PROJECT DEFENDER WORKSTREAM 1

D1.4-2 – Forecast Scenario Methodology report

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Definitions

Name	Acronym (if applicable)	Description
Energy Performance Certificate	EPC	A record of energy performance criteria for an address containing information on building fabric, heating system, and performance. Approx. 60% UK coverage.
Archetype		Primary categorisation of addresses by construction age, type, and form factor
Sub-archetype		Secondary categorisation of addresses by the level of insulation
National Grid Electricity Distribution	NGED	Formerly known as WPD
Heat Thermal Coefficient	HTC	Heat flow rate divided by indoor and outdoor temperature difference (W/K)
U-value		Heat flow rate divided by indoor and outdoor temperature difference and surface area (W/m^2K)
Unique Property Reference Number	UPRN	Unique identifier for all UK addresses
Geographic Information System	GIS	Mapping software used to do analysis
Feeder		Network cables connecting secondary substations to customer endpoints
Distribution Future Energy Scenarios	DFES	Projection of energy technologies to 2050 under a scenario framework down to primary substation level
Electricity Supply Area	ESA	Areas around primary substations used in DFES modelling
Output Area/Lower Layer Super Output Area	OA / LSOA	Geographic area built from clusters of adjacent postcodes in the UK. OA = 120 households. LSOA = 650 households. There are 65 OAs that overlap the 3 feeder areas.

1. Workstream 1 Energy Efficiency Scenarios

1.1. Model objectives

- To create future energy efficiency scenarios for domestic homes and generate substation profiles to be used in network modelling studies
- To provide NGED with an Excel-based tool that can be used to create energy efficiency scenarios for different areas of their network and replace/enhance existing processes that estimate heat demand reduction
- To improve the forecasting of volumes of energy efficiency uptake in the distribution future energy scenarios (DFES). Currently, the DFES assumes a non-regionalised fixed year-on-year percent decrease of demand. The new proposed method aims to improve the estimation of demand reduction from energy efficiency based on building attributes.

1.2. Overview of Modelling Approach

The approach detailed in this specification document relates to the modelling tasks needed to carry out the energy efficiency scenario analysis. Report writing tasks are not shown. These are split into four core exercises, which will be delivered by The Carbon Trust:

1. Building stock database creation for the case study areas
2. Characterisation of archetypes into low, medium and high thermal efficiency
3. Using the Distribution Future Energy Scenarios to determine rate of interventions
4. Cost optimisation of fabric measures

The outputs of the scenario model can be uploaded directly to the Hildebrand developed Glow tool to produce a diversified profile for the scenario and year of interest. The Carbon Trust will also hand over the tool to NGED and Frontier Economics so that energy efficiency scenarios can be created for network areas beyond the scope of this project.

This report details the most up-to-date methodology. There have been developments in our approach since the write-up of the original methodology report D1.1-2 – High level solution design – modelling methodology, therefore, where there are conflicts between the documents, this should be treated as correct.

1.3. Detailed methodology

1.3.1. Creating a building stock database for the case study areas

Case study areas

In the initial scoping phase of the project, the project partners agreed on three case study areas on NGED's network to test the profile and scenario models. The three feeder areas were selected based on the following:

- High proportion of domestic buildings
- High DFES heat pump projection
- Availability of network data
- Good EPC coverage
- Proximity to a weather station

Primary substation / ESA	Feeder name	Number of secondary substations	Number of dwellings
Axbridge	180017/0001	2	252
Mackworth	870038/0010	17	3,362
Withycombe Raleigh	310037/0024	13	1,843

For each of the 32 substations, polygons were drawn around the boundaries of their cable files using GIS which enabled address UPRNs to be mapped using a proximity-based analysis.

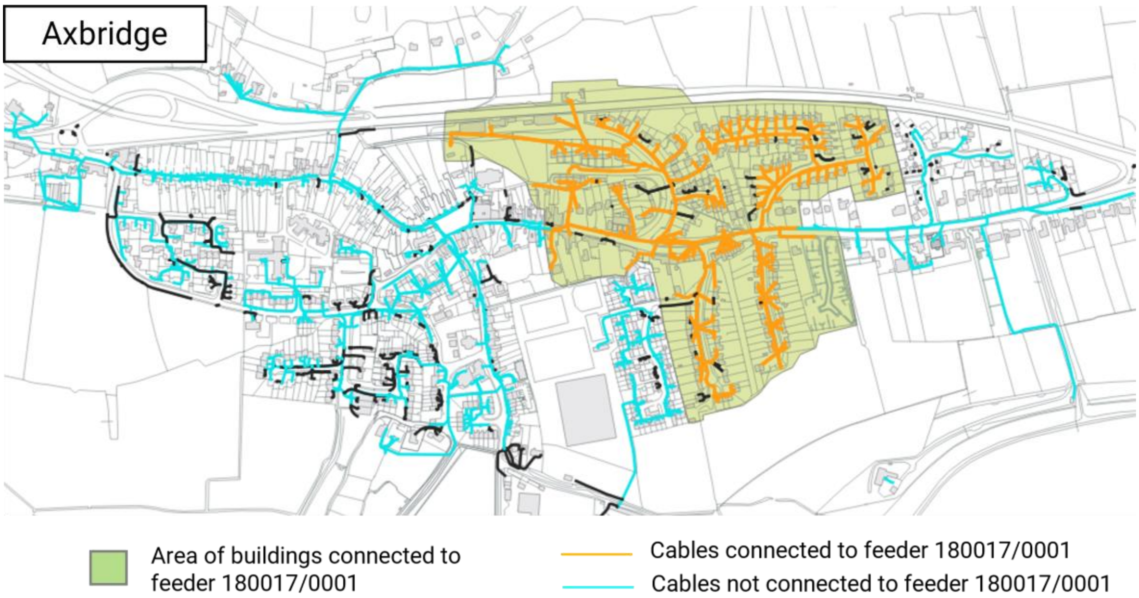


Figure 1. Image of GIS proximity analysis showing how network cable files were used to draw polygons (shown in green) to map buildings connected to feeder 180017/0001

We used GIS to allocate a secondary substation to each building in the building stock database through a proximity-based analysis of network cable files. GHD provided Carbon Trust with the number of MPANs in each substation area which was used to verify the results of this analysis.

Address-level data

The Carbon Trust has a well-established address-level database architecture. Our address-level model enables a more accurate assessment of building-level energy demand and provides a detailed platform for assessing decarbonisation interventions and scenarios.

We developed a high-granularity database, sourcing detailed building attribute data (building use type, age, footprint and height, wall type, etc.) for every building in the case study areas using the following steps:

1. Develop a list of all residential and commercial addresses in the area using AddressBase Unique Property Reference Numbers (UPRN).

2. Match Energy Performance Certificate Data from (source) to each UPRN.

3. Extract the following relevant property attribute data from EPCs:

    - Property age
    - Property type (house/flat)
    - Property footprint (m^2) and building dimensions
    - Wall type & insulation
    - Floor type & insulation
    - Roof type & insulation
    - Window glazing
    - Fuel type
    - Heating system etc

4. Use statistical and geospatial analysis to extrapolate property attribute data to addresses with no EPC record (approximately 40% of addresses did not have an EPC record).

    The extrapolation was done by assigning the most common sub-archetype in each Output Area (OA) to the unknown properties within the OA. The AddressBase data contains some building information, enabling us to do the extrapolation separately for detached, semi-detached, terrace, and flats.

    For example, the Output Area E00100762 has 84 detached homes, 59 have an EPC record, and 25 do not. The sub-archetypes for the 59 homes are listed in Table 1 below. The most common sub-archetype for detached homes in OA E00100762 is 45-45 therefore, the 25 unknown properties were assigned sub-archetype 45-45.

Table 1. Sub-archetype counts for Detached homes with EPCs records in OA E00100762 (Withycombe Raleigh).

Sub-archetype	Count
34-25	1
42-52	1
45-30	3
45-34	4
45-39	1
45-45	**11**
45-49	7
45-52	9
45-54	1
45-8	4
46-30	1
46-34	1
46-37	1
46-43	1
46-45	7
46-49	2
46-52	3
48-32	1

We also considered an even distribution method for assigning the archetypes to the unknown properties which would result in another possible archetype portfolio. However, the high frequency of unique, single house archetypes in all of the Output Areas meant that there was a higher degree of uncertainty with using this method. Although other house archetypes are prevalent in this OA (e.g. 45-52), this characteristic is not repeated in all 260 OAs in the analysis which further justifies using the ‘most common’ sub-archetype method to maintain consistency.

1.3.2. Characterising the building stock

In the first modelling exercise in Workstream 1, we established a method for categorising the buildings in archetypes based on thermal performance as well as possible retrofit options. This archetype framework forms the basis of the scenario modelling by projecting changes to the insulation attributes of a building stock database.

The following steps were used to characterise the building stock database for each case study area:

1. Allocate every address in the database into 1 of 68 archetypes. Each archetype represents a unique combination of property type, built form, age, floor type, roof type and wall type.

Archetype					
Property type	**Built form**	**Construction age band**	**Floor type**	**Roof type**	**Wall type**
	Mid-terrace	before 1930	Solid	Flat	Cavity wall
House	Semi-detached	after 1930	Suspended	Pitched	Solid wall
	Detached		Other premises	Other premises	
	Bottom floor flat				
Flat	Mid floor flat				
	Top floor flat				

2. Further allocate all addresses 1 of 2,905 possible sub-archetypes which represent an archetype with unique combinations of floor insulation, roof insulation, wall insulation and window glazing.

Sub-archetype			
Floor insulation	**Roof insulation**	**Wall insulation**	**Window glazing**
No insulation	No insulation	No insulation	Single glazing
Partial insulation	Partial insulation	Insulated	Double glazing
Insulated	Insulated		Triple glazing
Other premises	Other premises		

3. Calculate a unique Heat Transfer Co-efficient for each of the 2,905 sub-archetypes. The Heat Transfer Co-efficient expressed in W/m^{2}K refers to the amount of energy lost through 1m^2 of building fabric for every 1 degree of temperature difference between the inside and outside environments.

4. Assign each sub-archetype into one of three groups (high, medium and low thermal efficiency). Determining whether each archetype's thermal efficiency is low medium or high was done by applying thresholds to heat transfer coefficients (HTC) using the insulation parameters for walls, windows, floor and roof as indicators. The following principles describe how these archetypes were assigned:
   - Typically, low thermal efficiency was assigned to sub-archetypes with higher HTC than that of the sub-archetype with double glazing, roof insulation, and no insulation on the walls or floor.
   - High thermal efficiency was assigned to sub-archetypes that typically wouldn't install any additional energy efficiency measures i.e. buildings with nearly maximum levels of insulation.
   - Medium thermal efficiency was assigned to the middle bracket of sub-archetypes, which have lower HTC than the 'low' category but, could feasibly install more measures to upgrade to 'high' thermal efficiency.

   Insulation thresholds are consistent between archetypes, but HTC values are not. This means that low, medium and high are relative within an archetype, or in other words, buildings on the efficient end of 'low thermal efficiency' could in theory have a lower HTC than a building classed as having 'medium thermal efficiency' from another archetype.

   For example, archetype 17 describes a mid-terrace house which has two exposed walls and therefore has a lower average HTC than archetype 47, a detached house with four exposed walls as shown in the tables below. The efficient end of 'low thermal efficiency' for archetype 17 is sub-archetype 26, which has an HTC of 399 W/K. The corresponding sub-archetype for archetype 47 is sub-archetype 32 (it has the 32nd highest HTC within the archetype) with an HTC of 508 W/K.

For houses, there are 54 possible combinations of sub-archetypes for each archetype and for flats there are fewer. In general, the ratio of low/medium/high sub-archetypes is 40:40:20.

Parent archetype	Property type	Built form	Construction age band	Wall type	Floor type	Roof type
17 (1)	House	Mid-Terrace	before 1930	Solid wall	Suspended	Pitched
47 (2)	House	Detached	after 1930	Cavity wall	Suspended	Flat

Floor insulation	Roof insulation	Wall insulation	Window glazing	Low/Med/High classification	Sub-archetype (1)	HTC (W/K) (1)	Sub-archetype (2)	HTC (W/K) (2)
No insulation	No insulation	No insulation	Single glazing	Low	17-1	508.0	47-1	805.7
No insulation	Insulated	No insulation	Double glazing	Low	17-26	398.5	47-32	507.7
Insulated	Insulated	Insulated	Triple glazing	High	17-54	257.8	47-54	366.7

Characterising the buildings this way allows us to:

- Project changes to building sub-archetypes based on moving from low to medium, low to high, or medium to high thermal efficiency.
- Visualise changes to an area's building stock under different scenarios. See the figure below.

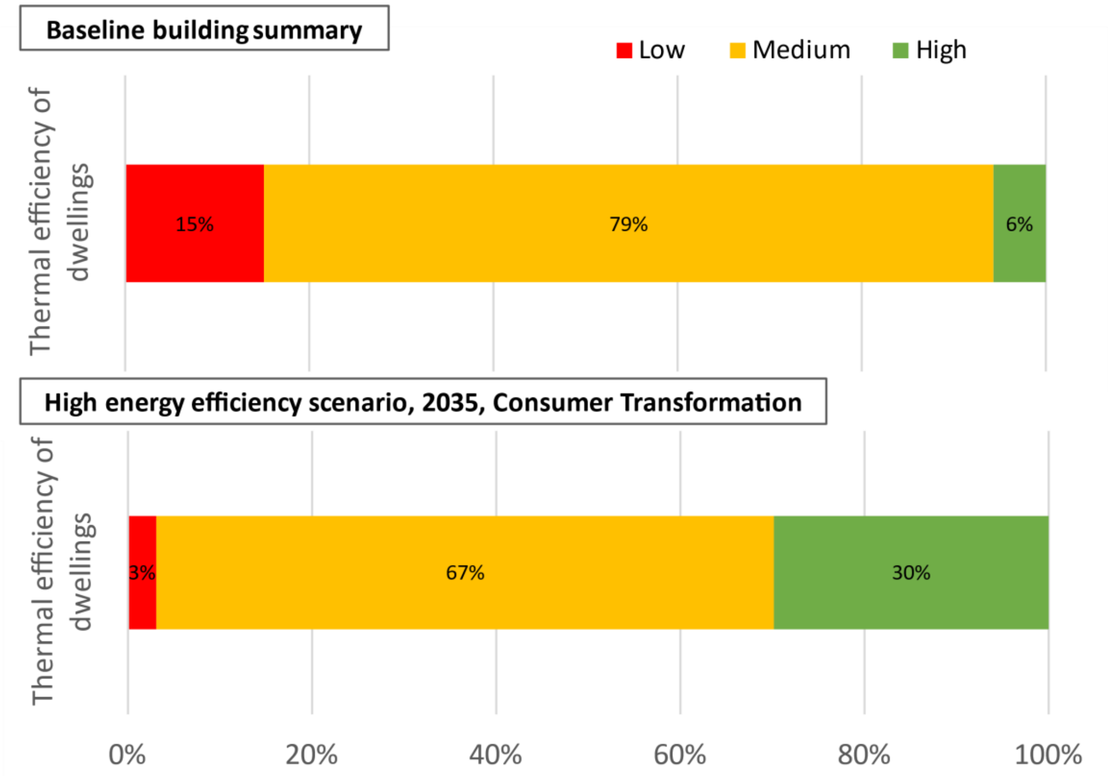


Figure 2. Example output graph for Mackworth feeder showing the change in the building stock's thermal efficiency between the current baseline level and the building stock in 2035 under a 'high energy efficiency retrofit' scenario. The low/medium/high legend refers to the thermal efficiency of buildings. The Top graph is the baseline building summary – typically most buildings are classed as having 'medium' levels of thermal efficiency. The Bottom graph is the building stock in 2035 under a high energy efficiency scenario assuming Consumer Transformation DFES rate for heat pump deployment.

- Evidence the scenario assumptions and compare results to literature. For instance, literature papers and institutions often use EPC bands to target fabric improvements e.g. minimum EPC C by the year 2050. This can be matched to a scenario that moves all low thermal efficiency properties to medium or high.

Automation

The processes described in the above sections '1.3.1. Creating a building stock database for the case study areas' and '1.3.2. Characterising the building stock' can be automated to enable quick determination of the archetype portfolio in a specified geographic area.

It is beyond the scope of the current project to build this automation. We would recommend for future use of the scenario model and the Demand Profiling tool to develop this automation.

The script would need to interface with GIS and the national EPC database. The following steps describe how it could operate:

1. Upload a geographic area. Either as a local authority area, a list of postcodes, or, as we have done in this study, a GIS Shapefile
2. Extract the relevant EPC records from the national EPC database and remove superseded records
3. Use lookup tables to simplify the relevant EPC fields and determine the sub-archetypes
4. Determine the sub-archetypes of properties with no/incomplete EPC records by extrapolating the sub-archetype counts of known properties using the number of domestic MPANs as an estimation for the number of domestic dwellings in an area

1.3.3. Projecting rates of energy efficiency measure uptake

In order to project fabric retrofit measures, we must determine the rate of interventions. This was done by linking the rate of interventions to the distribution future energy scenarios (DFES) rates of heat pump installations. This top-down approach ties the energy efficiency scenarios to the DFES scenarios to achieve one of the core objectives of this modelling exercise – to update the DFES scenario assumptions on demand reduction from energy efficiency in domestic homes. The method used is as follows:

1. Obtain 2022 DFES projections for the total volume of heat pumps (both air-source and ground-source) at a primary substation (or Electricity Supply Area) level.
2. Factor in new development projections and volumes of heat pumps installed in new dwellings to derive the deployment of heat pumps as a percentage of existing homes
3. Apply the ESA percentages to their corresponding feeder case study area for each year. This determines the number of heat pumps installed each year and varies by DFES scenario.
   The scenario tool produces three energy efficiency scenarios (high, medium and low) for each of the four deployment rates from the DFES scenarios, and projects out to 2050.

Given that >85% of properties in NGED's licence areas are fossil fuel heated, we can assume that energy efficiency measures are installed at any time between the baseline year and the year of heat pump installation as the demand reduction is only observed on the grid when the heat technology is electrified.

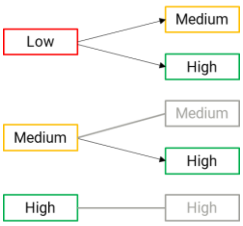
For the network analysis carried out in this study, we have used one DFES scenario – Consumer Transformation as this represents the most ambitious rate of heat pump deployment. The other two Net Zero compliant DFES scenarios (System Transformation and Leading the Way) have relatively high proportions of hybrid heat pumps, hydrogen heating, and district heat networks. For this study, we are not considering energy efficiency measures in these properties. The Falling Short scenario has low heat pump deployment and does not reach Net Zero 2050 – we considered running energy efficiency scenarios for the Falling Short DFES scenario as a base case however, due to the time it takes to run the model for all the substations and the limited additional value, we have moved this task to 'Further Work'.

1.3.4. Projecting types of energy efficiency measure uptake

This section details the assumptions regarding the degree and cost of energy efficiency measures installed alongside (or prior to) the DFES heat pump projection.

In general, the scenarios project movements in sub-archetype populations as a result of energy efficiency measures. We developed high, medium and low energy efficiency scenarios separated by the proportion of homes installing a heat pump in a given year that changes thermal efficiency from:

- Low[1] to medium
- Low to high
- Medium to high
- Stays as medium
- Stays as high



Cost optimisation

Firstly, to determine the fabric measures needed to change the thermal efficiency of an archetype, a cost optimisation module was created that selects the most cost-effective measure, or combination of measures, that upgrades the thermal efficiency of an archetype.

For example, archetype 33 describes a pre-1930 detached house with a pitched roof, solid walls and a suspended floor, and sub-archetype 33-10 has >150mm loft insulation, no wall or floor insulation, and has single glazing. The cheapest way to upgrade this property to medium thermal efficiency is to install double glazing and floor insulation (assumed easy access) which has a cost of £22,196. These measures move the sub-archetype from 33-10 to 33-37. See the figure below.

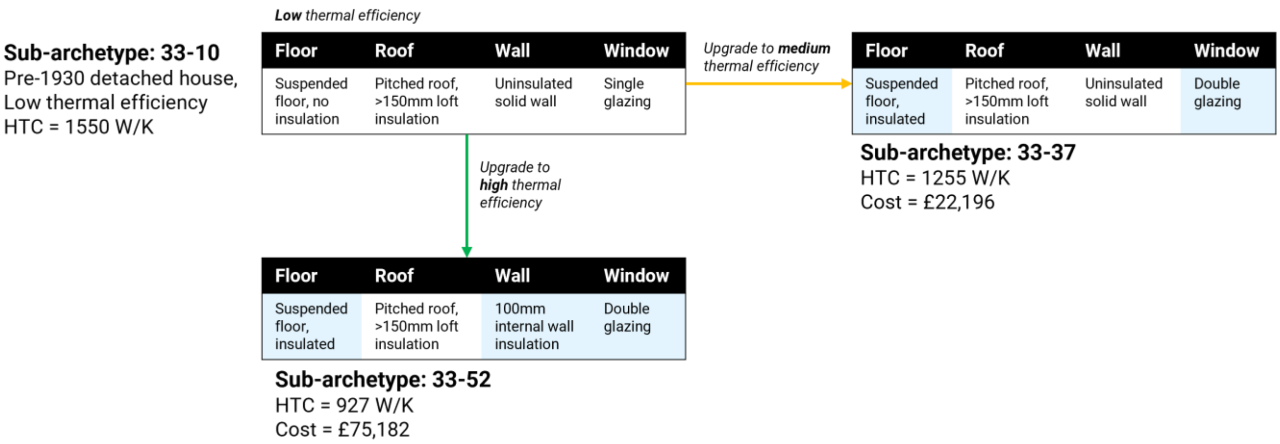


Figure 3. Diagram showing the cost optimal interventions required to move sub-archetype 33-10 (low thermal efficiency) to medium and high thermal efficiency

The cost data is Carbon Trust proprietary data using a combination of inputs including Spon's Architects' and builders' price book 2021[2], BEIS, in-house market research, published construction market data etc.

We made the following assumptions with the Spon's data:

- Pitched loft insulation happens at the joists (270mm)
- Insulation on suspended floors is assumed to be "easy access"

[1] Broadly, homes classed as having low thermal efficiency are less likely to install a heat pump due to the limited capacity of a standard air-source heat pump. High-temperature heat pumps have been ruled out due to running costs. Therefore, we have assumed in the model that homes with low thermal efficiency must move to either medium or high before installing a heat pump.

[2] Spon's Architects' and builders' price book is a paid-for dataset

- Filled cavities are assumed to be fully insulated
- Unfilled or partially filled cavities receive cavity wall insulation
- Pre-1930s solid walls receive 100mm internal wall insulation
- Post-1930s solid walls receive 200mm external wall insulation, with a higher rate for flats.

Allocating fabric measures under the high, medium and low energy efficiency scenarios

The scenario model generates three energy efficiency scenarios – high, medium and low. The DFES scenario gives the rate (i.e. the number of properties each year that install a heat pump).

The parameter settings for the different scenarios are the percentage of homes that change thermal efficiency from low to medium, low to high, and medium to high. The following rules for the scenarios were applied:

- Buildings that have high thermal efficiency do not install additional fabric upgrades in any scenario
- The high and low energy efficiency scenarios represent the extremes, where:
  - In the high scenario, all 'low thermal efficiency' buildings move to high, and all 'medium thermal efficiency' buildings move to high
  - In the low scenario, all 'low thermal efficiency' buildings move to medium, and all 'medium thermal efficiency' buildings remain as medium
- The medium scenario has been set to match the Committee on Climate Change's (CCC) Balanced Pathway in their 6th Carbon Budget[3].

Low energy efficiency scenario

Low to High TE:	0%	Medium to High TE:	0%
Low to Medium TE:	100%	Medium (no upgrade):	100%
	100%		100%

Medium energy efficiency scenario

Low to High TE:	32%	Medium to High TE:	66%
Low to Medium TE:	68%	Medium (no upgrade):	34%
	100%		100%

High energy efficiency scenario

Low to High TE:	100%	Medium to High TE:	100%
Low to Medium TE:	0%	Medium (no upgrade):	0%
	100%		100%

Figure 4. Summary logic for the energy efficiency scenarios

It is important to note, the resulting projections for the high medium and low energy efficiency scenarios are largely influenced by both the thermal efficiency that exists in the baseline housing stock, and the rate of heat pump penetration in DFES.

Summary of assumptions

- Homes classed as having low thermal efficiency will not install a heat pump without additional fabric improvements
- The model results show the fabric improvements at the point of heat pump installation, whereas in actual fact, the fabric improvements can be made between the baseline year up until the year of heat pump installation due to the impact on the electricity network
- Dwellings classed as having high thermal efficiency will not make any additional fabric improvements

[3] Committee on Climate Change's (CCC) 6th Carbon Budget
CCC Balanced Pathway projects the number of wall, floor and roof insulations out to 2050 which was used to calibrate the medium energy efficiency scenario – roughly a third of low thermal efficiency homes move to high, and two thirds to medium; two thirds of medium thermal efficiency homes move to high, and a third remain as medium

- High and low scenarios represent the extreme cases, whereas the medium scenario reflects the CCC's Balanced Pathway in their 6th Carbon Budget
- Heat pump installations each year are evenly split between low medium and high thermal efficiency (no weighting towards more efficient homes)
- Detached and semi-detached homes are the early adopters of heat pumps, while flats adopt heat pumps later in the scenario period. As the DFES heat pump penetration does not reach 100% in 2050 in the most ambitious scenario, some flats will not change from the baseline heat technology and thermal performance
- When there is a mix of heating technologies in the baseline for a single archetype, the model assumes that fossil fuel-heated homes are converted to heat pumps first, then direct electric, and finally, night storage heaters last.
- The Spon's Architects' and builders' price book data was converted into a usable format using EPC building dimensions for the cost optimisation

Outputs

The scenario model takes a baseline building stock in the format of sub-archetype counts by heat technology, and outputs a new building stock in the same sub-archetype format. Building stocks written in this format can be directly uploaded to the Demand Profiling Tool (created in the first modelling exercise) to calculate a daily, or annual, aggregated electricity profile.

This was done for the three case study areas to produce 36 scenarios with the following conditions:

- Three case study areas (with 32 substations across them)
- Two DFES scenarios to represent the highest and lowest rate of heat pump uptake (Consumer Transformation and Steady Progression)
- Two benchmark years (2030 & 2050)
- Three energy efficiency scenarios (high, medium, low)

The 36 scenario sub-archetype counts were uploaded to the Demand Profiling Tool and profiles were created for four representative weather days in each of the benchmark years. This was then provided to GHD for further network modelling.

The cost optimisation module was provided to Frontier Economics to support their analysis of building interventions. The cost optimisation module identifies suitable fabric measures for all the commonly occurring sub-archetypes to upgrade them from low to medium thermal efficiency, medium to high, and low to high. It also specifies the cost of the fabric measures and the associated reduction in heat transfer coefficient (HTC), used for heat demand calculation.

1.4. Limitations, further use and recommendations

Limitations

The approach taken in this analysis has potential limitations:

- Updates or adjustments would be required to enable replicability of the modelling across other Distribution Network Operators (DNOs). The points below explain what aspects of the modelling this affects:
  - HTC calculations – we used a representative sample of homes to obtain average building dimensions for each archetype which was used in the calculation of thermal properties including HTC. This representative sample featured buildings exclusively on NGED's network.
  - Cost of energy efficiency measures – the building dimensions from the same representative sample were used to estimate costs for energy efficiency measures
  - DFES heat electrification rates – each DNO produces their own DFES at a granular level, therefore, using heat electrification as a proxy for the rate of energy efficiency measures is replicable across the DNOs
  - Outputs – the outputs of the Demand Profiling tool are set up to interface with SINCAL(NGED's network flow tool). For DNOs that do not use SINCAL for their network flow analysis, two options are available. Firstly, the user has the option of using the "Export to csv" function, which allows the time and date and demand profile to be downloaded to csv and any further adjustments eg mapping to substations can be performed outside of the Glow Tool. Alternatively, the Glow Tool has been made open source, allowing the user to make modifications to the underlying code to alter the format of downloads to suit their requirements.
  - Address dataset – the building stock database uses Ordnance Survey address data, specific to the case study area. This data was provided to the Carbon Trust by NGED under a Contractor license for the sole purpose of completing this project. Equivalent address data would need to be sourced for the analysis to be replicated by other DNOs.

- EPC coverage is typically around 60%, therefore, an extrapolation method was used to complete the building stock database. This means that while the sub-archetype counts are not fully accurate, they reflect the most likely sub-archetype counts for each case study area.

- The model uses a unique archetype framework which requires processing EPC data to determine the sub-archetype of a property, or group of properties. There are a few ways to do this:
  - Use lookup tables (provided by Carbon Trust) on a subset of EPC data to determine the sub-archetype counts
  - Run the model using only commonly occurring sub-archetypes to represent all homes. This is a quick and easy way to use the tool and provides a rough estimation of demand reduction from energy efficiency.
  - Use the Demand Profiling Tool's automated sub-archetype profiling function from geographic area input. This function will not be available before the end of the project and is instead listed as a recommendation for further use.

- The scenario model selects the cost optimal combination of measures to upgrade an archetype, irrespective of the heat technology installed. It is possible that in a few cases, the type of new or existing heat technology will influence the optimal energy efficiency measures being installed e.g. if pipework needs upgrading in a wall or floor then the property owner may choose to insulate as well.

- High-temperature heat pumps have not been considered in this analysis due to their low penetration in domestic settings. High-temperature heat pumps are mainly used for industrial and commercial applications, and in some cases, large inefficient domestic buildings where energy efficiency upgrades are not feasible e.g. listed buildings. It is possible that a dwelling with 'low' thermal efficiency can install a high-temperature heat pump, though it is generally more financially favourable to install a regular heat pump with energy efficiency upgrades.

- The analysis also does not consider other forms of heating projection in the DFES beyond what is already in the baseline, such as storage heaters, heat networks, and hydrogen. The DFES scenario used in the analysis, Consumer Transformation, was chosen because of its high uptake of heat pumps.

- The top-down approach of linking the scenarios to DFES rates of heat pump installations fulfils a core objective of this modelling task, but it doesn't consider other factors that could be used to determine the rate of interventions e.g. regional historic rates of fabric upgrades, local schemes, stakeholder engagement, national policy and funding.

- The model only considers interventions in existing homes. It does not include new developments.

- The demand profiling of future scenarios relies on historic smart meter and weather data (i.e. from 2017 to present) and therefore does not consider future changes in consumption patterns. This period also features behaviour changes as a result of COVID-19 which we have chosen to include in the analysis as it reflects new flexible working practices.

Ongoing usage of the scenario forecasting tool

There are three main inputs that would need to be updated for ongoing use of the scenario tool:

- Energy efficiency measure cost data – the costs reflect current market prices which can change over time
- Rate of heat electrification – DFES data is updated annually for every DNO
- Baseline building stock – the baseline building stock is taken from EPC data whose entries are updated regularly. For any new analysis, the latest EPC data would have to be extracted to get a more accurate archetype portfolio

So far, the scenario tool has been used to generate energy efficiency scenarios that are linked to DFES for the purpose of investigating future domestic loads on 32 substations across three feeder areas. The tool can further be used beyond the timeline of this project to support the following types of analysis:

- Generate energy efficiency scenarios for any area on NGED's network, by uploading the relevant DFES volumes and sub-archetype counts from an analysis of EPC records. This could be of value to local authorities undergoing local area energy plans.

- Estimate domestic energy demand reduction from fabric efficiency measures. The granularity is flexible – the user can choose a single archetype to represent all homes connected to NGED's network, or a known portfolio. The user can also analyse different network hierarchies e.g. secondary substation and feeder level (as we have done in this analysis), primary substation or ESA level, licence area level, or all four licence areas.

Recommendations for further development

- Align or integrate energy efficiency scenarios with DFES analysis.
  Currently, the scenario tool and the DFES use different archetype frameworks. In this project, the impact and cost of energy efficiency measures were assessed by differentiating dwellings in terms of their built form, age, and construction type, whereas in the 2022 DFES, archetypes are based on factors that influence heat technology projections (e.g. on/off gas, night storage, EPC B+, tenure etc.). It is possible

to combine the two frameworks by grouping construction types and insulation parameters and merging them with heating technologies. All these factors can be derived from the EPC database.

- Tracking of energy efficiency installations.
  The EPC database provides a good estimation of the baseline levels of energy efficiency but does not capture efficiency upgrades in real time. In the absence of a centralised database that tracks retrofit upgrades, we suggest one of the following two methods:
  - Continue using EPC data, but with a more tailored approach to the extrapolation that only considers the most recent records. For example, if the most recent EPC record in an uninsulated block of flats shows that recent upgrades have taken place, then the whole block can be assumed to be insulated.
  - As part of NGED's domestic customer connections process (mainly used for EVs and heat pumps), include an additional form asking residents for information on energy efficiency.

- Integrating/combining the scenario and demand profiling tools with other NGED models.
  The tools produced in this study examine the impacts of energy efficiency and heat pump uptake on the Low Voltage (LV) network. The validity of the outputs diminishes with time as additional LV loads, not captured in the project, are connected to the network e.g. Electric Vehicles (EVs) and rooftop solar PV. We recommend combining the relevant tools NGED use to study the LV network to produce more accurate profile forecasts.

- Further detailed analysis of the three case study areas by running the energy efficiency scenarios (at a substation level) for the Falling Short DFES scenario which would give a base case comparison.

- Automation of steps 1.3.1. and 1.3.2. This is described in more detail at the end of section 1.3.2.