16th 'empty' archetype. Users can adjust the demographic, buildings and transport characteristics of this archetype and assess the resulting change in household costs[8]. Users are also able to test alternative assumptions regarding the timing and type of low-carbon technologies taken up

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[5] The discount rate is set to 3.5% in the model as a default, in line with Green Book values. However, this can be adjusted by the user. HMT (2022), Green Book, https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

[6] See, e.g. page 20 https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-Methodology-Report.pdf

[7] For example, taking mean or median income from each for each of the 15 groups, would not adequately reflect the distribution of income in the population at large, as diversity within each of the groups would be masked. See Section 4 for more detailed discussion of this.

[8] For example, users can adjust: i) Household characteristics (net income, tenure, housing type, housing size, starting EPC rating, rurality, house value); ii) Building characteristics (heating technology, heating requirements, non-heating requirements); and iii) Transport characteristics (number of cars, car fuel type, mileage).

by the archetype.[9] When adjusting these inputs, it is important that the user inputs reasonable values. For example, users should ensure that entries are internally consistent[10] and we would advise that users take care not to enter very extreme and/or unrealistic inputs.

- **Funding of policies**. The model links each direct policy instrument (e.g. grants) to a funding or spending mechanism (e.g. energy charges). Funding can be either revenue neutral (where the costs and benefits of policy instruments are redistributed to households), or an option can be chosen which allows the user to specify that additional costs and benefits are borne by sectors other than households (i.e. the policies are not revenue neutral). Where the latter option is selected, the user can see the net impact on Exchequer costs and benefits. There are three types of broad funding mechanisms:

  - **Exchequer funding**. All policies include an option for policy costs / revenues to be borne by households via changes in general taxation[11]. This means that the costs of these policies are redistributed in the model, with the amount allocated to each archetype varying according to the income level of each archetype.

  - **Funding through energy charges or road pricing**. For policy instruments in the residential buildings sector, users can choose for policy costs / revenues to be funded through changes in energy charges (i.e. gas or electricity charges). For policy instruments in the surface transport section, users can choose for policy costs / revenues to be funded via changes in road pricing (on all users or targeted in urban areas only).

  - **Funding from outside the household sector**. It is also possible for the user to assume that the policy packages as a whole are not revenue neutral. If this option is selected, users can observe the size of the funding gap that would need to be sourced from other sectors (or surplus that could be directed towards other sectors) if the selected policies were not funded through mechanisms in the buildings and transport sectors.

    Users' ability to select and apply both transport and buildings policies simultaneously also allows for some cross-sector subsidisation of polices across the buildings and transport sectors. For example, users could select a transport policy that provides grants to low-income households by increasing general taxation, as well as a road pricing charge that raises revenue which is spent on reducing taxation.

- **Cost pass-through**. The NZDM assumes full pass-through of costs as a default. This implies that energy charges or levies on suppliers will be passed through to energy users; regulations or mandates that are targeted to landlords or property developers will be passed on to households in higher prices or rents; and tradable obligations on Original Equipment Manufacturers (OEMs) will be passed through to boiler prices. However, the model allows users to test the impact of alternative assumptions on the proportion of costs passed through to consumers.

[9] For example, users can adjust uptake assumptions by selecting the year in which archetypes switch heating technology (e.g. to a heat pump, district heat or electric heating), switch car type (to an EV/PHEV) or take-up insulation (e.g. roof / floor/ wall / other insulation).

[10] For example, users should ensure that the level of electricity and gas consumption is consistent with the heating technology of the archetype.

[11] See section 5.4 below for a description of this process.

- **Replacement capital costs.** For the purposes of model tractability, we make the simplifying assumption that archetypes who replace their existing technology (e.g. petrol car or gas boiler) incur the same cost as when the archetype first took up that technology. This means that archetypes do not benefit from reductions in capital costs of technologies, unless they switch to a new technology (e.g. a new low-carbon technology).[12] This assumption means that the model may not perform well if extreme assumptions about the profile of technology costs over time are entered (e.g. material declines in technology costs over time). Users can counteract this assumption by entering an average technology cost value across snapshot years and further extensions to the model could allow the replacement capital costs to be updated at the end of the asset's lifetime.

- **Non-financial impacts**. The NZDM includes information on total GHG emissions associated with the CCC's Sixth Carbon Budget uptake scenarios and obtained directly from the CCC Sixth Carbon Budget. The model also includes a qualitative assessment of the air quality impacts associated with different kinds of policies, based on the CCC Sixth Carbon Budget. The model does not consider any other health or wellbeing benefits or costs associated with the uptake and use of low-carbon technologies, although as highlighted by the CCC, these are likely to be significant and could exceed estimated costs[13]. The model also does not include any broader impacts, such as potential changes in the values of properties that could result from policy instruments in the building sector, or changes to congestion.

[12] This also means that archetypes who replace their low-carbon technology during the modelling period are assumed to incur the installation costs that they first incurred when they switched to the low-carbon technology.

[13] CCC (2019), *Net Zero – The UK's contribution to stopping global warming*, https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

3 Approach to modelling policy instruments

This section describes our approach to choosing, specifying, and modelling policy instruments. We set out our approach in three steps:

- **Identifying a long list of policy instruments.** We first identify a list of potential Net Zero policy instruments in the household buildings and transport sectors.
- **Specifying the list of policy 'structures' to be modelled.** We then describe each policy on the long list in terms of its fundamental characteristics (e.g. grant, charge or obligation), and group the policies into different 'structures' (i.e. a direct policy instrument with a set of features, an ability to target, and an associated funding / spending mechanism). This allows us to specify the list of distinct policies to model.
- **Specifying policy parameters.** We then populate the model with default policy parameters that can be changed by the user (e.g. the level of a grant in £ per household or the road pricing charge in £ per km).

We discuss each step in more detail in turn below.

3.1 Identifying the 'long list' of distributional policy instruments

The first step in developing our policy approach was to generate a long list of distributional policies to consider as part of this work, based on published policy proposals from BEIS and the CCC, and discussions with stakeholders (see Annex D). This long list covers a range of different policy aims (e.g. incentivising switching to heat pumps, incentivising uptake of electric vehicles) and policy types (e.g. grants, taxation, energy charges or levies, regulations or mandates and tradable obligations). The long list of policies is presented in Annex A.

3.2 Specifying policy 'structures' to be modelled

Using the long list of policies identified in the previous task, we specified a set of policy 'structures' to be modelled. Each of the policies on the long list can fall into these structures. Each policy structure consists of:

- A direct policy instrument (e.g. grants or fuel duty);
- A mechanism for funding the policy costs (or distributing the policy revenues raised) (e.g. energy charges); and
- Targeting options (e.g. low-income households targeting), where applicable.

In specifying the policy instrument targeting options, we have used the following definitions:

- **For policy instruments targeted at low-income households**: Low-income households are defined as households whose annual net household income is below the UK median household income for the snapshot year. Users are also able to adjust the income threshold.
- **For policy instruments targeted at 'high efficiency' homes**: We define a home to be 'high efficiency' if its EPC rating is EPC C or above in 2021. For all years following 2021, a home can also become classified as 'high efficiency' if the archetype has taken up cavity wall insulation, solid wall insulation or floor insulation in the previous year.

The policy structures were stress-tested with the CCC and external stakeholders to ensure that all important options were included. Table 1 below sets out the policy structures included in the model.

We note that regulations (e.g. on home energy efficiency) and mandating (e.g. on boiler phase outs) may be employed by Government on a path to Net Zero. These types of policy instruments allocate any associated costs directly to the household affected by the policy. Given the starting point of the NZDM is to allocate costs on a 'user pays' basis, these types of policies are not modelled as options in the NZDM. Instead they represent the default situation. That is, if the model user wanted to understand the impact of mandates and regulations on households' costs, they could simply run the model, without selecting any additional policies in each subsector, The resulting outputs would represent a 'user pays' situation for households, and therefore would be in line with a scenario where changes were delivered via mandating or regulation.

Table 1 List of policy structures

DIRECT POLICY INSTRUMENT	TARGETING OPTIONS	FUNDING / SPENDING MECHANISM
Grants		
Upfront grants for heat pumps[14] *(£ / household)*	• Low-income households • Off-gas grid households • Low-income households off the gas grid	• Exchequer funding (by households or other sectors) • Gas charges • Electricity charges
Upfront grants for insulation[15] *(£ / household)*	• Households with poor energy efficiency • Low-income households with poor energy efficiency • Social renters with poor energy efficiency • Private renters with poor energy efficiency • Owner-occupiers with poor energy efficiency	• Exchequer funding (by households or other sectors) • Gas charges • Electricity charges

[14] We model separate grants for three types of heat pumps: i) hybrid heat pumps; ii) air source heat pumps; and iii) ground source heat pumps.

[15] We model separate grants for five types of insulation: i) floor insulation; ii) roof insulation; iii) solid wall insulation; iv) cavity wall insulation; and v) other insulation (i.e. draught proofing and hot water tank insulation).

DIRECT POLICY INSTRUMENT	TARGETING OPTIONS	FUNDING / SPENDING MECHANISM
Upfront grants for electric vehicles / plug-in hybrids *(£ / car)*	• No targeting • Low-income households	• Exchequer funding (by households or other sectors) • Road pricing (untargeted / urban areas only)
Upfront grants for district heat (£ / HH)	• No targeting • Low-income households	• Exchequer funding (by households or other sectors) • Gas charges • Electricity charges
Taxation		
Taxes on heating gas / oil *(£ / kWh)*	• No targeting	• Exchequer funding (by households or other sectors) • Electricity charges
Fuel Duty on petrol / diesel *(£ / litre)*	• No targeting	• Exchequer funding (by households or other sectors) • Road pricing (untargeted / urban areas only)
Stamp duty discount *(% discount on house value)*	• Based on home being 'high efficiency'	• Exchequer funding (by households or other sectors) • Gas charges • Electricity charges
Council tax discount *(£ per household)*	• Based on home being 'high efficiency'	• Exchequer funding (by households or other sectors) • Gas charges • Electricity charges
Obligations		
Renewable Transport Fuel Obligation (RTFO) *(£ / litre)*	• No targeting	• Cost borne by users of petrol / diesel
Boiler obligation *(% change in capital costs)*	• No targeting	• Cost borne by gas boiler purchasers
Energy charges and levies		
Reduction in electricity costs by shifting policy costs *(£/kWh)*	• No targeting	• Exchequer funding (by households or other sectors) • Gas charges
Low emissions vehicle zones *(£ / ICE car / day in an urban area)*	• Only applies to urban areas	• Exchequer funding (by households or other sectors)

DIRECT POLICY INSTRUMENT	TARGETING OPTIONS	FUNDING / SPENDING MECHANISM
		• Road pricing (untargeted / urban areas only)
Increase in vehicle excise duty (VED) *(£ / ICE car / year)*	• No targeting	• Exchequer funding (by households or other sectors) • Road pricing (untargeted / urban areas only)
Road pricing *(£ / km or £/km in urban area)*	• No targeting • Urban areas only	• Exchequer funding (by households or other sectors)
Investment in decarbonisation of public transport (rail / bus) *(£ / year)*	• No targeting	• Exchequer funding by households
Investment in cycling / walking infrastructure *(£ / year)*	• No targeting	• Exchequer funding by households
Investment in electric vehicle charging infrastructure *(£ / year)*	• No targeting	• Exchequer funding by households
Regulations and mandates		
Phase-outs of fossil fuel boilers	• Not modelled explicitly as it is reflected within the CCC's uptake scenario.	
Home energy efficiency standards		
Mandating district heat in specific areas		
Phase-outs of petrol / diesel cars		
End diesel public transport (rail / bus)		

3.3 Specifying incremental policy parameters

The next step is to populate the policy 'structures' in the model with default policy parameters that can be changed by the user. This includes specifying the monetary values associated with policy instruments (e.g. level of grants in £ per household or road pricing charge in £ per km), informed by existing government policies, discussions with the CCC and other published research.

As explained in section 2.1, all household costs are estimated relative to the CCC's baseline scenario. This means that all policy parameters are specified as incremental to this baseline. For example:

- We do not calculate absolute costs for metrics such as grants and general taxation (e.g. how much tax an archetype pays in the baseline). Instead, the change in household costs reflects the additional grants or taxation of the archetype in the scenario, relative to the baseline.

- We do calculate absolute energy costs (i.e. the total fuel costs across buildings and transport for each archetype). Since the retail energy price projections in the baseline will already account for the effect of existing policy costs such as Renewable Transport Fuel Obligation (RTFO) and Fuel Duty, we model changes to these policies in the NZDM, in the following way:
  - **Renewable Transport Fuel Obligation (RTFO):** We model a doubling of the pence per litre impact based on a Department for Transport forecast for the current design of this policy.[16] This involves adding c. 1p to a litre of petrol and diesel.
  - **Fuel duty on petrol / diesel:** The current level of fuel duty is 52.95p per litre (inclusive of the temporary 5p discount)[17].

[16] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/644843/renewable-transport-fuel-obligations-order-government-response-to-consultations-on-amendments.pdf, page 30 of Annex A.

[17] https://www.gov.uk/government/publications/changes-to-fuel-duty-rates/fuel-duty-rates-2022-23

4 Approach to modelling archetypes

We developed household archetypes to ensure that distributional consequences of different policies can be fully captured in the model.

The archetypes are households that represent distinct groups or 'clusters' of households in the UK population. These clusters vary according to physical household characteristics (e.g., heat usage, or car ownership) and economic household characteristics (e.g., income or house value). Each archetype is associated with a number of UK households, that fall into the cluster that it represents. The clusters when taken together, broadly represent the population of the UK.

Using these archetypes in the model, instead of basing the model on average or total households, allows users to explore the distributional consequences of different policy options, and to target policies to households with certain economic or physical characteristics. It also allows users to identify household characteristics that make them more likely to face higher costs or benefits from particular policies or policy packages.

However, archetypes do not represent the full extent of diversity within the UK population. The approach of clustering customers according to key characteristics necessarily means that not every combination of household characteristics that exists in the underlying population will be included.[18] In addition, the need to cluster based on a wide range of characteristics means that the specific characteristics attributed to a given archetype do not apply to all customers uniformly within each archetype's cluster[19].

It is also important to recognise that there is an element of judgement in the development of the archetypes, particularly in two key areas:

- the choice of household characteristics to include and exclude when developing clusters[20]; and
- the approach to choosing the representative characteristics from clusters for each archetype (for example, where mean or median characteristics are not possible to select[21], where characteristics are descriptive or binary (e.g. housing types, whether a household is on or off the gas grid, or whether a household has a diesel or petrol car).

To ensure that the approach is as robust as possible, we have taken a transparent and systematic approach based on statistical clustering analysis, supplemented by allocation rules. We have provided the CCC with an Excel-based model that allows changes to be made to key assumptions and allocation rules. We also

[18] As explained in Section 2.1, we do include an 'empty archetype' in the model, so that the user can consider the impact on policies on households with alternative combinations of characteristics.

[19] An explanation of how representative characteristics are chosen for each archetype is given in Section 4.5.

[20] The development of the long list of characteristics and the shortlisting process were informed not just by data analysis, but also by stakeholder engagement and expert input. This process is set out in Section 4.1 below.

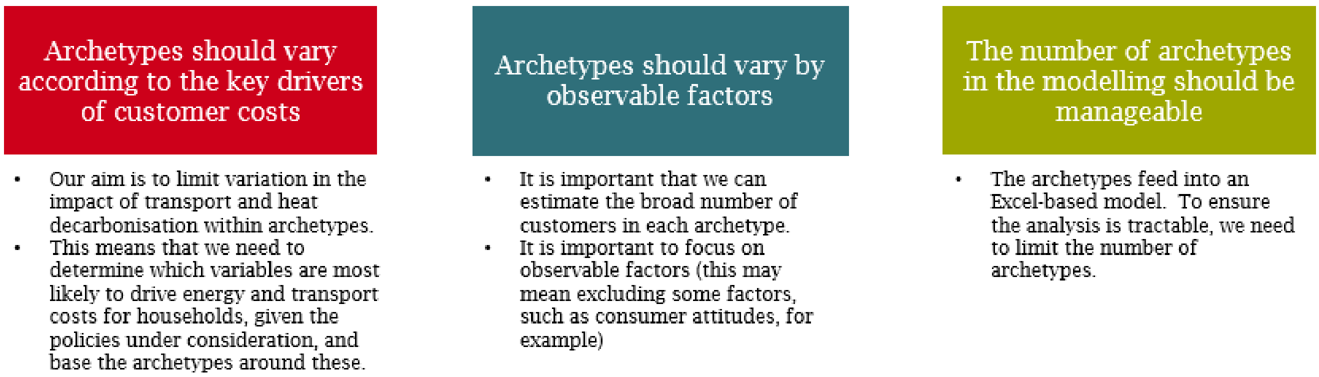
[21] For example, it is not possible to "select" a mean or median house type, since this variable is descriptive, rather than numerical.

presented our approach to stakeholders for discussion and challenge (further details of our stakeholder engagement are presented in Annex D).

4.1 Process for archetype development

Our development of archetypes was guided by the following principles (Figure 2).

Figure 2 Principles for development of archetypes



Given these principles, our approach to developing archetypes is structured around the four main steps set out in Figure 3 below (which we discuss in more detail in the sections that follow). These four steps result in the starting characteristics for our archetypes, which then feed into the NZDM. The model then contains analysis to project how these archetypes could change out to 2050. A description of the methodology for these projections is covered in Section 5.

Figure 3 Process for developing archetypes

4.2 Developing a long list of archetypes

The aim of producing archetypes is to allow analysis of the distributional outcomes of heat and transport decarbonisation policies. We therefore want to build archetypes around the key characteristics that would drive differences in the costs and benefits to households of different policies.

As a starting point, we used the characteristics underlying the 13 archetypes identified by Ofgem based on the Centre for Sustainable Energy (CSE)'s 2020 report[22]. This analysis already includes a number of relevant variables for estimating policy impacts on consumer bills such as household size, energy type, engagement with the energy market. We built on Ofgem's list of characteristics in two ways.

- We supplemented the list of Ofgem's characteristics to include additional characteristics related to household heating and transport usage (e.g., including measures of public transport use).
- We excluded some of the characteristics that were included in Ofgem's archetypes from our long list since they are less relevant for the purpose of this project. This includes characteristics related to internet access and smart phone use.[23]

Figure 4 below summarises the long list of characteristics we considered in this project.

Figure 4 Long list of characteristics

Demographic characteristics	Housing characteristics	Transport characteristics
Income	Tenure	Car ownership
Economic status of household reference person	Building type	Car usage
Age of household reference person	Building energy efficiency	Car type / size
Number of children	Type of heating technology (e.g. boiler / heat pump)	Accessibility
Rurality	District heat connection	Public transport milage / no. trips
Number of inhabitants	Housing value	Public transport potential travel time
Number of dependents	Gas usage	Public transport expenditure
Deprivation	Electricity usage	Walking and cycling milage
Population density	Heating appliance efficiency	Access to EV charging

Legend: Characteristics considered by both Ofgem and Frontier (grey) | Additional characteristics considered by Frontier (teal)

[22] CSE (2020), *Ofgem energy consumer archetypes*, https://www.ofgem.gov.uk/sites/default/files/docs/2020/05/ofgem_energy_consumer_archetypes_-_final_report_0.pdf

[23] The long list does not include the following variables that are included in Ofgem's archetypes: Internet in the home, use smart phones to access the internet, any engagement with energy market in the last 12 months, have a degree qualification (or higher), long term health conditions that affect daily activities a lot, households on disability benefits, households in poverty, been in arrears on electricity or gas.

4.3 Shortlisting characteristics

We refined the long list of potential archetype characteristics to a shortlist of variables to include in the clustering in three steps (Figure 5).

Figure 5 Process for shortlisting archetype characteristics

We summarise each step and the results below. I

4.3.1 Qualitative assessment.

As a first step, we carried out a qualitative assessment of the importance of each characteristic in driving differences between household archetypes. This step draws on input from Frontier experts in the transport and buildings sectors and from the CCC and from wider stakeholders.[24] Using these inputs, we allocate a binary allocation (ticks or crosses) to each characteristic, reflecting the importance of reflecting the characteristic in the clustering analysis. Further detail on our qualitative assessment can be found in Annex B.

4.3.2 Data assessment.

We then assessed the availability and robustness of data for characteristics that have passed the qualitative assessment.

The data required for the characteristics in the long list is incomplete at the geographic level required (LSOA level). As a result, we have adopted two methods to supplement the available data. These are discussed below in ranked order of preference.

1. **The use of historic data**. We are using 2018 to 2020 data for the analysis, where available. Where 2020 data is not available, historic data, such as 2011 census data, is updated using projections

[24] See Annex D for a description of our stakeholder engagement.

created from higher level geographic data. Where 2020 is likely to have been affected by the COVID pandemic (e.g. mileage and house prices) we also use 2019 data instead.

2. **Proxy variables**. Where historic data or projections are not available, we use proxies. For example, location-specific data is not available for the heating technology that households have. In this case we instead use a proxy variable based on whether households in that LSOA are on or off the gas grid. While this is imperfect (it would not pick up variations in off gas grid technologies, such as electrification, oil, or LPG), it is the best publicly available data at the level of granularity that we require.

We use the following ratings:

- **Green rating**: Where LSOA data is available, we have rated the characteristic as green. This indicates that robust data is available, that is specific to the characteristic, and at the targeted level of granularity. Green therefore allows a high level of confidence to be attributed to the data.
- **Amber rating:** Where we have had to supplement the data with historical data or proxies or where recent data is not available, we have rated the characteristic as amber. Where data is rated amber, we have a lower level of confidence in the data, because of these required adjustments.
- **Red rating:** Where no data was available, we have rated the characteristic as red.

Further detail on our data assessment can be found in Annex B.

4.3.3 Correlation analysis

We then undertook analysis to understand correlations between each of the long-listed characteristics. This is to ensure that variables that are closely correlated (and therefore may be capturing the same drivers of energy and transport costs) can be excluded. Excluding these variables can help avoid inadvertently biasing the results by over-weighting certain factors through including more than one measurement variable.

The results of the correlation analysis are presented in Annex B. This finds that there are strong correlations between the following variables:

- share of commuting in cars and share of commuting by transit;
- total index of multiple deprivation score and sub-score of the IMD index related to income deprivation;
- share of households with the household reference person unemployed and the income sub-score in the index of multiple deprivation.

To avoid weighting these factors too highly in the clustering analysis, only one out of each correlated variable is taken through to the next stages of the analysis. Specifically, we retain the share of commuting in cars, the total index of multiple deprivation score and the share of households with the household reference person unemployed.

The results from this shortlisting process are shown in Figure 6 below.

Figure 6 Shortlisted variables

Characteristic	Measure	Unit	Qualitative check (pass = Y)	Data availability / robustness (RAG)	Correlation check (pass = Y)	Variables used in clustering
Income	Gross annual income	£	Y	Amber	Y	Y
Employment status of HRP	Share of households with HRP unemployed	%	Y	Amber	Y	Y
Age of HRP	Share of households with HRP under 35	%	Y	Amber	Y	Y
Age of HRP	Share of households with HRP over 65	%	Y	Amber	Y	Y
Number of dependant children	Share of population under 16	%	N	Green	N	N
Number of inhabitants			N	Amber	n/a	N
Number of dependents			N	Red	n/a	N
Deprivation	Index of multiple deprivation	Higher = more deprived	Y	Green	Y	Y
	Income sub-score of multiple deprivation		Y	Green	N*	N
Population density	Population density		Y	Green	Y	Y
Rurality	LSOA RUC score	1- 6; higher= rural	Y	Green	Y	Y
Tenure	Share of flats amongst dwellings	%	Y	Green	Y	Y
	Share of privately rented dwellings	%	Y	Green	Y	Y
	Share of publicly rented dwellings	%	Y	Green	Y	Y
Building type	Share of houses that are detached etc	%	N	Green	n/a	N
	Floor area	m2	N	Green	n/a	N
Building energy efficiency	Share of households with EPC E/F/G	%	Y	Green	Y	Y
	Share of households with EPC A / B	%	Y	Green	Y	Y
Type of heating technology	Share of households on gas grid	%	Y	Amber	Y	Y
District heat connection		n/a	N	Red	n/a	N
Housing value	House value	£	Y	Green	Y	Y
Gas usage	Gas consumption	kWh	Y	Green	Y	Y
Electricity usage	Electricity consumption	kWh	Y	Green	Y	Y
Heating appliance efficiency			Y	Red	n/a	N
Car ownership	Number of cars	Number	N	Green	Y	N
	Average number of cars per person	cars / person	Y	Green	Y	Y
Car usage	Share of people who commute by car	%	Y	Amber	Y	Y
Car type / size	Share of diesel cars	%	N	Green	n/a	N
	Share of hybrid cars	%	N	Green	n/a	N
	Share of petrol cars	%	N	Green	n/a	N
Accessibility	Captured through IMD index		Y	Amber	Y	Y
Public transport mileage / no. trips	Share of people that commute by transit	%	Y	Amber	N*	N
	Share of people that commute in other ways	%	Y	Amber	N**	N
Public transport potential travel time			Y	Red	n/a	N
Public transport expenditure			Y	Red	n/a	N
Walking and cycling milage	Share of people commuting by foot / bike	%	Y	Amber	N**	N
Access to EV charging			Y	Red	n/a	N

*Note: *Indicates variable dropped due to correlations check; ** indicates variable dropped due to multi-collinearity. The UK government defines the RUC score as a classification system used to produce a rural / urban view from government statistics. The score ranges from 1 to 6, where 6 is the most rural / remove and 1 is the most connected / urban*

4.4 Clustering analysis

Using the shortlisted characteristics from the previous step, we then undertook a statistical clustering exercise in Stata using local super output area (LSOA) data.

We considered the use of two types of clustering methodologies on the shortlisted characteristics.

- **k-means or k-median clustering** is generally more appropriate for large data sets, including a majority of non-categorical (i.e. numerical) variables, and in analysis where the number of clusters is predetermined.

- **Hierarchical clustering** is more appropriate for data sets including fewer variable dimensions, a larger share of categorical variables, and where the number of clusters is unknown. The results of hierarchical clustering may result in clusters based on a small number of LSOAs and other clusters based on a large number of LSOAs and a large variation within the cluster. These issues can be difficult to detect using statistical methods.

Given its higher level of reliability for large data sets, we used k-median clustering. We chose k-median rather than k-mean clustering to ensure outlier data did not unduly affect the results.

To undertake the clustering, we set a target of 15 clusters and undertook the analysis in STATA.[25] 15 was agreed with the CCC to be an appropriate number, given the trade-offs between enabling model users to easily interpret the results across archetypes (which would drive the choice of a low number of clusters) and more fully representing the diversity between households (which would drive the choice of a high number of clusters).[26]

An extract of the raw STATA output is shown in Table 2.[27] Users can find the full STATA output in the archetypes model.

Table 2 Extract of STATA clusters

CLUSTER	NUMBER OF LSOAS IN CLUSTER	MEDIAN GAS CONSUMPTION (KWH)	MEDIAN ELECTRICITY CONSUMPTION (KWH)	MEAN SHARE OF HOUSEHOLDS ON THE GAS GRID	MEAN SHARE OF FLATS AMONGST DWELLINGS
1	3,142	10,544	2,572	90%	28%
2	3,327	11,247	2,725	91%	22%
3	2,963	10,566	2,578	71%	48%
4	1,918	10,469	2,318	86%	66%
5	4,621	11,511	2,739	90%	17%

[25] To clean the data before running the k medians clustering analysis, all LSOAs where any of the shortlisted variables were missing were dropped from the analysis

[26] We also included 'elbow graph' cross checks once we had undertaken the clustering analysis for iterations of 1 to 20 clusters. This suggested that 15 was a reasonable number of clusters (i.e. it was not significantly less explanatory than up to 20 clusters).

[27] We note that, after the clustering, we also incorporate three additional variables that may be useful for understanding the archetypes but were not included in the clustering. These were: the number of dependant children, the floor area in dwelling in metres squared and the share of total cars in each LSOA that are petrol / diesel / hybrid cars.

CLUSTER	NUMBER OF LSOAS IN CLUSTER	MEDIAN GAS CONSUMPTION (KWH)	MEDIAN ELECTRICITY CONSUMPTION (KWH)	MEAN SHARE OF HOUSEHOLDS ON THE GAS GRID	MEAN SHARE OF FLATS AMONGST DWELLINGS
6	763	11,983	2,863	88%	27%
7	1,441	14,559	3,131	96%	9%
8	2,921	14,294	2,993	92%	14%
9	4,079	13,270	2,989	92%	10%
10	1,313	14,836	4,171	22%	6%
11	1,874	13,745	3,404	66%	10%
12	3,207	12,033	3,028	90%	15%
13	2,674	9,570	2,370	78%	75%
14	2,710	13,916	3,012	88%	40%
15	2,805	18,234	3,743	91%	12%

4.5 Allocation rules

The output of this step is a set of 15 clusters and associated median characteristics for the households in the cluster. However, additional supplementation was required before these clusters could be entered into the NZDM for the following reasons:

- Some characteristics used in the clustering were descriptive rather than numerical (e.g. share of households on the gas grid). As a result, the clustering output reflects the median share of households on the gas grid for the cluster, rather than a binary indicator of whether a representative household within that cluster is on the gas grid or not (which is required for the NZDM).

- Some characteristics that are important for assessing distributional impacts were not included in the clustering due to lack of data availability at the LSOA-level (e.g. car mileage).

- In some cases, the clustering results did not identify certain household types which were important for the distributional analysis. For example, the median gas consumption values for all clusters reflected households with a gas boiler. Additional supplementation was required to incorporate a representative archetype with alternative heating (e.g. electric heating or oil boilers), which is important for assessing distributional impacts in the NZDM.

We therefore supplemented the results of the clustering analysis with a set of systematic rules for allocating additional characteristics to each cluster. The detailed decision rules for each characteristic are described in the archetypes model. A high-level description of the analysis is as follows.

- **Where the archetype characteristic is binary or descriptive, the characteristic is allocated to clusters in order of its percentage incidence, until the total incidence is in line with actual rates** in the UK population.** For example, the clustering analysis gives the proportion of household off the gas grid in each cluster. Rules are then used to allocate this characteristic to archetypes that contain the highest proportions of off gas grid households, while taking account of the number of households in the overall UK population that should have this characteristic. Specifically, the clusters with the highest percentage of households off gas grid are allocated 'yes' to off the gas grid until the number of households within these archetypes is approximate to the equivalent share of the population off the gas grid according to the BEIS data. The remaining archetypes are then allocated 'no'. This type of analysis is applied for heating fuel, housing type, EPC rating, tenure, rurality, number of cars, car fuel, and access to parking.

- **Where consistency within an archetype requires certain characteristics, we make manual adjustments based on UK-level data.** For example, if an archetype is not on the gas grid, we assume their gas consumption is zero, or if the archetype is allocated an oil boiler, we calculate the total kWh consumption of oil using the annual heat demand for an off-gas grid household and the average heating efficiency of an oil boiler. This type of analysis is also applied for the number of trips in urban areas and car mileage.

- **Where the clustering analysis masks significant diversity with LSOAs, we supplement the results to ensure a wider range of characteristics are included.** The raw clustering results for income included no archetypes with low incomes. This is because the use of LSOA-level data in the clustering analysis does not capture the full range of diversity in incomes within the clusters, since incomes are averaged across LSOAs. To ensure low-income households can be represented in the archetypes, we ranked the clusters according to the Index of Multiple Deprivation[28]. For the three clusters that scored most highly in this index, we reduced income by 56%, which is the difference between the 2nd and the 5th income decile at the national level according to the ONS[29].

It is important to note that this process results in the identification of 'representative' rather than 'average' characteristics for each archetype. The focus on representative rather than average characteristics is required to ensure a broad range of characteristics are represented in the modelling. There are two reasons why we focus on representative, rather than average characteristics.

- For binary or descriptive characteristics, such as car fuel or housing type, a mean or median concept is not meaningful.

- Focussing on averages would reduce the usefulness of the distributional analysis by masking key differences (for example, as illustrated above, no low-income households would be represented in our clusters under a median based approach).

[28] https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019 (England), https://statswales.gov.wales/Catalogue/Community-Safety-and-Social-Inclusion/Welsh-Index-of-Multiple-Deprivation (Wales), and https://www.gov.scot/collections/scottish-index-of-multiple-deprivation-2020/ (Scotland)

[29] https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/datasets/theeffectsoftaxesandbenefitsonhouseholdincomehistoricaldatasets

However, the production of archetypes based on representative rather than average households means that multiplying up the costs for each archetype by the number of households in each group will not allow total UK-wide household costs to be estimated.

4.6 Outputs: Archetype starting characteristics

The outputs of this analysis are a set of starting characteristics that apply to the representative household in each archetype in 2021. An extract of these characteristics is shown in Figure 7 below.

We describe how we take into account changes to the archetypes out to 2050 in Section 5 below.

Figure 7 Selected archetype characteristics

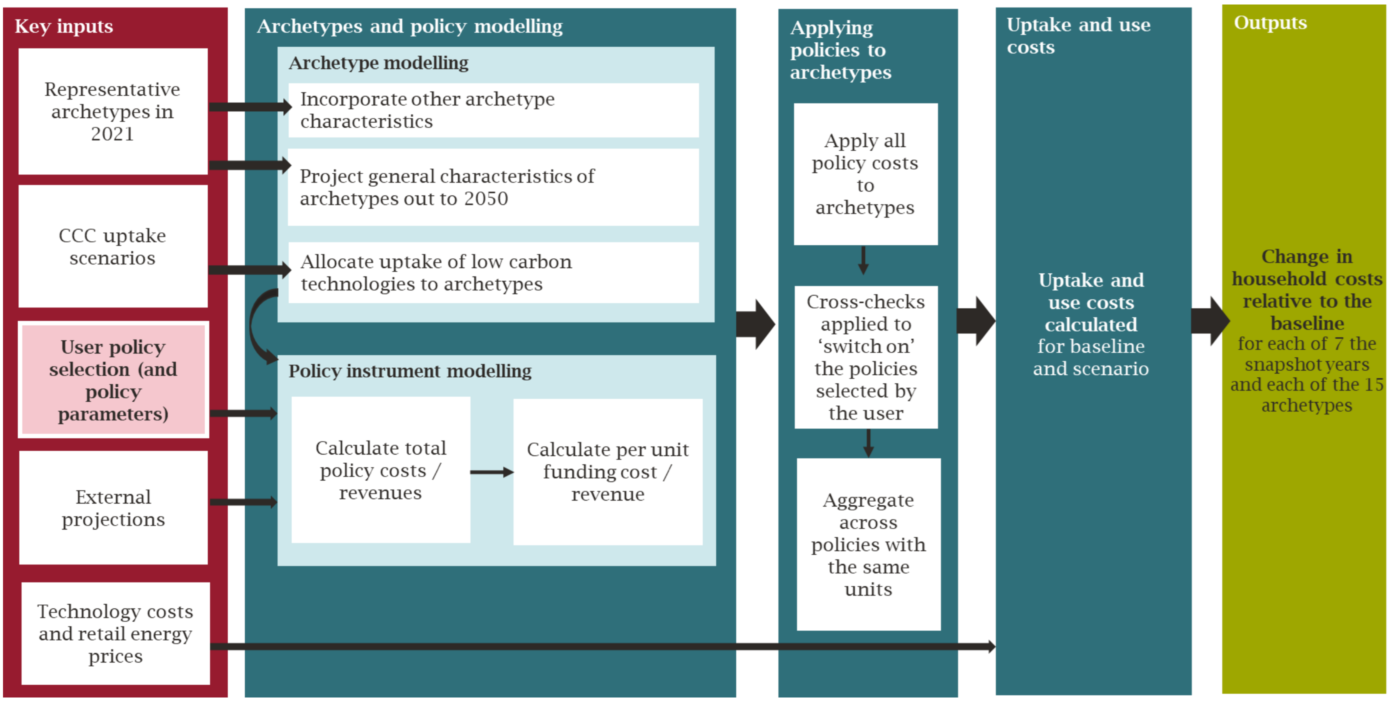
	Income group (based on IMD income proxy)	Description	No. households	Net household annual income	Heating fuel	Gas kWh	EPC rating	Housing type	Tenure	Rurality	Number of cars	Car fuel	Car 1 - mileage	Car 2 - mileage
A1	Low income	Low income, urban, EPC C, no car	2,215,911	12,655	Gas boiler	10,544	C	MidTerrace	Social renter	Urban	0	-	-	-
A2	Low income	Low income, urban, EPC C, high mileage	2,046,371	14,267	Gas boiler	11,247	C	Semi Detached	Social renter	Urban	2	Diesel	12,969	12,969
A3	Low income	Low income, urban, EPC E, no car	2,326,553	14,590	Gas boiler	10,566	E	Flat	Private renter	Urban	0	-	-	-
A4	Low income	Low income, urban, EPC C, medium mileage	676,600	22,193	Gas boiler	10,469	C	MidTerrace	Social renter	Urban	2	Petrol	8,692	8,692
A5	Average income	Average income, urban, EPC D, high mileage	3,117,335	31,559	Gas boiler	11,511	D	MidTerrace	Owner occupier	Urban	2	Diesel	12,969	12,969
A6	Average income	Average income, urban, EPC B, medium mileage	472,605	33,355	Gas boiler	11,983	B	Detached	Social renter	Urban	1	Diesel	12,969	-
A7	Average income	Average income, urban, EPC D, medium mileage	565,726	33,544	Gas boiler	14,559	C	Semi Detached	Owner occupier	Urban	1	Diesel	12,969	-
A8	Average income	Average income, urban, EPC C, high mileage	1,702,103	33,868	Gas boiler	14,294	D	Semi Detached	Owner occupier	Urban	2	Petrol	8,692	8,692
A9	Average to high income	Average to high income, urban, EPC D, low mileage	2,689,403	35,768	Gas boiler	13,270	D	Detached	Owner occupier	Urban	1	Petrol	8,692	-
A10	Average to high income	Average to high income, rural, electric heating, high mileage	860,483	36,952	Electric heating	-	E	Detached	Social renter	Rural	1	Diesel	24,522	-
A11	Average to high income	Average to high income, rural, oil heating, high mileage	1,290,881	37,248	Oil boiler	-	E	Detached	Social renter	Rural	1	Diesel	24,522	-
A12	Average to high income	Average to high income, urban, EPC C, low mileage	2,386,510	40,281	Gas boiler	12,033	C	Semi Detached	Owner occupier	Urban	1	Petrol	8,692	-
A13	Average to high income	Average to high income, urban, EPC C, no car	2,197,987	41,361	Gas boiler	9,570	C	Flat	Private renter	Urban	0	-	-	-
A14	Average to high income	Average to high income, urban, EPC D, medium mileage	2,031,144	44,268	Gas boiler	13,916	D	MidTerrace	Owner occupier	Urban	2	Petrol	8,692	8,692
A15	Average to high income	Average to high income, urban, EPC D, medium mileage	1,806,021	45,264	Gas boiler	18,324	D	Detached	Owner occupier	Urban	1	Petrol	8,692	-

5 Approach to modelling distributional impacts

In this section, we summarise the approach that we have used to model distributional impacts of policy instruments on each archetype's energy and transport costs.

Figure 8 provides an overview of the modelling process. We discuss each step of this process in turn below.

Figure 8 Description of modelling process



5.1 Key Inputs

5.1.1 User policy selection

The user can run the NZDM by selecting different combinations of policy instruments. For each policy instrument the user can select:

- Type of policy instrument (e.g. a grant for heat pumps);
- Targeting of policy instrument (e.g. targeted at low-income households); and
- Funding/spending mechanisms (e.g. funded via general taxation).

The user can also adjust the parameters associated with each policy instrument (e.g. the £ value of the grant, and the years that it applies).

5.1.2 Other inputs

The model results also rely on data relating to the archetypes and to fuel and technology scenarios. These have been populated with default values but can be updated as new evidence emerges.

- **Representative archetypes:** The 15 representative archetypes developed in Section 4 are an input into the NZDM.
- **CCC uptake scenarios:** We have used assumptions on the deployment of low-carbon technologies from the CCC's Sixth Carbon Budget. As explained in Section 2.1, each scenario is associated with different levels of uptake of low-carbon technologies, technology costs, retail prices and behavioural assumptions. As a default, the CCC's Balanced Pathway scenario is selected.
- **User policy selection:** Model users can select different combinations of policy instruments and apply them to different archetypes by selecting the targeting associated with each instrument (e.g. grants targeted at low-income households).
- **External projections (e.g. for policy cost modelling):** We have gathered published data from sources such as the Department for Transport on key metrics for policy cost modelling. For example, this includes projections for the total kilometres travelled by cars in England and Wales per year (which we use to produce forecasts for the whole of the UK).[30]
- **Technology costs and retail energy prices:** We obtained data on technology costs (e.g. upfront capital costs, operating costs, asset lifetimes) from the CCC. We also obtained retail gas, electricity, hydrogen, and district heat prices from the CCC, and petrol, oil, and diesel prices from the government Green Book guidance[31].

Table 3 lists the inputs that are flexible for the users to select or change in the model.

Table 3 Adjustable user inputs

ADJUSTABLE INPUT	EXAMPLE (S)
Policy instrument selection	
Policy instrument	• Grants for energy efficiency retrofits • Road pricing
Targeting of policy instrument	• Low-income households only • Urban areas only

[30] https://www.gov.uk/government/publications/road-traffic-forecasts-2018

[31] BEIS (2021) *Green Book Supplementary Guidance*, https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

ADJUSTABLE INPUT	EXAMPLE (S)
Funding / spending mechanism	• Costs funded by the exchequer through an increase in general taxation on households
Scenario and technology assumptions	
Policy parameters	• Level of the retrofit grant in £ / household • Level of the road pricing charge in £ / km
Technology prices / efficiencies / asset lifetimes	• Upfront capital costs • Ongoing (non-fuel) maintenance costs
Uptake scenarios	• The CCC's Balanced Net Zero Pathway
Retail fuel prices	• High / Central / Low retail energy prices
Pass-through assumption	• The proportion of grants and capex passed through from landlords to private and social renters
Discount rate	• Discount rate of 3.5%
Behavioural change assumptions	• Percentage change in annual household energy requirements, relative to the baseline • Percentage change in annual household mileage, relative to the baseline
Archetype projections	• Annual growth in house value • Annual population growth
Year in which gas network switches to hydrogen	• The model assumes that the gas network uses natural gas and there is no switch to hydrogen. However, users can adjust this assumption by selecting a year in which the gas network switches to hydrogen.
Empty archetypes	
Empty archetype characteristics	• Household income • Heating technology • Mileage
Empty archetype uptake	• The year in which archetypes take-up insulation (and which kind of insulation) • The year in which archetypes take-up a low-carbon heating technology (and which kind of technology)
Uptake allocation assumptions	
Allocation of uptake across archetypes	• The year in which archetypes take-up insulation (and which kind of insulation)

5.2 Archetype Modelling

From the archetypes model we obtain a set of representative archetypes for the year 2021, which are an input into the NZDM. There are three additional modelling steps in the NZDM to generate a full set of archetype characteristics over time.

- **First**, we add in three additional archetype characteristics (heating and non-heating requirements, income decile and building size) which are calculated within the NZDM.[32]

- **Second**, since the model aims to estimate the distributional impact of policy instruments from 2021 to 2050, we need to factor in that archetype characteristics such as income will change in this time. To do this we project each archetype's general characteristics (i.e. characteristics that are unrelated to their uptake of low-carbon technologies) to 2050.

- **Third**, we allocate the uptake of low-carbon technologies such as EVs, heat pumps and insulation across archetypes out to 2050.

We discuss each in turn below.

5.2.1 Incorporating additional archetype characteristics

The output from the archetypes model (described in Section 4 above) is a set of 15 representative archetypes with particular characteristics. There are three additional archetype characteristics which are not calculated in the archetypes model and which are calculated within the NZDM. These relate to:

- **Energy requirements**. We calculate each archetype's heating and non-heating energy requirements in the following way.

  - *For archetypes with oil boilers / electric heating:* using the allocation rules in the archetypes model, we have assigned electric heating to one archetype (A10) as its heating technology, and an oil boiler to another archetype (A11) for its heating technology. Since the clustering analysis does not produce consumption estimates for an archetype which has electric heating or an oil boiler, we calculate the heating requirements for these archetypes in the NZDM.

  - *For all archetypes:* we distinguish between heating and non-heating energy requirements. This distinction is required to estimate changes in archetypes' heating requirements following their take-up of insulation. The approach to calculating heating and non-heating energy requirements differs depending on the starting technology of the archetype and is outlined in Annex C.

- **Income deciles**. An output from the archetypes model is the net annual household income for each archetype. In the NZDM, we assign each archetype an income decile, based on a) the income they

[32] These characteristics are calculated in the NZDM (rather than the archetypes model) for consistency with the NZDM calculations for the 'empty archetype' and to ensure consistency with other assumptions in the NZDM (e.g. technology efficiencies which are used to calculate heating requirements).

have been allocated in the clustering analysis; and b) ONS data on deciles[33]. For example, the ONS first decile (in 2019 prices) in disposable income is £9,707 and second decile is £17,738. Archetype A1, with a net household income of £12,655 is therefore assigned to Decile 2. Assigning an income decile is required to calculate the impact of policy instruments which are funded via changes in general taxation. This is because households on different levels of income will be affected differently by changes in taxation (given the progressive nature of the tax system)[34].

- **Building size description**. An output from the archetype model is each archetype's building size in square metres. To map the costs of insulation from the CCC (which provides costs for small, medium, or large homes) to the archetypes, we assign each archetype a size description of "small", "medium" or "large".[35]

5.2.2 Projection of general characteristics

To take account of changes in the general characteristics of archetypes, we apply projections based on UK-wide data. The data used includes:

- ONS net median household income projections to estimate the expected change in net income.[36]

- ONS population projections to estimate changes in the number of households in each cluster.[37]

The projections are included in the NZDM and are applied uniformly across archetypes. Users can update these as updated projections are released.

5.2.3 Uptake allocation

As described in Section 4 above, uptake and use of low-carbon technologies is exogenous in the model. This means uptake and use is not affected by the policies chosen and is instead driven by exogenous scenarios inputted by the user. The default scenario is the CCC's Balanced Pathway scenario. This includes pathways of uptake and use for key low-carbon measures across different types of low-carbon heating technologies, electric vehicles, and home insulation. These technologies are allocated across archetypes in the model. We have developed a set of rules to determine this allocation, considering two key aims.

- **Uptake of low-carbon technologies should be consistent with the starting characteristics of the archetypes**. For example, archetypes that start with high buildings efficiency should not take up insulation, and archetypes with no vehicles should not take up EVs.

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[33] We use ONS data on the distribution of tax (net of benefits) across income deciles. ONS (2019), *Effects of taxes and benefits on household income: historical household-level datasets*, https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/datasets/theeffectsoftaxesandbenefitsonhouseholdincomehistoricaldatasets (Table 14)

[34] See Section 5.5 below for further details on the application of changes in taxation across households.

[35] The CCC / Element Energy data uses the following definitions: i) "Small" refers to homes under 60 square metres; ii) "Medium" refers to homes between 60-90 square metres; and "Large" refers to homes larger than 90 square metres.

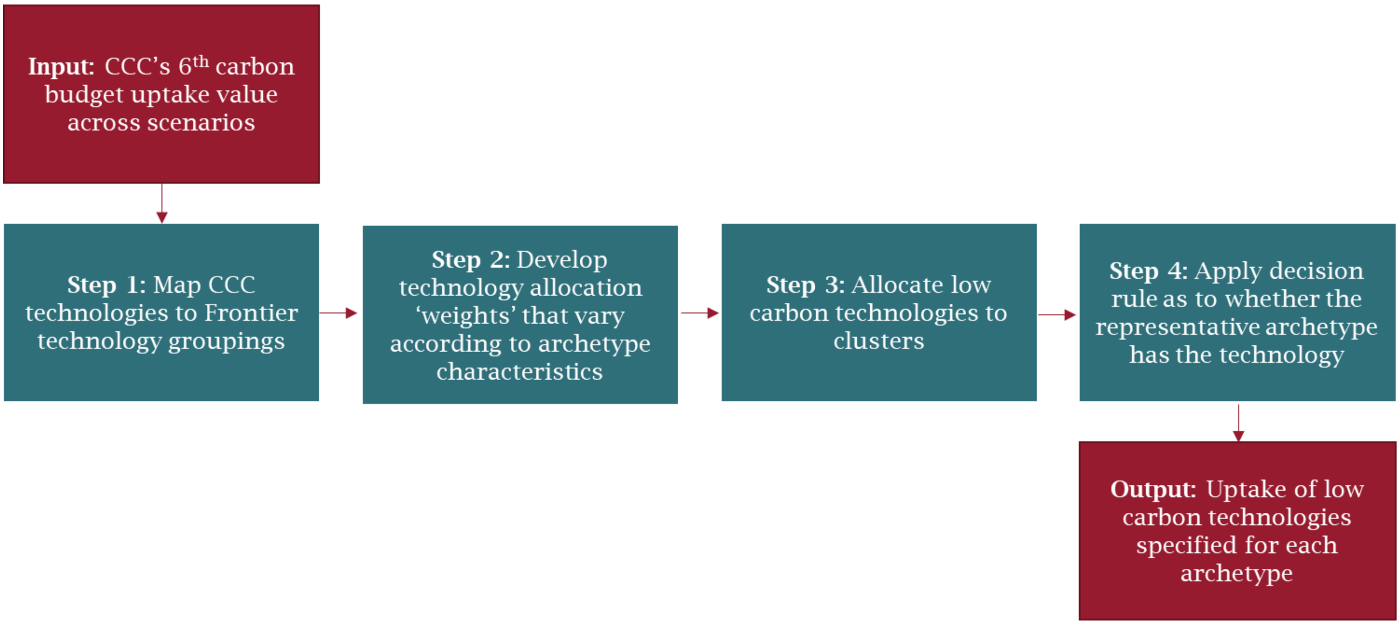
[36] Effects of taxes and benefits on household income: historical household-level datasets - Office for National Statistics (ons.gov.uk)

[37] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/localauthoritiesinenglandtable2

- **Uptake across archetypes should result in household numbers with each technology that are broadly consistent with the overall scenarios**. Allocation rules have been developed that result in an outcome that is broadly consistent with the CCC Balanced Pathway in aggregate. Because the archetype households are representative rather than average, and because grouping households into 15 archetypes entails a loss of granularity, the aggregate uptake numbers do not exactly match. However, the user can override this uptake allocation to test different potential outcomes (see Section 3.4 in the NZDM User Guide).

Figure 9 below describes how uptake of low-carbon technologies is allocated across archetypes in the model, as a default. Further detail is given on each step below.

Figure 9 Uptake allocation process



Step 1: Mapping of CCC technologies to Frontier technology groupings

The CCC Balanced Pathway Scenario[38] describes multiple low-carbon technologies at a high degree of granularity (for example, including factors such as storage type and high/low temperature). We aggregate the granular list of CCC technologies to higher-level groups (e.g. 'air source heat pumps' or 'ground source heat pumps'). The list of technologies captured in the model is shown below.

Table 4 List of technologies

STARTING TECHNOLOGIES	LOW-CARBON-TECHNOLOGIES THAT CAN BE TAKEN UP BY ARCHETYPES
Buildings	

[38] CCC (2020), *Sixth Carbon Budget*, https://www.theccc.org.uk/publication/sixth-carbon-budget/

STARTING TECHNOLOGIES	LOW-CARBON-TECHNOLOGIES THAT CAN BE TAKEN UP BY ARCHETYPES
• Gas boiler • Oil boiler • Electric heating (i.e. electric resistive / electric storage)	• Air source heat pumps • Ground source heat pumps • Hybrid heat pumps • Electric heating (i.e. electric resistive / electric storage) • District heat • Cavity wall insulation • Solid wall insulation • Floor insulation • Roof insulation • Other insulation (i.e. draught proofing and hot water tank insulation)
Transport	
• Petrol ICE car • Diesel ICE car	• Electric vehicle • Plug-in hybrid vehicle

Step 2: Development of technology allocation 'weights'

Each scenario in the NZDM is associated with a certain level of low-carbon technology take-up. For example, the Balanced Pathway includes 23,562 additional air source heat pumps taken up in 2025. For each low-carbon technology and for each archetype, we set a rule which determines the proportion of the total quantity of each low-carbon technology that is to be allocated to a given archetype in each year. This rule involves allocating a percentage of the total quantity of each technology to each archetype (referred to as 'weights' in the model). The weights for a given technology must sum to 100%. They can be used to vary: (i) the archetypes that are 'eligible' to take up the technology (eligible archetypes will have a weight that is greater than 0%), and (ii) the relative weighting of uptake between eligible archetypes. For example, Table 5 shows that as a default, we have assumed that (i) only archetypes with detached homes are eligible to take up ground source heat pumps, and (ii) that the ground source heat pumps taken up each year are distributed evenly across archetypes with detached homes.

The model is currently populated with the rules set out in Table 5 as a default. As shown in Table 5, these rules are used to assume different eligibility for technologies across archetypes, but the relative weighting between archetypes that take up the technologies is assumed to be even. These assumptions can be updated by the user, both in terms of changing the eligibility of archetypes to take up technologies, and in terms of the spread of these technologies across the eligible archetypes (see Section 3.4 in the NZDM User Guide). This can allow the user to explore different technology outcomes for each representative archetype (noting that, as described in Section 4 above, archetypes are representative rather than average).

Table 5 Development of technology allocation weights

LOW-CARBON TECHNOLOGY	UPTAKE IS EVENLY ALLOCATED ACROSS...
Air source heat pumps	… **all archetypes except** those that live in **detached houses**
Ground source heat pumps	… **only detached houses**
Hybrid heat pumps	…all archetypes who are **on the gas grid**
Electric heating	…all archetypes who live in **flats**
District heat	.. archetypes who live in **flats**
Cavity wall insulation	… all detached (urban only) and semi-detached household archetypes that have **EPC rating D or below**
Solid wall insulation	… all detached (rural only), terraced and flats that have **EPC rating D or below**
Roof and Floor insulation	… archetypes with **EPC rating D** or below, excluding those who live in **flats**.
Other insulation	…all archetypes
Electric and hybrid electric vehicles	… archetypes **who have a car** at the start of the modelling period

Step 3: Allocation of low-carbon technologies to archetype

We then allocate each low-carbon technology to an archetype according to the rules set out in Table 5. Each technology is initially allocated to the archetypes by multiplying the total take up of that technology by the percentage weighting allocated to the specific archetype for that technology. However, it may be the case that too much technology is allocated to an archetype, if the population of the archetype is less than the weighting multiplied by the CCC uptake level. This means that we need to redistribute this 'additional' technology to the other archetypes. We do this by redistributing these additional technologies across the remaining eligible archetypes, based on the original weightings, adjusted to exclude the archetype that is 'at capacity' (i.e. all households within that cluster already have been allocated the new technology). This process is repeated iteratively where necessary until the technology in question has been fully allocated across eligible archetypes[40].

Step 4: Application of decision rule to determine representative uptake

[39] Other insulation refers to draught proofing and hot water tank insulation.

[40] Full allocation may not be possible in all cases. For example, we assume that archetypes who do not have a car at the start of the modelling period cannot take up electric or hybrid electric vehicles. However, the total population size of the archetypes who start off with a car is lower than the total projected uptake of electric and hybrid electric vehicles (even adjusting for more than one vehicle per household). Therefore, at the end of the modelling period, there are some electric vehicles from the CCC uptake scenarios which could not be allocated to any archetype.

As noted in Section 4.5 above, the archetypes are defined as representative households, rather than as the average household within each archetype cluster. The steps outlined above means that households within a given cluster can take up different technology substitutes (e.g. air source vs ground source heat pump as substitutes for low-carbon heating). Once we have allocated the technologies to the clusters, we therefore need to decide what technology the 'representative archetype' takes-up. The model does this by picking the most frequent technology for each cluster (for example, the heating or transport technology that appears in the highest numbers in each cluster) based on rule defined for the user. By default, the model uses a threshold of 70% i.e. a representative archetype is considered to take-up a technology when 30% or more of the households within that cluster have the technology. An example for Archetype 1 is described in the box below.

Once an archetype has switched to a low-carbon technology, we assume that they do not switch again, except in the case of hybrid heat pumps / hybrid cars, where archetypes can switch again to an alternative low-carbon technology before 2050.

Decision rule example for Archetype 1 and low-carbon heating

Within the cluster that Archetype 1 represents, some households may take up air source heat pumps and some may take up hybrid heat pumps or district heating. In this example, Archetype 1's starting heating technology is a gas boiler, and we assume that all households within Archetype 1's cluster start off with a gas boiler. Over time, households within that cluster take up low-carbon heating technologies, including air source heat pumps, hybrid heat pumps and district heat.

The uptake volumes of low heating technologies are governed by the technology allocation assumptions set out in Table 5 above. These rules distribute the total technology take up associated with the CCC Balanced Pathway across the clusters. These rules determine that Archetype 1 cannot upgrade to a ground source heat pump or electric heating and hence we set the Archetype 1's technology allocations for these technologies to zero, and positive weights for other heating technologies.

The result of applying these rules means that for Archetype 1's cluster, the majority of households rely on gas boilers as their heating technology up until 2040. Only from 2040 do more than 30% of households have air source heat pumps and therefore in our model Archetype 1 takes up an air source heat pump in 2040.

5.3 Policy instrument costs and benefits

As set out above, uptake and use of low-carbon technologies is exogenous in the model. We therefore do not model behavioural changes associated with the policies. Instead, we are concerned with the overall costs and benefits associated with each policy instrument that will impact the Exchequer household costs. For example, a grants policy will have an overall cost in line with the number of grants multiplied by the value of the grant. This total cost will impact the Exchequer, or the level of energy charges that need to be received. It will also result in a benefit per household targeted by the grant, in line with the value of the grant.

We consider policy instrument costs and benefits in two steps:

- **First**, the model calculates the total costs (or revenues) associated with the policy instrument; and
- **Second**, the model converts the total costs (or revenues) into a per unit cost or benefit that can be applied to the archetypes.

We discuss each step in turn below.

Step 1: Total policy instrument costs (or revenues) to be funded (or distributed)

Based on the policy instruments selected by the user, the model calculates the total costs and benefits associated with each instrument by multiplying the value of the policy instrument (e.g. the grant value) by the relevant quantity (e.g. the number of households receiving the grant).

Table 6 below sets out an illustrative calculation for a grant targeted at low-income households and funded through electricity charges. In this example, the model would calculate the total cost of providing grants to low-income households, based on the number of households in the target group and the value of the grant.

Table 6 Illustrative calculation of total policy instrument costs

METRIC		VALUE	UNIT
Grant value	[A]	1,000	£ / household / year
Number of low-income households receiving the grant	[B]	2	Million households
Cost to be funded	[C] = [A] × [B]	2,000	£ million / year

To calculate quantities associated with each policy instrument (e.g. the number of low-income households receiving the grant, or [B] in the example above), we use two broad approaches:

- A **top-down approach** using external UK-wide projections (e.g. on total mileage driven by cars in the UK and total gas and electricity demand). For example, for the road pricing policy instrument we calculate the total revenue raised by applying the road pricing charge to the total UK mileage driven by cars in each of the snapshot years.
- A **bottom-up approach** which uses the uptake data for the archetypes (e.g. the number of households taking up heat pumps). For example, we calculate the total cost of providing heat pump grants to low-income households using the total number of heat pumps (from the CCC scenario) that were allocated to our low-income clusters.

Annex C summarises which of these two approaches we have followed for each policy instrument, as well as the decision-making process we used to determine which approach was most appropriate for each policy instrument.

Step 2: Converting total costs to a per unit cost

The NZDM then converts the total costs associated with each instrument into a per unit cost to be recovered from consumers / taxpayers or to be spent (on reducing charges or lowering taxation).

Table 7 below continues the illustrative calculation for a grant targeted at low-income households and funded through electricity charges. In this example, the model would spread the total policy cost calculated in the previous step across total electricity demand to calculate the per unit electricity charge needed to fund the required level of grants.

Table 7 Illustrative calculation of per unit funding costs

METRIC		VALUE	UNIT
Cost to be funded	[C]	2,000	£ million / year
Total household electricity demand	[D]	100	TWh / year
Per unit electricity charge	[E] = [C] / [D] / 1,000	0.02	£ / kWh

The output of these steps is a set of policy cost / benefit parameters for each direct policy instrument and the associated funding mechanism (e.g. expressed in £ per household, £ per kWh or £ per km).

5.4 Applying policies to archetypes

We have allocated the per unit policy costs / benefits to the archetypes in three steps:

- **First**, the model matches every combination of direct policy cost / benefit and associated funding per unit cost to each household archetype in each of the seven snapshot years. At this stage in the model structure, the model does not consider which policy instruments have been selected by the user. Instead, the aim of this step is to allocate each archetype a potential per unit policy cost for every combination of direct policy instrument and funding option that the user *could* select.

- **Second**, the model then applies a series of 'cross-checks' to determine which policy costs should actually be applied, given the policy options that have been selected by the user. These cross-checks consider the following:
  - Which policy instrument(s) have been selected by the user?
  - Which targeting options have been selected for those policies?
  - Which funding / spending mechanism has been selected by the user?
  - Is it logically feasible to apply the policy instrument to the archetype, based on the archetype's uptake? For example, an archetype is only eligible to receive a grant for a low-carbon technology if the archetype takes up that technology in the relevant snapshot year.

- **Third**, the model summarises the net effect across both direct policies and their associated funding impacts by aggregating across policies that have the same units. For example, if the user has chosen to apply a tax on gas consumption of 2p/kWh and a policy instrument that is funded through gas charges (and which raises gas prices by 1p / kWh), the model would calculate a net policy impact of 3p / kWh.

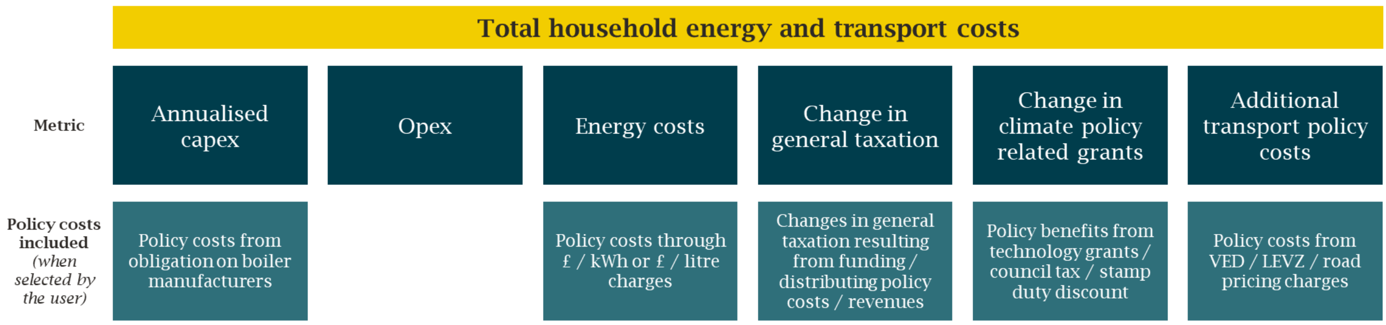
The output of this step is a summary of net policy impacts (e.g. in £ / household or £ / km or £ per kWh terms) that reflect the policy instruments and targeting options selected by the user.[41]

5.5 Uptake and use costs

The NZDM then calculates the household energy and transport costs for each archetype. These costs include the capital costs of taking up technologies, ongoing (non-fuel) costs, fuel / energy costs and other policy costs. Where relevant, policy costs calculated in the previous step are also incorporated into this cost components (e.g. energy costs include any policy impacts in the form of £ / kWh or £ / litre charges). All costs are calculated for both the baseline and the uptake scenario selected by the user.

We describe our approach for modelling each cost component in turn below.

Figure 10 Components of household costs



5.5.1 Annualised upfront capital costs

Types of capital costs

We use data on capital costs from the CCC's published Sixth Carbon Budget. There are three types of upfront capital costs:

- **Fixed capex (£ / asset):** All technologies except electric heating have a fixed capex cost. In the model, this fixed capex is constant across archetypes, but varies overtime and by uptake scenario. The level of fixed capex can be adjusted by the user.

[41] Even if the user has not chosen to apply any policy instruments, the net policy impacts calculated in this step will be non-zero. This is because we assume that investment-related policy instruments (i.e. investment in decarbonisation of buses / rail, investment in EV charging infrastructure and investment in cycling / walking infrastructure) always apply by default. This means that, even if no other policy instruments are selected by the user, the net policy impacts will reflect the per unit impact associated with funding these investments.

- **Marginal capex (£ / kW):** All heat pumps and electric heating have a 'marginal capex' cost that allows the total cost of technologies to vary according to the installed capacity of the technology.[42] The total capex of a technology is made up by the fixed capex, plus marginal capex multiplied by its capacity. In the model, this marginal capex is constant across archetypes, but varies over time and by uptake scenario. The level of marginal capex can also be adjusted by the user.

- **Installation costs (£ / asset; £ / kW; £ / m2):** There are additional costs associated with switching from an existing heating technology to a new technology. For example, this includes additional wiring and installation costs when switching from non-electric to electric heating or costs for decommissioning gas boilers. In the model, these installation costs are constant across archetypes, time, and uptake scenario.[43]

We add the three capex components above to derive total fixed capex for each archetype. This is then annualised over the lifetime of the asset taken up by the archetype. This annualised capex is then incurred in each year in which the household archetype has the technology.

Policy impacts affecting capital costs

The boiler obligation policy instrument has an impact on upfront capital costs. If the user selects for this policy to be applied, an increment is removed from the annualised capex of heat pumps while an increment is added to the annualised capex of gas boilers.[44] A detailed list of the assumptions used to model this policy can be found in the assumptions log of the NZDM.

5.5.2 Operating costs

We use data on non-fuel operating costs (e.g. maintenance) of heating technologies and electric vehicles and PHEVs from the CCC. For heating technologies, these operating costs are constant across time and archetypes, while for EVs and PHEVs, operating costs are constant across archetypes and scenarios but vary over time.

5.5.3 Energy costs

For each household archetype, the model calculates buildings energy costs (for heating and for non-heating) and fuel costs. Figure 11 below shows the break-down of the components included in total energy costs in the NZDM. We explain the calculation steps involved in turn below.

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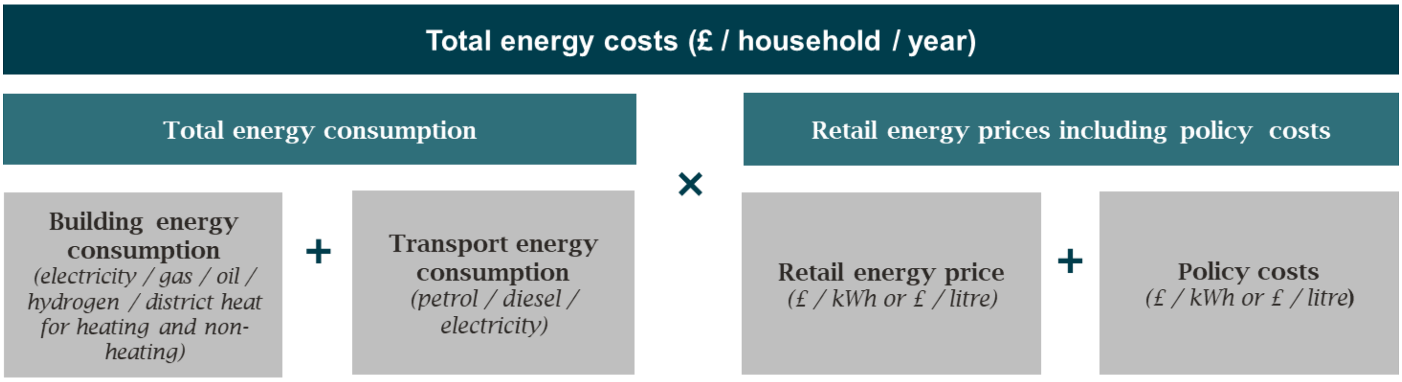
[42] We calculate the installed capacity for each archetype's technology in the following way: i) The archetypes annual heating requirements post insulation (kWh / year) is divided by the number of hours in a year (i.e. 8,760); ii) this hourly heating requirement is then divided by the load factor (%). Data on load factors was obtained from published data from the CCC / Element Energy.

[43] We note that the annualization of total capex (i.e. capex including installation costs) may over-state annualised capital costs for archetypes which take up low-carbon technologies earlier and therefore replace their low-carbon technology during the modelling period. This would only affect archetypes who take up district heat / air source heat pumps / hybrid heat pumps or electric heating in 2035 or earlier (since these technologies have an asset life of 15 years) or take-up ground source heat pumps in 2030 or earlier (since this technology has an asset life of 20 years). In the default settings of the model, this would affect 5 archetypes.

[44] This increment is calculated as: i) the percentage change in capex (which can be adjusted by the user) multiplied by the capex (fixed and marginal) cost of the archetype.

Figure 11 Components of total energy costs



Step 1: Calculate building energy consumption for each archetype

We calculate household energy consumption in three steps:

- **First**, in cases where an archetype has taken up insulation in a particular year, we re-calculate the archetype's heating requirements to account for the energy savings from installing insulation.[45]

- **Second,** we adjust the heating requirements by the efficiency of the archetype's technology to calculate the electricity, gas, oil, hydrogen or district heat consumption used by the archetype for heating.

- **Third**, we add the archetype's non-heating electricity consumption or gas consumption (e.g. for cooking) to the archetype's energy consumption for heating.

Step 2: Calculate transport energy consumption

We calculate transport energy costs by adjusting the archetype's mileage (km / year) by the efficiency of their car to calculate their consumption of petrol, diesel, or electricity per year.

Step 3: Calculate total energy consumption

We add the buildings and transport energy consumption to obtain total energy consumption for each archetype in each year (in £ / kWh of electricity, gas, oil, hydrogen, district heat, petrol and/or diesel).

Step 4: Add policy instrument costs to retail energy prices

We have obtained retail energy prices from the CCC and the government Green Book guidance:

[45] Energy savings from insulation were provided by the CCC and vary by house size (e.g. small / medium / large) and house type (e.g. detached, semi-detached, terraced and flats).

- For the baseline, we have used retail energy prices from the government Green Book Supplementary Guidance.[46],[47] The exception is for 2021 and 2025, where costs have been provided by the CCC. This is to reflect the exceptionally high current energy costs, which diverge significantly from the Green Book projections.

- For each uptake scenario, we have used retail petrol, diesel and oil prices from the Green Book Guidance and retail gas, electricity, hydrogen, and district heat prices shared with us by the CCC.

We add to these retail prices the net impact of the policy costs calculated in section 5.4. For example, if the retail gas price is 10p / kWh and the net policy impact is an additional 3p / kWh, the model would calculate a new retail gas price of 13 p/kWh for that snapshot year.

Step 5: Calculate total energy costs

Lastly, we apply the new retail energy prices to each archetype's consumption of each fuel type to obtain their total energy costs.

5.5.4 Changes in general taxation

For each archetype and snapshot year, we aggregate all changes in general taxation across all policy instruments selected by the user to obtain a total change in general taxation (in £ / household) for each archetype. We also record changes in taxation driven by policy instruments in the transport sector (e.g. due to grants for EVs) separately from changes in taxation driven by policy instruments in the buildings sector (e.g. due to grants for heat pumps). Further details on changes in general taxation are applied across households are set out in the box below.

[46] BEIS (2021) *Green Book Supplementary Guidance*, https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[47] We do not include baseline retail prices for hydrogen or district heat since the model assumes that there is no uptake of hydrogen in the baseline and no uptake of district heat.

THE IMPACT OF INCREASES OR DECREASES IN GENERAL TAXATION ON ARCHETYPES

Changes in Exchequer spending or revenue may affect tax and benefit levels in complex ways. The UK system includes many different taxes, with multiple structures (e.g. targeting or banding within taxes), Changes in spending and revenue may feed through to higher or lower taxes for households but can also affect changes in spending and taxation elsewhere in the economy, or rates of Government borrowing.

To ensure we are taking account of the impact of changes in Exchequer spending or revenue on households, we apply the following simplified approach.

- Where a revenue neutral approach is chosen, we assume that new spending or additional revenue collection is distributed across households in line with the current allocation of tax and benefits[48]. This assumes that Government will continue to adjust the tax system to keep distribution of tax (net of benefits) broadly constant, rather than making the system more progressive or regressive.

- The model user can also choose to apply policy instruments that are not revenue neutral. In this case the impact on the Exchequer is estimated in the output sheet, but the costs and benefits of the change are not redistributed to households. This is in line with a situation where impacts on the Exchequer are met by changes in spending and taxation outside the household sector.

5.5.5 Changes in climate-related policy grants

For each archetype and snapshot year, we aggregate all the net impacts of grant policy instruments and other similar instruments. This includes aggregating across:

- The net impact of all grant policies in £ / household (e.g. for retrofits, heat pumps, EVs/PHEVs, and district heat); and

- The net impacts of tax discounts (i.e. council tax and stamp duty discount) in £ / household.

Again we also distinguish between changes in grants related to the buildings sector and the transport sector.

5.5.6 Additional transport policy costs

For each archetype and snapshot year, we also calculate additional transport policy costs arising from the following policy instruments:

- **Road pricing**: To calculate an archetype's road pricing cost, we apply the road pricing charge (in £ / km) to the archetype's mileage.

[48] To do this, we use ONS data on the distribution of tax (net of benefits) across income deciles. ONS (2019), *Effects of taxes and benefits on household income: historical household-level datasets*, https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/datasets/theeffectsoftaxesandbenefitsonhouseholdincomehistoricaldatasets (Table 13)

- **Low Emissions Vehicle Zones (LEVZ):** To calculate an archetype's LEVZ cost, we apply the LEVZ charge (in £ / ICE car / per day driven in an urban area) to the archetype's number of car trips per year in urban areas.

- **Vehicle Excise Duty (VED):** To calculate an archetype's VED cost, we apply the VED charge in £ / ICE car / year to each archetype with an ICE car in all the years in which the archetype has an ICE car.

5.6 Outputs

The last step of the model is to compare the household costs under the CCC's uptake scenario against the household costs in the baseline scenario to calculate the change in household costs relative to the baseline.

The model shows three types of outputs:

- Change in household costs across archetypes and across time;

- Total energy costs in absolute terms; and

- Wider impacts (e.g. impacts on Exchequer spending / revenue or emissions associated with each CCC uptake scenario)

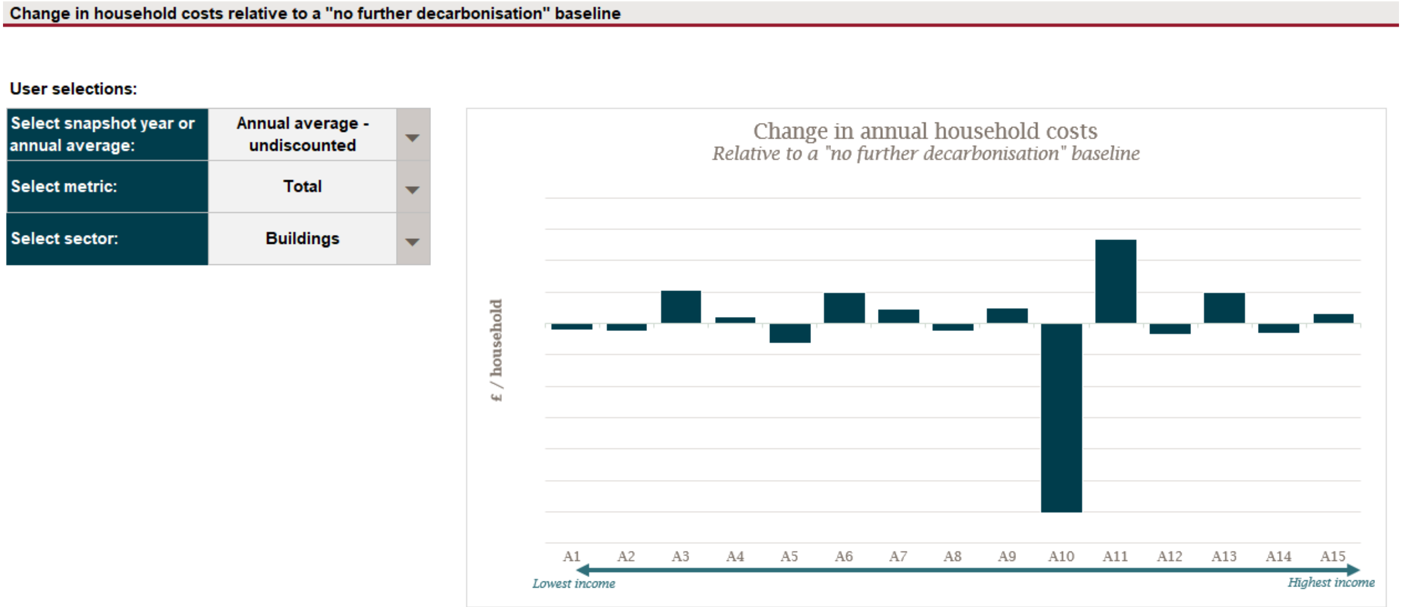
We discuss each in turn below.

5.6.1 Change in household costs across archetypes and across time

A core output from the NZDM is the change in household costs across archetypes and over time, relative to the baseline scenario. Figure 12 provides an illustrative example of an output from the model, where the user has selected to view results for the buildings sector only and has not selected to apply any policy instruments.

Since no policy instruments have been selected, the chart should be interpreted as showing the additional costs / benefits borne by the archetypes from taking up low-carbon technologies (e.g. an air source heat pump), relative to a baseline where the archetypes maintain their starting technologies (e.g. a gas boiler). In this example, some archetypes (e.g. A11) experience a net increase in household costs; while other archetypes (e.g. A10) experience a reduction in costs (i.e. a net benefit) from taking up low-carbon technologies, relative to the baseline.

Figure 12 Illustrative change in household buildings costs



Users can then “switch on” different combinations of policy instruments and observe the change to the distribution of cost shown in Figure 12. The user can compare the change in household costs (relative to the baseline) of different combinations of policies across:

- The 15 household archetypes for a given snapshot year or annual (undiscounted) average;
- Different cost metrics (e.g. total household costs, annualised capital cost of technologies, energy costs, change in taxation / grants / transport related costs due to policies, ongoing non-fuel costs),
- Snapshot years for a specific archetype; and
- Both the transport and buildings sectors, or for each sector individually.

In addition, as explained in section 2.1, users can create their own household archetype by selecting new assumptions about the archetype’s characteristics and take-up of technology. The change in household costs for this archetype can be viewed over time and on an annual average basis.

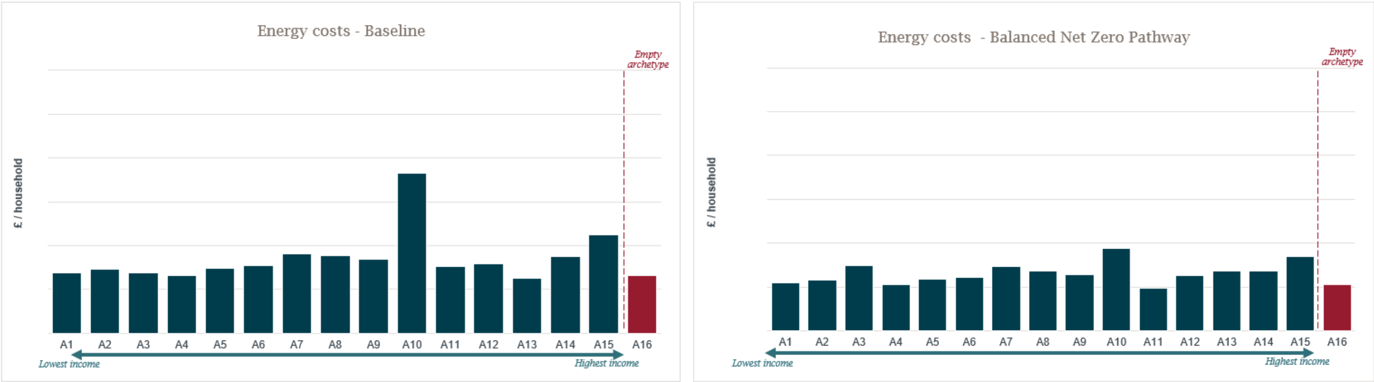
5.6.2 Total energy costs in absolute terms

While most model outputs are presented as a change in cost (i.e. relative to the baseline), the model also includes a breakdown of total energy costs in absolute terms for both the baseline and in the uptake scenario. Model users can compare total energy costs:

- Across archetypes for a selected snapshot year (or the undiscounted annual average across snapshot years); and
- Across both the transport and buildings sectors, or for each sector individually.

Figure 13 below provides an illustrative example of the model output.

Figure 13 Illustrative energy costs



5.6.3 Wider impacts

In addition to the impact on household costs / benefits, the model also shows the impact on Exchequer spending / revenues of different combinations of policy instruments. For example, if users can specify that policy costs and revenues are not passed onto households through taxation, the model calculates the total revenues / costs that the Exchequer would incur as a result.

In addition, users can also view the value of emissions associated with each of the CCC's uptake scenarios, relative to the baseline. These emissions are based on the CCC estimates and do not vary depending on policy instruments selected by the user.

6 Next Steps

In this section we highlight areas for potential future work.

The model is pre-populated with existing and published data and is intended to provide a structure which allows users to update assumptions as and when new data becomes available or to extend the analysis further. For example, users may wish to continue to update the model as more information about policy design or as alternative information about pathways to decarbonisation becomes available (e.g. the role of hydrogen, relative take-up of different technologies and associated costs).

We have identified the following as key areas for potential future work:

- **Policy design.** The model is populated with a default set of policy instruments and targeting metrics. Further extensions to the analysis could consider introducing alternative policy instrument structures (e.g. grant structures differ by house size or type), alternative targeting metrics (e.g. targeting policy instruments based on take-up of technologies) or targeting single policy instruments to multiple targeting groups (e.g. targeting both privately rented and owner-occupied homes with the same or different grant policies, rather than one group or the other group). In addition, the methodology for policy instruments such as the boiler obligation and the stamp duty discount could be reviewed and updated as more information about the likely design and impacts of such policies becomes available.

- **Funding / spending mechanisms**. The model specifies four broad funding options (i.e. Exchequer funding through general taxation or not, energy charges, and road pricing). Future work could consider alternative funding mechanism designs, for example different types of gas and electricity demand could be tested as a means to spread the costs and benefits of policy instruments, and investment in transport infrastructure (e.g. EV charging infrastructure) could be spread across different types of user charges.

- **Retail energy prices.** Retail energy prices are a key input to the NZDM. We recommend that users continue to update the retail energy prices in the model as new information becomes available. Future work could also consider adding differentiated electricity prices for households with or without parking.

- **Low-carbon technologies**. The model is populated with a set of 12 low-carbon technologies which archetypes can take-up. Users may wish to extend the model in the future to incorporate alternative technologies (e.g. alternative types of air source heat pumps; petrol vs diesel PHEVs) or alternative technologies.

- **Replacement capital costs.** The model currently assumes that archetypes who replace their existing technology (e.g. petrol car or gas boiler) incur the same cost as when the archetype first took up that technology. This means that archetypes do not benefit from reductions in capital costs of technologies, unless they switch to a new technology (e.g. a new low-carbon technology). Further extensions to the model could allow the replacement capital costs to be updated at the end of the asset's lifetime.

- **Archetype characteristics**. Future extensions to the analysis could incorporate additional archetype characteristics such as the age of each archetype's technology at the start of the period and car size and age.

Users can also find a detailed log of the assumptions in the NZDM, including a risk rating of all assumptions and suggestions on next steps.

Annex A - Modelling policy instruments

6.1 Policy instrument long list

Table 8 Policy instrument long list

POLICY INSTRUMENT	POLICY OPTION	SPECIFIC POLICY EXAMPLES
Increase energy efficiency of domestic buildings		
Grants / subsidies	• Grants to cover home improvements	• Green Homes Grant Scheme
	• Targeted grants	• Social Housing Decarbonisation Fund
Regulation / mandates	• Technology specifications	• Mandate for all gas boilers in new homes to be hydrogen ready
	• Home energy efficiency standards	• Private-rented sector (PRS) minimum efficiency standards • Owner occupier minimum efficiency standards • Future Homes Standard
	• Product energy efficiency standards	• Increased minimum standards on products (e.g. boilers, cookers, etc)
Incentivise switching away from fossil-fuel based heat		
Grants / subsidies	• Upfront grants / loans to cover part / all of low-carbon assets	• Boiler Upgrade Scheme
Taxation	• Tax discounts / rebates	• Stamp duty discount for lower carbon homes (and/or penalties for higher-carbon homes) • Council tax discount for lower carbon homes (and / or penalties for higher-carbon homes)
Obligations	• Obligations on manufacturers	• Obligations on manufacturers of fossil fuel boilers to sell certain numbers of heat pumps (i.e. the BEIS market-based mechanism)
Regulation / mandates	• Phase-outs of high-carbon assets	• Phase-out of installation of new natural gas heating systems • Phase-out of installation of new fossil fuel heating systems • Regulations ending gas grid connections to new homes
Address / limit funding gaps		
Charges / levies	• Levies on suppliers	• Policy costs such as ECO

POLICY INSTRUMENT	POLICY OPTION	SPECIFIC POLICY EXAMPLES
Taxation	• Public funding through general taxation	• Increases in general taxation
Internalising externalities associated with fossil-fuel based heat		
Regulation / mandates	• Shifting policy costs from electricity to gas	• Change in allocation of policy costs across gas and electricity bills
	• Shifting policy costs from electricity onto the Exchequer	• Shift from levies on bills to general taxation
Taxation	• Taxes on fossil-fuel based heat	• Carbon tax applied to heating fuels
Supporting fuel poor / re-distributing costs		
Grants /subsidies	• Discounts on energy bill	• Warm Home Discount
	• Grants to cover part / all of low-carbon assets	• Home Upgrade Grant
Obligations	• Obligations on energy suppliers	• Energy Company Obligation (ECO) scheme
Incentivise uptake of electric vehicles		
Grants / subsidies	• Grants to incentivise purchase of electric vehicles	• Up-front purchase subsidies for electric vehicles
Taxation	• Tax discounts/rebates	• Fuel duty exemption for electric vehicles (and/or penalties for petrol/diesel cars) • Reduced vehicle excise duty for electric vehicles (and/or penalties for petrol/diesel cars) • Favourable (e.g. low or zero) benefit-in-kind tax rates on zero-emissions company cars
Regulations / mandates	• Technology specifications	• Phase-out new fossil fuel vehicles • Mandate a particular CO2 efficiency / fuel-efficiency for new vehicles
	• Obligations on manufacturers	• Vehicle mandates requiring car manufactures to sell a particular proportion of zero-emissions vehicles
Encourage shift away from fossil fuel		
Taxation	• Tax discounts / rebates	• Low emission vehicle zones • Renewable Transport Fuel Obligation (RTFO) • Fuel tax
Regulation and mandates	• Transport fuel standards	• End diesel trains on railways • End new diesel bus and coach sales
Support infrastructure in delivering capabilities for electric vehicle uptake		

POLICY INSTRUMENT	POLICY OPTION	SPECIFIC POLICY EXAMPLES
Grants / subsidies	• Grants to fund electric vehicle charging points	• Financial support for electric vehicle charging infrastructure provided through home and workplace charge point installation • Financial support to Local Authorities to fund public charge points • Financial support for high-powered charge points on the strategic road network (e.g. Project Rapid)
Regulation / mandates	• Obligations on energy networks	• Regulation for energy networks to ensure future demand levels for electricity can be accommodated
Incentivise alternatives to road travel		
Grants / subsidies	• Increased funding for cycling and walking	• Invest in cycling and walking schemes
	• Increased funding for public transport	• Subsidies rail/bus fairs • Increase provision of bus lanes and high-occupancy vehicle lanes
Taxation	• Disincentives for driving	• Congestion charge / road pricing • Restricted or expensive parking

Annex B - Modelling Archetypes

6.2 Results of the qualitative assessment

Table 9 Qualitative assessment

CHARACTERISTIC	RATING	RATIONALE
Demographic characteristics		
Income	✓	Driver of household consumption
Employment status of household reference person (HRP)	✓	Driver of household consumption; included in Ofgem analysis
Age of household reference person (HRP)	✓	Driver of energy usage; included in Ofgem analysis
Number of dependant children	×	We have exercised judgment in selecting variables for inclusion; this variable was excluded for simplicity
Number of inhabitants	×	We have exercised judgment in selecting variables for inclusion; this variable was excluded for simplicity
Number of dependants	×	We have exercised judgment in selecting variables for inclusion; this variable was excluded for simplicity
Population density	✓	Expected to capture potential public transport usage
Deprivation	✓	To be estimated through index of multiple deprivation (IMD) measures, capturing both disability and wider deprivation measures
Rurality	✓	Rurality is a key driver of transportation usage
Housing characteristics		
Housing value	✓	Captures household wealth; policy impact expected to vary by housing value (e.g. stamp duty)
Tenure (e.g. rented)	✓	Captures control over technology; policy impact expected to vary by tenure
Building type	×	Although building type is a key driver of energy consumption and technologies available to the archetype, we expect that this variable can be proxied by tenure.
Floor area	×	Although building type is a key driver of energy consumption and technologies available to the archetype, we expect that this variable can be proxied by tenure.

CHARACTERISTIC	RATING	RATIONALE
Building energy efficiency	✓	Driver of energy consumption; policy impact expected to vary by energy efficiency
Heating appliance efficiency	✓	Driver of energy consumption
Boiler/heat pump/other technology	✓	Driver of energy consumption; policy impacted expected to vary by technology
District heat connection	×	District heat not currently widely deployed; policies may be specific to district heat customers
Gas consumption	✓	Captures energy consumption
Electricity consumption	✓	Captures energy consumption
Transport characteristics		
Car ownership	✓	Driver of fuel/energy consumption; policies are expected to impact car owners differently
Car usage	✓	Driver of fuel/energy consumption; policies are expected to vary based on usage (e.g. road pricing)
Car type (e.g. diesel / petrol / hybrid)	×	We have exercised judgment in selecting variables for inclusion; this variable was excluded for simplicity.
Accessibility	✓	Captures potential public transport usage
Public transport mileage / number of trips	✓	Captures actual public transport usage
Public transport potential travel time	✓	Captures incentives to use public transport
Public transport expenditure	✓	Captures incentives to use public transport
Walking and cycling mileage	✓	Expected to capture potential for modal shift
Access to EV charging	✓	Driver of energy consumption; to focus on access to on or off street parking

6.3 Results of the data assessment

Table 10 Data assessment

CHARACTERISTIC	RATING	RATIONALE	DATA SOURCE AND METHODOLOGY (WHERE RELEVANT)
Demographic characteristics			

CHARACTERISTIC	RATING	RATIONALE	DATA SOURCE AND METHODOLOGY (WHERE RELEVANT)
Income		ONS data available for small areas only, so we apply a projection to the LSOA level using IMD income measure	We used 2018 ONS data on Income estimates for small areas (England and Wales) and 2018 NRS data on banded income statistics (Scotland). The ONS data is for Small Areas and so we project the data to the LSOA level using the IMD income decile.
Employment status of household reference person		2011 census data is available at the LSOA level	We use 2011 census data
Age of household reference person		2011 census data is available at the LSOA level	We use 2011 census data
Number of dependant children		2020 ONS data is available at the LSOA level	We use 2020 ONS data on population age and sex (England and Wales) and 2020 National Records Scotland (NRS) data on population estimates (Scotland)
Number of inhabitants		2011 census data is available at the LSOA level but needs to be projected to 2020	We used 2011 census data, projected to 2020 using Labour Force Survey (LFS) data available at the regional level
Number of dependants		Not available	
Deprivation		Index of Multiple Deprivation (IMD) available at the LSOA level	We used 2019 date from the Ministry of Housing, Communities & Local Government (England); 2019 data from Stats Wales (Wales) and 2020 data from NSG (Scotland)
Population density		ONS data available at LSOA level	We use ONS data on population density (England and Wales); and NRS data on population density (Scotland)
Rurality		ONS and NRS data at the LSOA level	We use 2020 ONS data on rural/urban classification (England and Wales) and 2020 NRS data on households and dwellings (Scotland)
Housing characteristics			

CHARACTERISTIC	RATING	RATIONALE	DATA SOURCE AND METHODOLOGY (WHERE RELEVANT)
Housing value		ONS data available at LSOA level	We use 2019 UK house price index from the ONS, supplemented with 2018 / 2017/2016 data where 2019 data is blank
Tenure (e.g. rented)		ONS data available at LSOA level	We use 2020 ONS data on households by tenure
Building type		ONS data available at LSOA level	We use 2020 ONS local authority housing statistics (England); 2020 Stats Wales new house buildings (Wales); and 2020 NRS new build housing starts and completion (Scotland)
Building energy efficiency		Energy performance certificate data at LSOA level	We use 2020 Energy performance certificate (EPC) data (England and Wales); and 2020 NRS domestic energy performance data (Scotland)
Heating appliance efficiency		Data not available	
Boiler/heat pump/other technology		Replaced with a proxy variable on whether a household is on or off the gas grid	We use 2020 Energy performance certificate (EPC) data (England and Wales); and 2020 NRS domestic energy performance data (Scotland)
District heat connection		Data not available	
Gas consumption		ONS data available at LSOA level	We use 2020 ONS data on gas and electricity consumption
Electricity consumption		ONS data available at LSOA level	We use 2020 ONS data on gas and electricity consumption
Transport characteristics			
Car ownership		DfT data available at LSOA level on number of cars	We use 2018 Department for Transport (DfT) data
Car usage		Data to be proxied using 2011 census data on share of people who commute by car	We use 2011 census data on travel to work as a proxy for car mileage. Travel to work is approximately 20% of all trips.[49]

[49] https://www.carbon.place/

CHARACTERISTIC	RATING	RATIONALE	DATA SOURCE AND METHODOLOGY (WHERE RELEVANT)
Car type		DfT data available at LSOA level on share of total cars in each LSOA that are petrol vs diesel vs hybrid	We use 2018 Department for Transport (DfT) data
Accessibility		We proxy accessibility to transport services via accessibility component of IMD index	2020 IMD access to services indicator
Public transport mileage / number of trips		Data to be proxied using 2011 census data on commuting to work	We use 2011 census data on travel to work as a proxy for transit mileage. Travel to work is approximately 20% of all trips.[50]
Public transport potential travel time		UK wide data not available	2020 National Audit Office (NAO) data on time to town centre
Public transport expenditure		Data not available at LSOA level	
Walking and cycling mileage		Data to be proxied using 2011 census data on commuting to work	We use 2011 census data on travel to work as a proxy for walking / cycling mileage.
Access to EV charging		Data not available	

Source: [Insert Source here]
Note: [Insert Notes]

[50] https://www.carbon.place/

6.4 Results of the correlation analysis

Figure 14 Correlation analysis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
Gas consumption (1)	1.00																							
RUC score (2)	0.06	1.00																						
Gross annual income (3)	0.32	0.01	1.00																					
Number of cars (LSOA level) (4)	0.22	0.40	0.38	1.00																				
Age of HRP (5)	-0.27	0.02	-0.13	-0.13	1.00																			
Cars per person (6)	0.44	0.47	0.23	0.70	-0.32	1.00																		
Electicity consumption (7)	0.68	0.31	0.45	0.44	-0.19	0.54	1.00																	
IMD score (8)	-0.45	-0.20	-0.45	-0.31	0.40	-0.53	-0.41	1.00																
IMD Income sub-score (9)	-0.49	-0.24	-0.52	-0.39	0.36	-0.56	-0.49	0.92	1.00															
House value (10)	0.32	-0.09	0.67	0.17	-0.11	0.07	0.38	-0.32	-0.36	1.00														
% commute by car (11)	0.22	0.43	-0.21	0.41	-0.16	0.65	0.26	-0.21	-0.21	-0.44	1.00													
% commute by transit (12)	-0.14	-0.60	0.24	-0.39	0.08	-0.58	-0.24	0.20	0.23	0.40	-0.84	1.00												
% commute by foot / bike (13)	-0.40	-0.06	-0.19	-0.31	0.24	-0.50	-0.40	0.29	0.26	-0.07	-0.49	0.04	1.00											
% commute in other ways (14)	0.38	0.43	0.31	0.32	-0.14	0.40	0.51	-0.39	-0.41	0.44	-0.06	-0.16	-0.18	1.00										
% dwellings on the gas grid (15)	0.05	-0.28	-0.02	-0.10	-0.04	-0.04	-0.29	-0.02	0.05	-0.05	0.13	0.04	-0.10	-0.40	1.00									
% flats amongst dwellings (16)	-0.35	-0.37	-0.05	-0.39	0.07	-0.53	-0.40	0.19	0.25	0.12	-0.64	0.53	0.40	-0.09	-0.26	1.00								
% private renters (17)	-0.24	-0.13	0.14	-0.07	0.23	-0.39	-0.20	0.21	0.11	0.15	-0.49	0.34	0.41	-0.07	-0.21	0.39	1.00							
% public renters (18)	-0.31	-0.05	-0.31	-0.21	0.17	-0.28	-0.25	0.49	0.56	-0.22	-0.04	0.05	0.14	-0.23	0.01	0.16	-0.25	1.00						
% low EPC score (19)	0.23	0.29	-0.03	0.12	0.05	0.19	0.30	-0.05	-0.11	0.03	0.04	-0.16	-0.05	0.44	-0.51	-0.10	0.00	-0.10	1.00					
% high EPC score (20)	-0.07	0.00	-0.01	-0.02	-0.11	-0.02	-0.02	-0.06	-0.05	0.01	-0.05	0.03	0.02	0.05	-0.11	0.16	-0.04	-0.01	-0.11	1.00				
Population density (21)	-0.30	-0.45	0.05	-0.45	0.21	-0.64	-0.37	0.24	0.25	0.16	-0.66	0.64	0.36	-0.29	0.05	0.49	0.41	0.05	-0.19	0.00	1.00			
% unemployed HRP (22)	-0.44	-0.26	-0.50	-0.43	0.30	-0.57	-0.47	0.80	0.87	-0.31	-0.27	0.27	0.27	-0.36	0.02	0.33	0.14	0.50	-0.10	-0.02	0.29	1.00		
% HRP under 35 (23)	-0.50	-0.32	-0.16	-0.43	0.19	-0.68	-0.46	0.36	0.35	-0.11	-0.55	0.42	0.58	-0.36	-0.11	0.59	0.52	0.14	-0.18	0.13	0.57	0.42	1.00	
% HRP over 65 (24)	0.26	0.32	0.11	0.44	0.01	0.47	0.24	-0.16	-0.20	0.08	0.36	-0.38	-0.23	0.31	0.00	-0.39	-0.26	-0.07	0.18	-0.13	-0.44	-0.30	-0.70	1.00

Legend
- Correlation >90%
- Correlation >80%

Annex C - Modelling distributional impacts

6.5 Archetype energy requirements

The approach to calculating energy requirements differed depending on the starting technology of the archetype as outlined below.

- **Archetypes with a gas boiler**. For archetypes with gas boilers, our starting point is the gas consumption (kWh) from the clustering analysis. We then distinguish between:
  - **Gas consumption for cooking (kWh gas):** We assume that gas consumption for cooking is 3% of the archetype's total annual gas consumption.
  - **Heating requirements (kWh):** We calculate the heating requirements as the total gas consumption (minus the gas consumption for cooking), adjusted by the efficiency of the gas boiler.
  - **Electricity for non-heating (kWh electricity):** The archetype's electricity for non-heating is obtained directly from the clustering analysis.
- **Archetypes with electric heating (i.e. electric resistive/storage)**. In the model default settings, there is one archetype with electric heating in 2021 (i.e. A10). We calculate the heating requirements in the following way.
  - **Heating requirements (kWh):** We do not have an estimate of electricity usage for a household with electric heating from the clustering analysis. Our starting point is therefore an assumption of 15,000 kWh of heat per year for the archetype's heating requirements. [51]
  - **Electricity for non-heating (excluding cooking):** We apply the same heating requirements as an archetype which uses gas but has otherwise similar characteristics. For example, we assume that archetype A10 (with electric heating) has the same electricity consumption as archetype A9 (with a gas boiler). [52]
  - **Electricity for cooking:** We assume that the archetype's electricity consumption for heating is the electricity equivalent of a similar gas boiler archetype's consumption. For example, we assume that archetype A10 (with electric heating) has an electricity consumption for cooking of 398 kWh electricity / year, based on the 398 kWh of gas / year for A9 (which uses gas for cooking).
- **Archetypes with an oil boiler**. In the model default settings, there is one archetype with an oil boiler in 2021 (i.e. A11). We calculate the heating requirements in the following way.

[51] BEIS, (2022), *Phasing out the installation of fossil fuel heating in homes off the gas grid,* Phasing out the installation of fossil fuel heating in homes off the gas grid (publishing.service.gov.uk), page 25.

[52] A9 and A10 both live in detached houses with relatively similar house size and poor EPC ratings.

- **Heating requirements (kWh):** We do not have an estimate of electricity usage for a household with oil boiler heating from the clustering analysis. Our starting point is therefore an assumption of 15,000 kWh of heat per year for the archetype's heating requirements.[53]

- **Electricity for non-heating (excluding cooking):** We apply the same heating requirements as an archetype with otherwise similar characteristics. For example, for archetype A11 with an oil boiler, we assign the same electricity consumption as for archetype A9.[54]

- **Electricity for cooking:** We assume that the archetype's electricity consumption for heating is the electricity equivalent of a similar gas boiler archetype's consumption. For example, we assume that archetype A11 (with an oil boiler) has an electricity consumption for cooking of 398 kWh electricity / year, based on the 398 kWh of gas / year for A9 (which uses gas for cooking).

6.6 Top-down and bottom-up approach

One of the core features of the model involves estimating the total policy costs and revenues to be funded or spent. There are two approaches to doing this:

- **'Top-down' approach**: using CCC data and external UK-wide assumptions; and

- **'Bottom-up' approach:** using archetype projections.

In deciding which approach to take, we have been guided by the overarching aim of trying to align total cost estimates to the CCC's scenarios wherever possible. This means that our approach is:

- By default, we use take the top-down approach (e.g. we use overall gas / electricity consumption from the CCC Sixth Carbon Budget rather than 'multiplying up' the projected electricity consumption of our archetypes and the number of households within cluster).

- We only use the bottom-up approach if we think that using the top-down approach would distort the results, and where we think that we can correct this distortion without a significant loss of accuracy, specifically the top-down approach might be inconsistent with the uptake allocation across archetypes.

This inconsistency is only likely to occur when two criteria are met:

1. The policy is targeted at particular archetypes; and
2. The policy directly relates to the timing of uptake of technologies.

In these cases, we correct for any potential inconsistency between our uptake allocation in the archetypes and the CCC's overall projections by using our archetype projections[55]. This does not however lead to a

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[53] BEIS, (2022), *Phasing out the installation of fossil fuel heating in homes off the gas grid,* Phasing out the installation of fossil fuel heating in homes off the gas grid (publishing.service.gov.uk), page 25.

[54] A9 and A11 both live in detached houses with similar house size and poor EPC ratings.

[55] For example, to calculate the total value of grants given to households with poor energy efficiency which take up insulation in a given year, we multiply the value of the grant by the number of households that are considered to have poor energy efficiency which take up insulation in that

large loss of accuracy, because the total uptake from our archetypes is based upon total CCC uptake. This process is described in Figure 15, which outlines the final approach taken for each policy.

We note that there are some cases in which basing our calculations of total policy costs / revenues on the archetypes may lead to an understatement of policy costs. Specifically, a distortion may arise since we project the number of households in each archetype cluster to 2050 using the same population growth rate across all clusters. This projection implies a growth in the existing stock of inefficient homes over time, alongside the growth in the stock of efficient homes, which would not reflect reality given energy efficiency standards for new homes. As a result, there is the potential for the following distortions for policy costs based on the bottom-up approach:

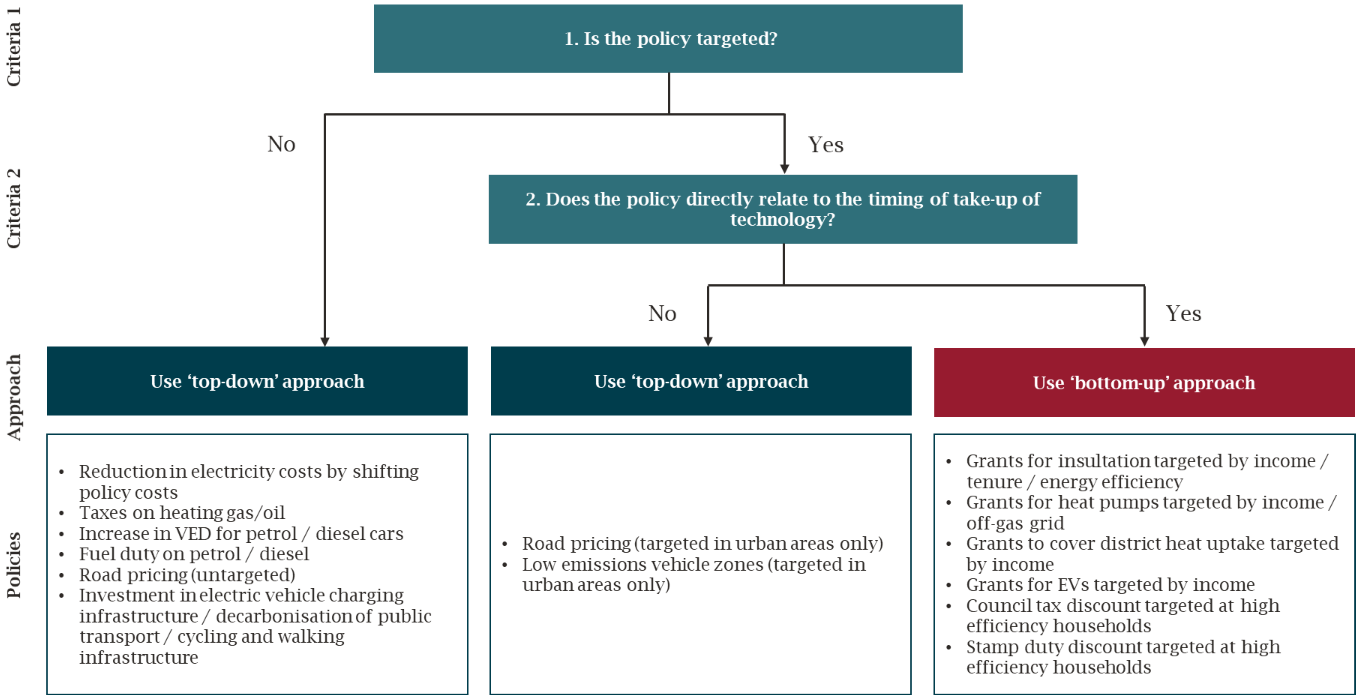
- Policy costs for the stamp duty discount and council tax discount policy (which are based on the number of households in each cluster which meet the 'high efficiency' threshold) may be understated. However, this effect may also be offset, at least in part, by the fact that the model necessarily assumes that all households within a cluster receive the stamp duty discount (if they are eligible) in a binary way, while only a proportion of households within a given cluster will receive the discount.

- For other policy instruments (e.g. grants), policy costs are based on the number of technologies in the CCC uptake scenario allocated to each archetype cluster. Although the total number of technologies across the archetypes will match the CCC total for almost all technologies[56], the allocation of the technologies to clusters is indirectly informed by the number of households in each cluster and so may also be affected by the household growth assumptions.

year. The number of households this applies to is modelled in the archetype uptake allocation, which may differ to what the CCC assume. To ensure the model is internally consistent between what is allocated to the archetypes and the total policy costs, we therefore take the bottom-up approach.

[56] The CCC uptake scenarios and the number of technologies taken up by the archetypes does not match for two technologies, district heat and electric vehicles. This is because the number of households within archetype clusters that have cars is smaller than the CCC's assumed uptake of electric vehicles. Similar, the number of households within archetype clusters that are eligible for district heat (i.e. households living in flats) is smaller than the CCC's assumed take-up of district heat.

Figure 15 Decision tree for choosing between a bottom-up or top-down approach to modelling policy costs and revenues



Note: No costs or revenues are modelled for the RTFO and boiler obligation policies, as these do not raise revenue or incur material costs for the government that requires funding.

Annex D - CCC and Stakeholder Engagement

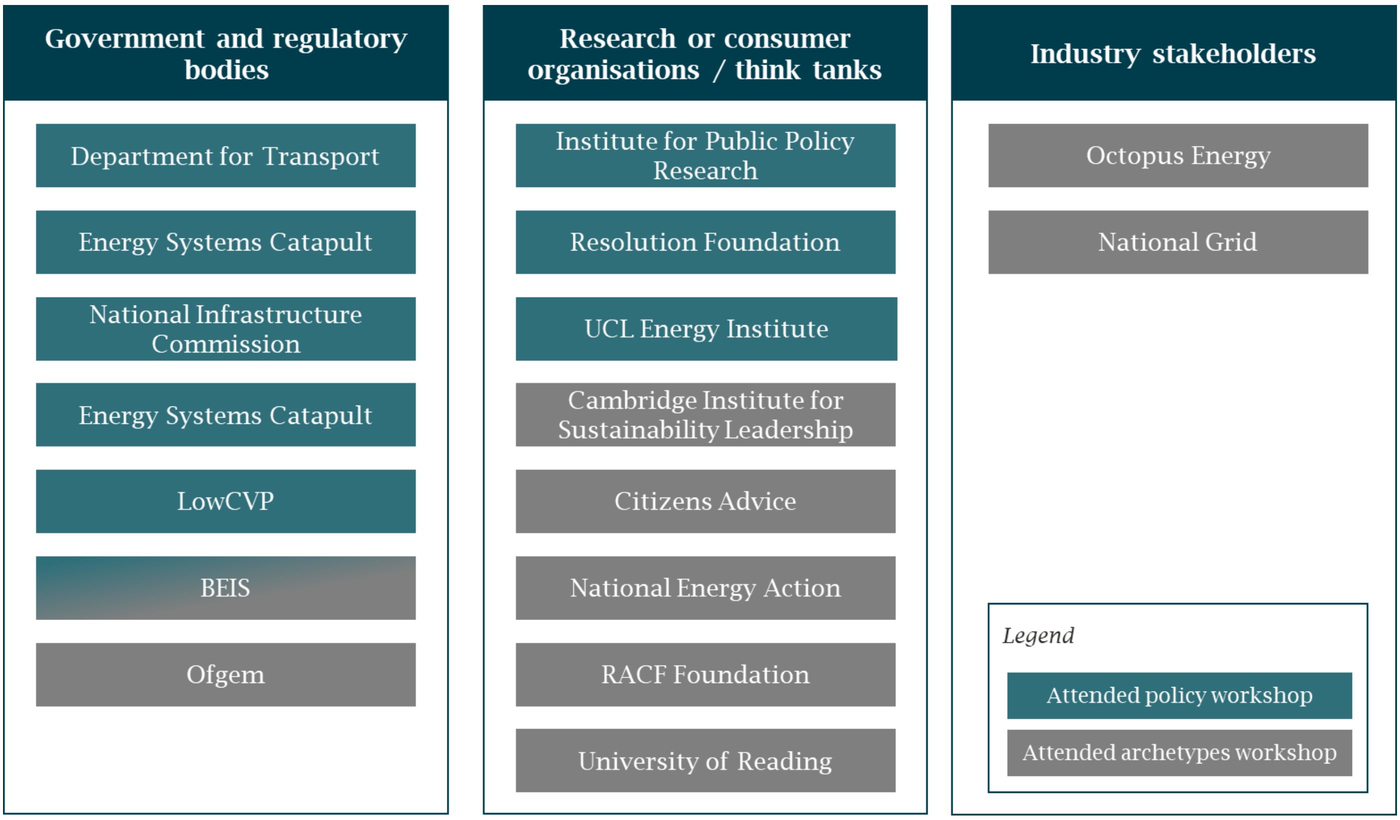
Ongoing collaboration with the CCC and engagement with external stakeholders was an important input to this project. We have carried out the following types of engagement:

- **Regular CCC engagement**: This project is carried out in close collaboration with the CCC. We engaged with the CCC project team through weekly calls and regular email exchanges. This has allowed the CCC project team to provide inputs to this project, agree the approach and direction of the project and act as a sounding board for our assumptions.

- **Wider engagement at key checkpoints**: We have engaged with wider CCC teams (e.g. CCC Buildings team, CCC Transport team, CCC Champions) and external stakeholders at key-checkpoints to communicate and sense-check emerging thinking as the project developed and to gather and incorporate feedback.

At the start of this work, the CCC and Frontier identified a range of key external stakeholders to engage. We carried out two separate workshops with external stakeholders: a workshop focused on stress-testing our approach to developing policies and the policy instruments to be considered as part of this work; and a workshop focused on stress-testing our approach to developing household archetypes and archetype characteristics to be considered as part of this work. Figure 16 sets out the external stakeholders we engaged in this work.

Figure 16 External stakeholders engaged in this work



We provide a summary of feedback from the wider CCC and external stakeholder workshops below.

- **Assumptions relating to exogenous uptake and use of low-carbon technologies**. Stakeholders noted that the uptake of low-carbon technologies would vary, depending on the policy instrument choice and that this would also be a relevant and interesting question to consider. We discussed that consideration of endogenous uptake and use was outside of the scope of the project but could be considered further by the CCC or in other projects. For the purposes of this project, we also noted that model users would be able to update the uptake pathways in the model.

- **Number of archetypes**. We discussed with stakeholders that we will need to limit the number of archetypes and carry out the analysis at the LSOA level (rather than the household level). This has some limitations, but it was agreed that this was a pragmatic response to data availability and project scope. We also noted that the model would include an empty archetype so that users can explore the impact of alternative assumptions for key archetype characteristics.

- **Cost pass-through assumptions**. Stakeholders agreed with our assumption that costs are fully passed through to consumers, but that it would be useful to include some flexibility in the model to test alternative assumptions on the proportion of costs pass through. We have implemented this in the model.

- **Archetype characteristics**. Stakeholders suggested several characteristics that could be explored as part of the long list of archetype characteristics. These included: number of children or dependants, the accessibility of public transport, public transport journey time, and walking and cycling that is classified as trip replacement rather than for recreational purposes.