Demand Forecasting Encapsulating Domestic Efficiency Retrofits (DEFENDER)

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1. Executive Summary

Net Zero decarbonisation of domestic building stock is expected to be achieved through a combination of: low carbon heating (primarily through electrified heat pumps); smart tariffs and demand management incentive schemes; and energy efficiency retrofits of building fabric. Understanding the net effect of these measures in combination is crucial for accurate electricity network forecasting, but the representation of this interactivity in forecasting best practice is minimal. In particular, the influence of building fabric on heat pump performance, as modulated by Energy Efficiency (EE) retrofits, is captured in limited fashion. Furthermore, it is currently unknown whether adoption of EE measures is a cost-effective option for networks to mediate or obviate reinforcement or flexibility costs.

Demand Forecasting Encapsulating Domestic Efficiency Retrofits (DEFENDER) is a project which used smart meter data, machine learning, retrofit planning tools and economic modelling to create tools to improve understanding of the impact of EE retrofits on domestic electricity demand. The project aimed to develop the capability of electricity networks to integrate assessment of the impact of EE retrofits into network forecasting tools, and understand the business case for retrofit investment as an alternative to reinforcement or flexibility.

The project developed an analysis tool ("Glow Simulator") capable of generating load profiles for a series of house archetypes determined by fixed and changeable form and fabric factors derived from the Energy Performance Certificate (EPC) database. Heat demand (electrical or non-electrical) for each archetype was deduced from Heat Transfer Coefficients (HTC) calculated from gas smart meter data, modelled retrofit impacts on building heat loss (U factor) and heating requirements derived from the difference between set desired internal temperature and real or modelled external temperatures. This allowed for customer heating behaviour to be estimated from a much wider pool of real heating data compared to limited datasets of heat pump usage.

DEFENDER created energy efficiency scenarios for domestic retrofits to generate substation demand profiles in the Glow Simulator. It developed a methodology for using these profiles in network modelling studies to integrate the forecasting of volumes of EE uptake in the Distribution Future Energy Scenarios (DFES). This approach was trialled and validated in a case study of three 11kV feeders on National Grid Electricity Distribution's (NGED) network. A cost-benefit analysis assessed the long-term costs and benefits of energy efficiency to distribution network operators (DNOs) on a per-archetype basis, using the archetypes developed for the tool.

Furthermore, DEFENDER analysed the existing process that NGED uses to make investment decisions when it identifies network constraints. It developed a set of tools to integrate into these processes to include the effect of EE retrofits on flexibility and reinforcement solutions. By comparing the costs with and without retrofit, a maximum "Ceiling Price" DNOs could be willing to pay for EE was calculated.

The areas of NGED's network where the Ceiling Price was highest were identified. An economic analysis examined the features of these network areas that most influenced Ceiling Price to understand the extent of the business case for DNO energy efficiency investment. From this, it identified the potential schemes by which DNOs could proportionally invest in EE retrofit.

Studies using outputs of the Glow Simulator found that the difference between the demand profiles for the low, medium and high EE scenarios in the case study areas investigated was small in 2030 and 2050 (less than 4% in 2050). However, the average load factor for all distribution substations considered increased by 25.9%. This increase, corresponding to flattening of the profile shape, represents a potential loss of cyclic capability.

Additionally, DEFENDER found that it is unlikely that capex-based EE grants that are similar to or less than the DNO's Ceiling Price will make a significant difference to consumer behaviour in most instances where the consumer would not have ever installed measures. Instead, take-up would be more efficiently incentivised by attempting to bring forward EE investment that would otherwise occur too late for the DNO's purposes.

2. Project Background

Net Zero decarbonisation of domestic building stock is expected to be achieved through a combination of: low carbon heating (primarily through electrified heat pumps); smart tariffs and demand management incentive schemes; and energy efficiency retrofits of building fabric. Understanding the net effect of these measures in combination is crucial for accurate electricity network forecasting, but the representation of this interactivity in forecasting best practice is minimal. In particular, the influence of building fabric on heat pump performance, as modulated by energy efficiency retrofits, is captured in limited fashion. As such, future domestic electricity demand, and therefore network reinforcement requirements, may currently be overestimated. Furthermore, it is currently unknown where there is a business case for DNOs promote adoption of energy efficiency measures as a cost-effective option to mediate or obviate reinforcement or flexibility costs.

3. Scope and Objectives

DEFENDER is a project which used smart meter data, machine learning, retrofit planning tools and economic modelling to create tools to improve understanding of impact of energy efficiency retrofits on domestic electricity demand. The project aimed to develop the capability of electricity networks to integrate assessment of the impact of energy efficiency retrofits into network forecasting tools, and understand the business case for retrofit investment as an alternative to reinforcement

The objectives for DEFENDER are given in the table below. An explanation of the assessed status is given in Section 6 (Performance Compared to Original Aims, Objectives and Success Criteria).

Table 3-1: Status of project objectives

Objective	Status
Develop an understanding of the electricity demand profile of UK domestic building stock pre- and post-retrofits to building fabric.	✓
Produce a methodology for integrating pre- and post-retrofit domestic demand profiles into network forecasting.	✓
Assess the potential savings on network reinforcement and flexibility from accounting for energy efficiency in demand forecasting.	✓
Perform an economic assessment of the potential benefits to networks from increased penetration of domestic retrofit interventions.	✓

4. Success Criteria

The success criteria for DEFENDER are given in the table below. An explanation for the assessed status is given in Section 6 (Performance Compared to Original Aims, Objectives and Success Criteria).

Table 4-1: Status of project success criteria

Success Criteria	Status
A profiling tool will be delivered which is capable of generating archetype demand profiles for domestic buildings pre- and post-retrofit, including transference from gas to electric heating.	✓
An investment appraisal tool will be delivered which is capable of supporting analysis of the business case for WPD [1]investing or promoting energy efficiency as constraint management option.	✓
The economic assessment will identify what, if any, are the most certain potential benefits to networks from energy efficiency.	✓
The economic assessment will identify what, if any, are the opportunities to pursue these benefits within the existing regulatory and commercial landscape.	✓
The profiling tool will be reusable and can be re-run with updated data.	✓
The outputs of these tools can be integrated into distribution network forecasting and planning.	✓
The methodology for the tools will be replicable across all distribution networks.	✓

[1] Now National Grid Electricity Distribution (NGED)

5. Details of the Work Carried Out

The project was delivered in three workstreams, as detailed below:

Workstream 0. Specification

This workstream carried out workshops with all project partners and NGED internal stakeholders involved in the DFES and Distribution Network Options Assessment (DNOA) processes. The aim of these workshops was to understand the following:

- Key research questions to answer regarding the cost effectiveness of energy efficiency
- How the tools and models produced in this project are intended to be used as part of BAU
- How constraint management decisions are made and the tools which are used
- Intentions to evolve these tools in RIIO-ED2 or beyond
- Key interfaces between the profiling tool, building stock mapping and network models
- Desired model validation and handover processes

This activity allowed the development of two specification documents, one for each of the subsequent workstreams. These specifications outlined the scope of activity and the requirements of the toolset to be developed in each of the workstreams.

Workstream 1. Development of Pre- and Post-Retrofit Profiling Tool

This workstream developed an analysis tool (“Glow Simulator”) capable of generating load profiles for a series of house archetypes derived from fixed and changeable form and fabric factors based upon fields in the Energy Performance Certificate (EPC) database. Bayesian techniques were applied to generate probabilistic load profiles from a smart meter database of over 6000 homes. The tool was developed in modular fashion, including modules for:

- Calculating electrical baseload for each house archetype
- Calculating heat demand for each house archetype
- Creating aggregated demand profiles for a user-defined mix of house archetypes
- User interface with the tool

Heat demand for each archetype was derived from Heat Transfer Coefficients (HTC) calculated from gas smart meter data, modelled retrofit impacts on building heat loss (U factor) and heating requirements derived from the difference between set desired internal temperature and real or modelled external temperatures. This allowed for customer heating behaviour to be estimated from a much wider pool of real heating data compared to limited datasets of heat pump usage.

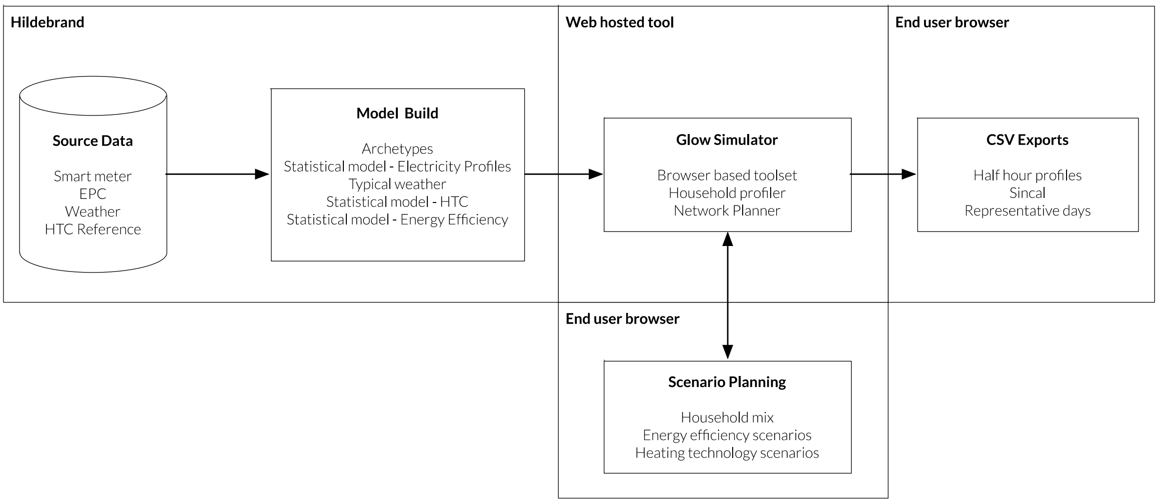

Figure 5-1. Overall system components

Concurrently, Workstream 1 created future energy efficiency scenarios for domestic homes which could be used to generate substation demand profiles in the Glow Simulator. A methodology was developed for using these profiles in network modelling studies to improve the forecasting of volumes of energy efficiency uptake in the Distribution Future Energy Scenarios (DFES). This was implemented in 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. This approach was trialled and validated in a case study of three 11kV feeders on NGED's network. Furthermore, an analysis was carried out to assess the long-term costs and benefits of energy efficiency to DNOs on a per-archetype basis, using the archetypes developed for the tool.

Workstream 1 was delivered in five work packages:

Work package 1.1. Tool development part one: Pre- and post-retrofit demand and half-hourly profiles.

This work package developed the modules for calculating the electrical baseload in terms of After Diversity Maximum Demand (ADMD) and heat demand for each house archetype.

The archetype structure and selection methodology from the EPC database developed in work package 1.4. was applied to the smart meter dataset. The rationale for the methodology was demonstrated through an analysis of the statistical separability between house archetypes.

The Bayesian models for calculating electrical baseload and heat demand, and the adjoining energy efficiency impact model were created and implemented in Python code. These models were validated via a comparison with published profiles and use of Bayesian model metrics to test robustness.

The user interface for the household-level elements of the Glow Simulator were developed in this work package, including tools for generating and visualising archetype and sub-archetype profiles and libraries for storage and retrieval of archetype and profile data.

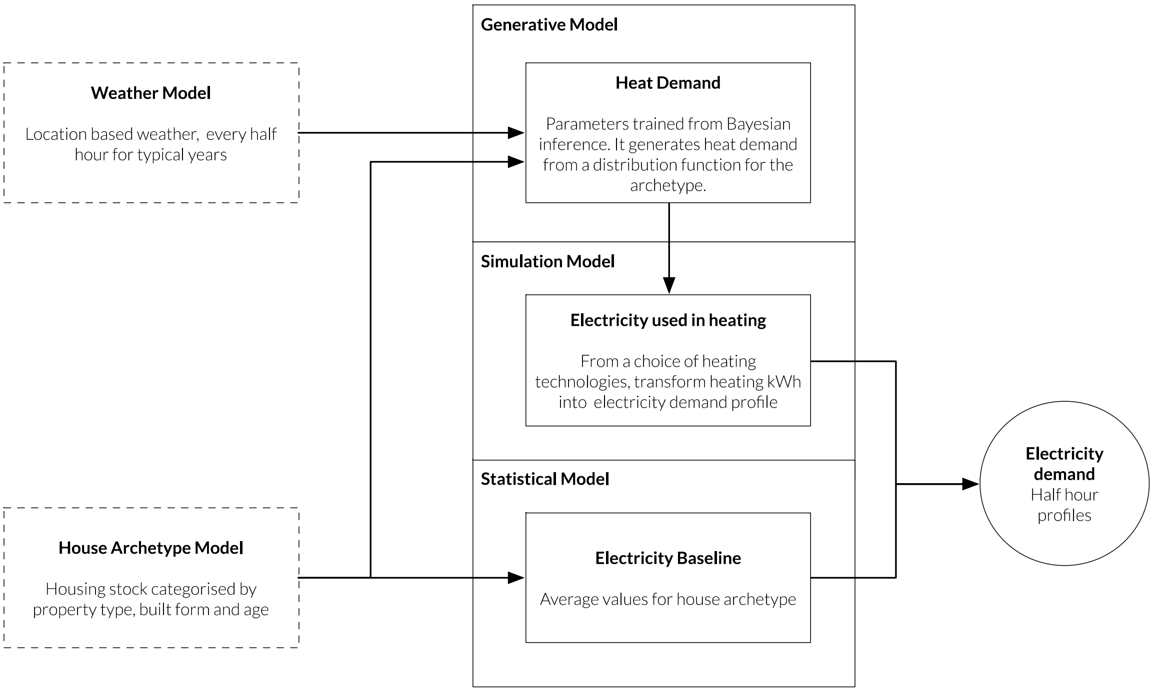

Figure 5-2. Model elements used to generate data

Work package 1.2. Tool development part two: Network planning outputs

This work package developed the module for constructing network scenarios defined by a mix of housing stock.

The Network Planner module constructs scenarios, using house archetypes generated by the models developed in WP1.1 and weather/location as input. This allows for scenario comparison of load profiles based on heating technology while considering energy efficiency measures.

The user interface for the Network Planner was developed to aid in selecting a group of buildings, assigning archetypes and then showing the combined electricity consumption profile for the group. Currently there are three input methods: manually defining archetypes, inputting a .csv file of numerically coded archetypes (see WP1.4 below) or loading a pre-saved scenario .json file.

Network planning level outputs were formatted at the tool level to be compatible with the PSS SINCAL modelling tool. The model simply generates data for each of the households, with the tool tagging, grouping and aggregating the results for feeder and substation levels. A SINCAL compatible file is simply a Comma Separated Values (CSV) file of readings and dates, therefore is easily translated to other network modelling tools in the future.

The outputs of the tool were validated against historic datalogger readings from three locations in NGED’s licence area.

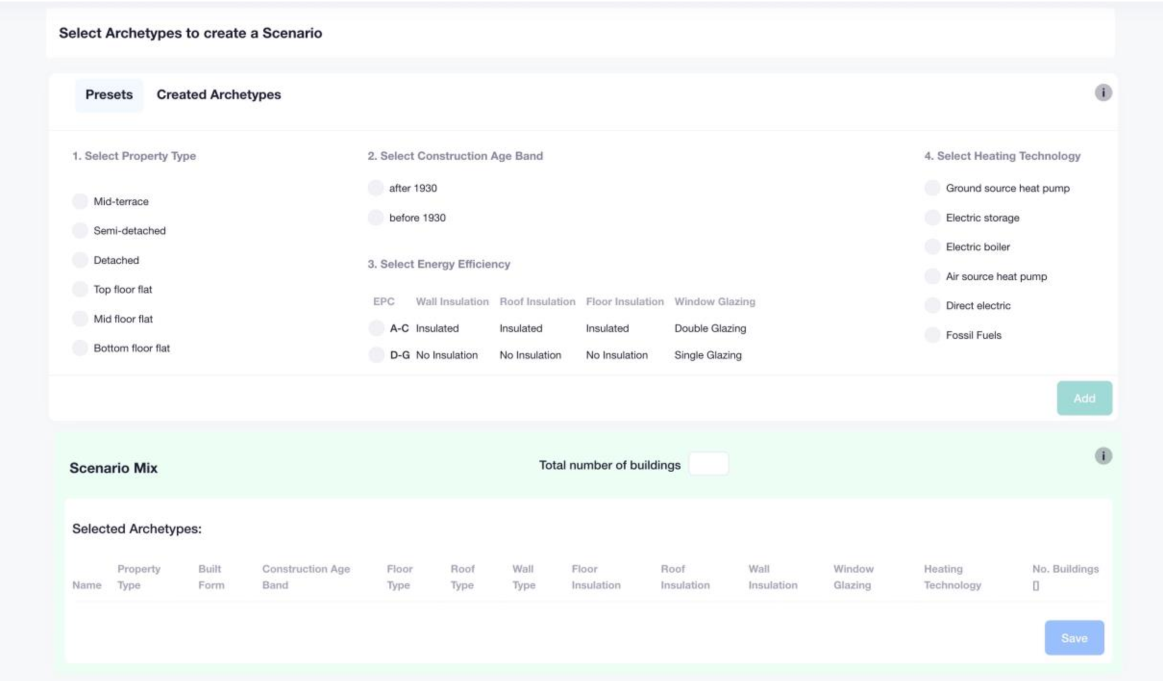

Figure 5-3. Generating a scenario from archetypes

Figures 5-4, 5-5 and 5-6 show example house-level outputs of the tool. These show a base archetype of a post-1930 mid-terrace house with a flat roof and solid floor. Figure 5-4 shows the archetype baseload demand. Figure 5-5 shows the sub-archetype with a ground source heat pump fitted with “low” insulation levels. Figure 5-6 shows the sub-archetype with a ground source heat pump and “high” insulation levels.

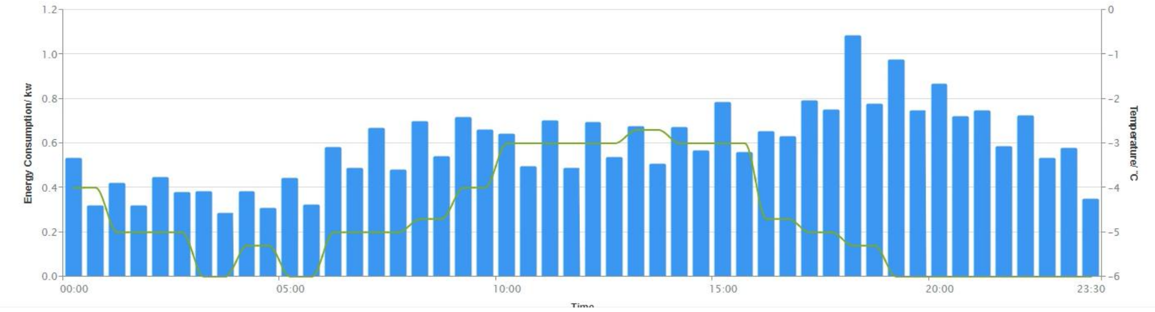

Figure 5-4. Post-1930 mid-terrace house with flat roof and solid floor, electrical baseload

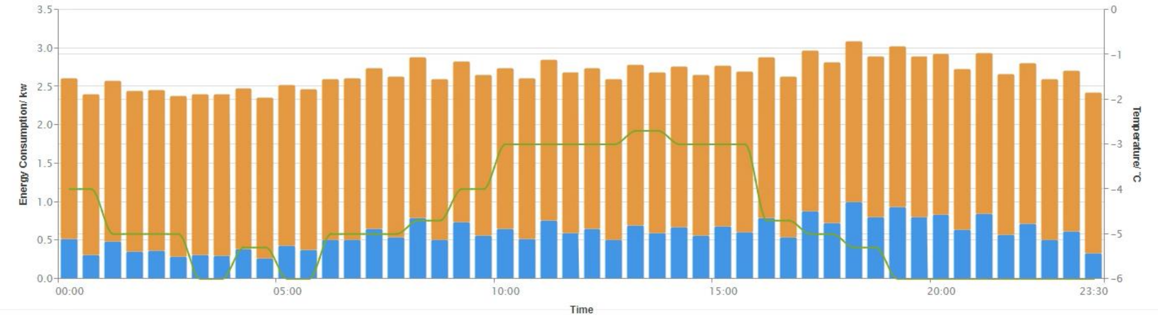

Figure 5-5. Post-1930 mid-terrace house with flat roof and solid floor, electrical baseload plus ground source heat pump with “low” insulation

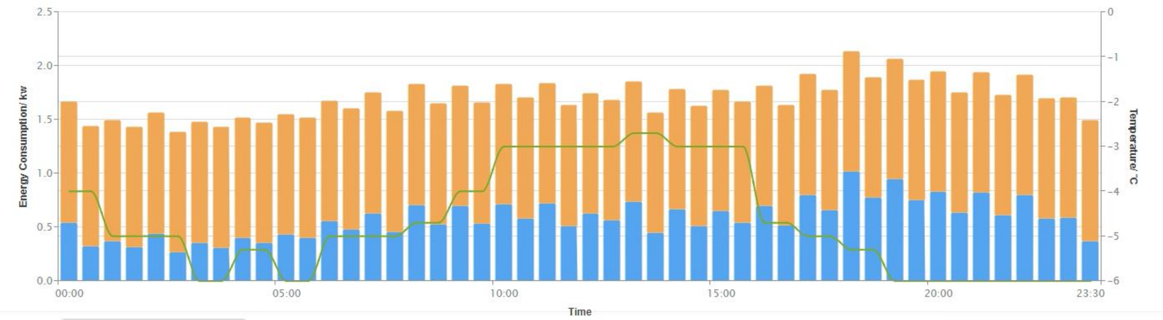

Figure 5-6. Post-1930 mid-terrace house with flat roof and solid floor, electrical baseload plus ground source heat pump with “high” insulation

Work package 1.3. Testing of profiling tool

This work package integrated the modules developed in WP1.1 and WP1.2 into a singular tool and user interface, the Glow Simulator.

Stakeholders carried out User Acceptance Testing (UAT) of the Glow Simulator to ensure its interface met functionality criteria and the outputs could be successfully integrated into PSS SINCAL power system models. The Glow Simulator was assessed as achieving a Minimum Viable Product (MVP) state, meeting its core functionality specifications. The main issues and changes can be found in Table 9-1 in Section 9.

This work package also developed the user guide for the Glow Simulator and produced the final as-built specification for the tool.

Work package 1.4. Applying the profiling tool to DFES forecasting

This work package was carried out in two parts.

In the first part, a literature review analysed existing scenario modelling approaches that have attempted to integrate energy efficiency scenarios into heat demand modelling.

Subsequently, the project team developed a methodology for creating a building stock database of house archetypes from the EPC database for network areas. This method characterises archetypes into low, medium and high thermal efficiency and defines the cost optimal approach to transition between efficiency categories. DFES scenarios define the rate of interventions transitioning the building stock between efficiency categories.

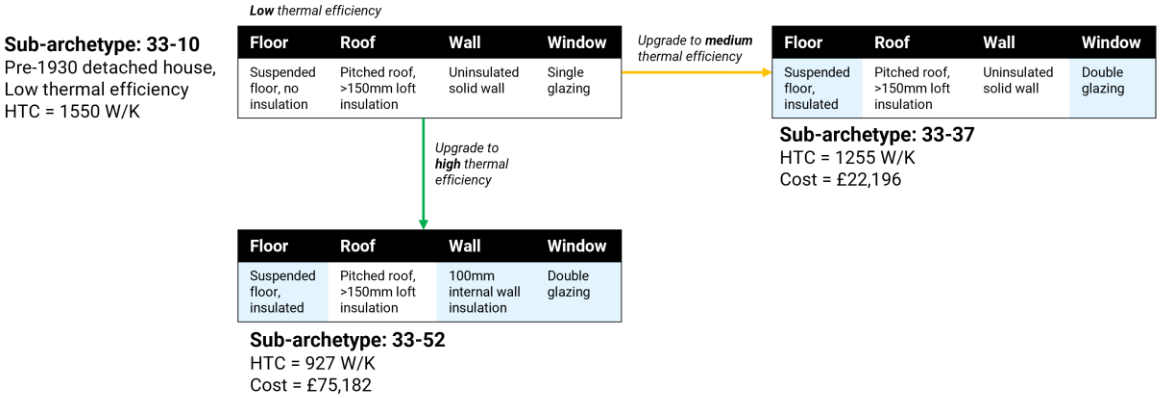

Figure 5-7. Example of a cost-optimal energy efficiency transition

In the second part, the scenario methodology was used to define energy efficiency scenarios within the Customer Transformation DFES scenario for uptake of heat pumps on three NGED 11kV feeders. Demand profiles for each distribution substation in each scenario were generated using the Glow Simulator. A load flow analysis compared the implications for network loading depending on efficiency scenario.

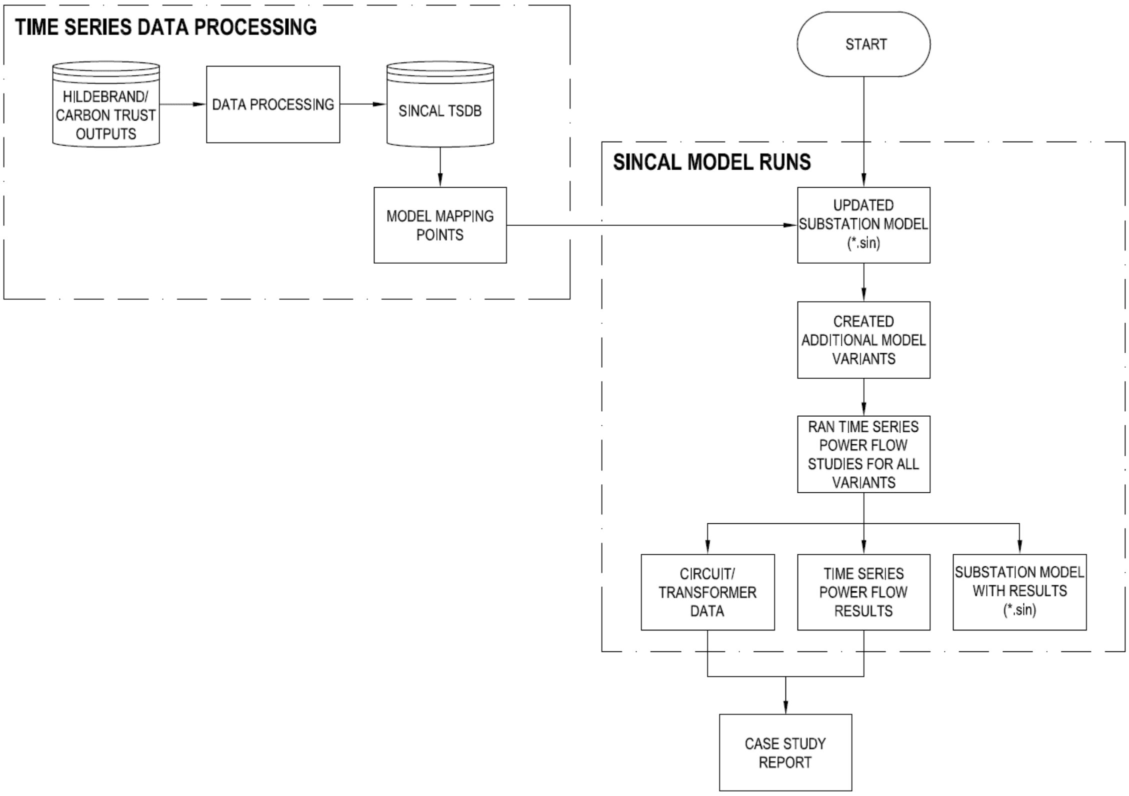

Figure 5-8. Time series study process diagram

Work package 1.5. Cost-benefit analysis of energy efficiency improvement

This work package carried out an analysis of the costs and benefits to the DNO for individual and combinations of energy efficiency interventions at both the individual house-level and the network level. This differs from the approach in Workstream 2, which looked to identify and assess specific commercial approaches to DNOs investing in energy efficiency within near-term RIIO timescales in defined network areas.

The house-level Cost Benefit Analysis (CBA) categorised the existing 100 most prevalent house sub-archetypes in NGED's licence area into low, medium and high energy efficiency categories, based on the current levels of thermal energy efficiency measures installed. The most cost-effective interventions for upgrading low efficiency homes to either medium or high categories and existing medium homes to high levels of energy efficiency were identified for each house archetype. A discounted cashflow analysis was completed for these archetypes to assess:

- Change in annual electricity consumption (kWh)
- Change in peak load (kW)
- Average annual operating cost saving (£/annum)
- 30-year Net Present Value (NPV) (£)
- Discounted payback period (years)
- Lifetime carbon savings (tCO_2)

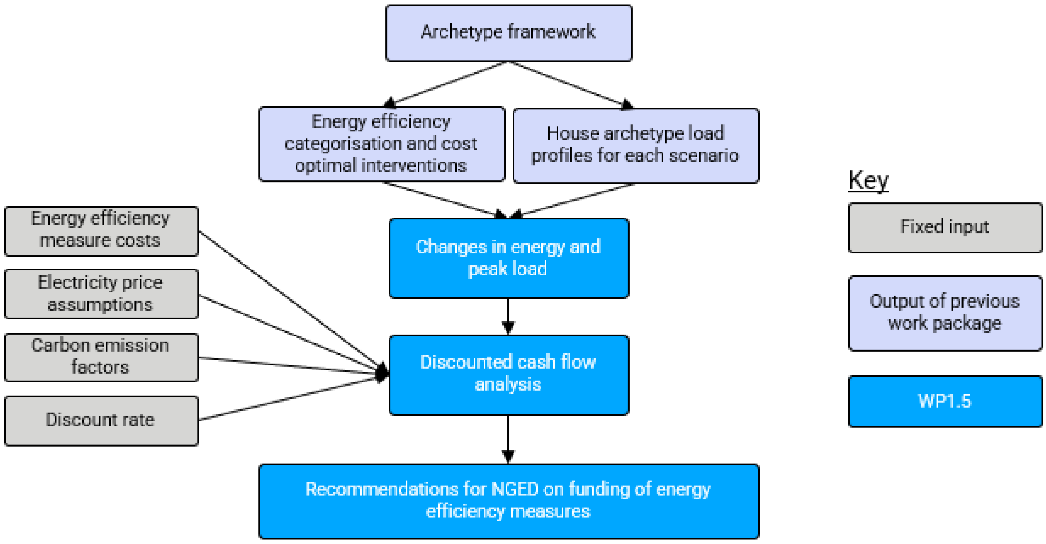

Figure 5-9. Inputs and approach to CBA

Workstream 2. Appraising investment in energy efficiency

This Workstream appraised the potential business case for DNOs investing in energy efficiency as an alternative to or in concert with flexibility or traditional reinforcement.

The Workstream team analysed the existing DNO process that NGED uses to make investment decisions when DFES forecasts or the Network Development Plan (NDP) identify network constraints. This included the Common Evaluation Methodology (CEM) used by every DNO and NGED's Flexibility Analysis Tool (FAT). It developed a set of tools to integrate into these processes to include the effect of energy efficiency retrofits on flexibility and reinforcement solutions, such as by decreasing flexibility costs or deferring reinforcement. By comparing the costs with and without retrofit, a maximum "Ceiling Price" that DNOs should be willing to pay for energy efficiency was calculated.

The areas of NGED's network where the Ceiling Price were highest were identified. An economic analysis examined the features of these network areas that most influenced Ceiling Price to understand the extent of the business case for DNO energy efficiency investment. Based on this, the potential schemes by which DNOs could invest proportionally invest in energy efficiency retrofit were identified.

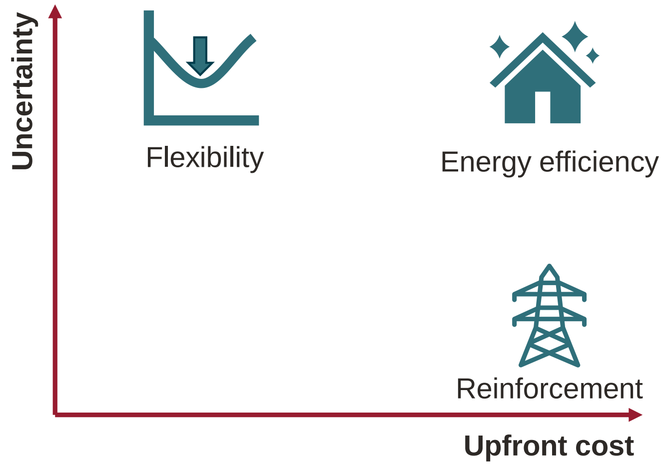

Figure 5-10. Characteristics of different DNO interventions

Work package 2.1. Development of investment appraisal tool

This work package created tools for constraint management optioneering, capable of assessing the value of energy efficiency retrofit, while accounting for uncertainty in investment outcomes. These tools consist of:

- An 'EE tool' which adjusts the profiles used in the FAT to account for a specified EE intervention (the DNO can adjust the intervention that is modelled); and
- An 'EE benefit calculator' which determines the DNO's 'Ceiling Price' for the EE intervention.

Initially, these tools were developed without reference to the profiles developed in Workstream 1, as a risk management measure in the event that Workstream 1 was unsuccessful. The effect of energy efficiency on demand was modelled using the Energy System Modelling Environment (ESME) data on space heat requirements before and after EE combined with heat pump profiles developed in the 2014 Customer-Led Network Revolution (CLNR) [check funding source] project.

Workstream 1 was successful and produced a capability to generate pre- and post-retrofit demand profiles. The tools developed in Workstream 2 were adjusted accordingly to incorporate the Workstream 1 approach to modelling and profiles generated by the Glow Simulator.

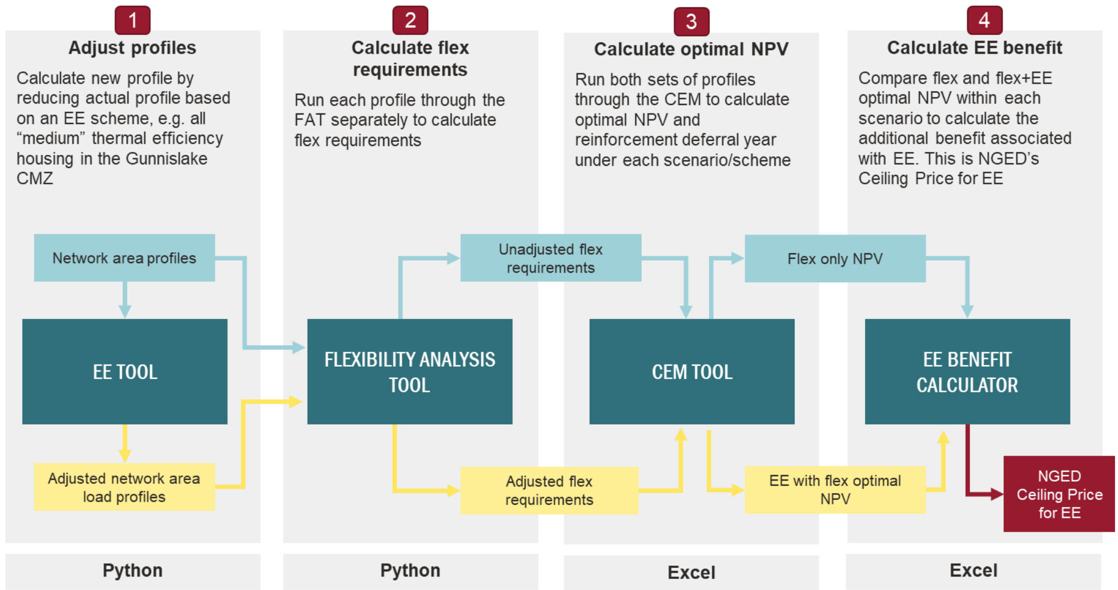

Figure 11. EE assessment process

Work package 2.2. Analysis and insights

This work package used the tools developed in WP2.1, to analyse the investment case for DNOs to pay for retrofit of domestic homes. Specifically, it used the tools to identify the main drivers of value to NGED (or other DNOs) for an EE intervention in terms of deferred reinforcement and/or reduced flexibility requirements. It also identified the types of areas where the value is likely to be highest.

The analysis considered the broader drivers of value for entities other than DNOs. This includes the value of carbon savings, and whole system benefits such as reduced power flows on the transmission network. It also quantified the private costs and benefits of EE measures incurred by property owners, which will affect the level of incentive DNOs may need to provide to bring about an EE retrofit. The risks and uncertainties involved in EE interventions were identified and built into the tools to carry out a “least worst regrets” (LWR) analysis to show how uncertainties may affect the overall value of EE interventions to DNOs.

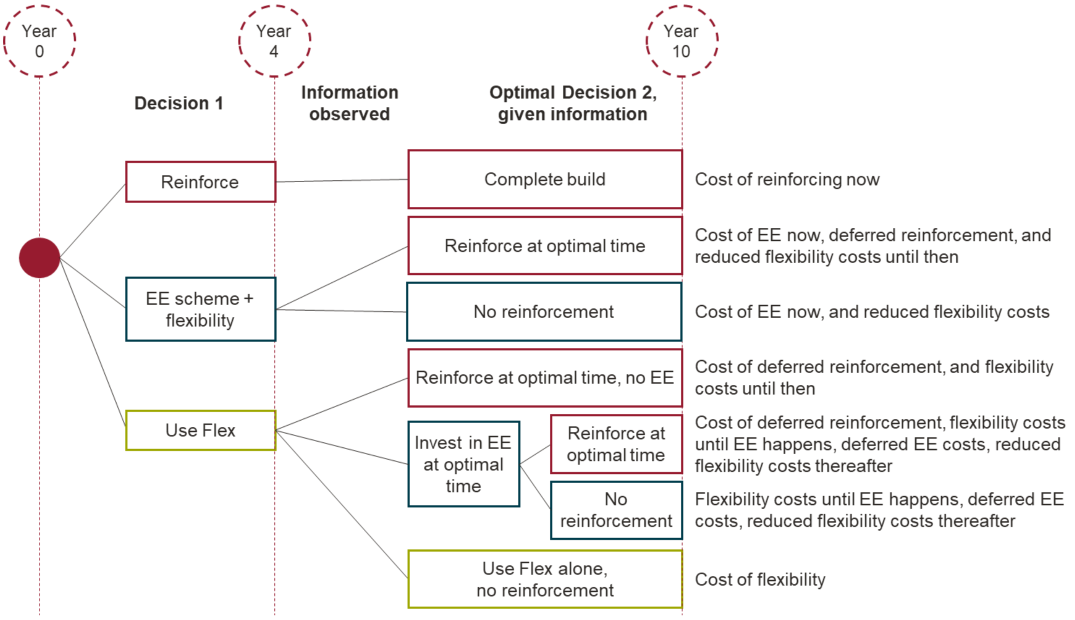

Figure 5-12. Decision tree underlying LWR approach

The analysis above was brought together to estimate over what proportion of NGED’s network there might be a positive value from engaging in EE interventions. Suggestions for some high level ways to implement these interventions were developed based on these findings. This includes the types of commercial arrangement which may help maximise value from EE interventions. The next steps to rolling EE interventions out towards Business as Usual (BAU) over the course of RIIO-ED2. This includes a suggested plan of action, as well as identifying any areas where regulatory intervention may be required.

6. Performance Compared to Original Aims, Objectives and Success Criteria

Table 6-1: Performance compared to project objectives

Objective	Status	Performance
Develop an understanding of the electricity demand profile of UK domestic building stock pre- and post-retrofits to building fabric.	✓	A toolset has been developed which can generate demand profiles of houses pre- and post-retrofit to building fabric based on real data. Analysis using these profiles in both network modelling and assessing investment options to manage constraints has greatly increased understanding the impact of energy efficiency on the demand profile on areas of the electricity network.
Produce a methodology for integrating pre- and post-retrofit domestic demand profiles into network forecasting.	✓	A methodology has been developed which ties energy efficiency retrofit scenarios into existing modelling of the adoption of electrified low carbon heating in Distribution Future Energy Scenario forecasts.
Assess the potential savings on network reinforcement and flexibility from accounting for energy efficiency in demand forecasting.	✓	A network investigation has compared electrical heating demand growth scenarios, accounting for different potential retrofit adoption scenarios. It assesses the impact of these retrofit adoption scenarios on the peak and shape of the load profile and provided learning on how this may impact network planning.
Perform an economic assessment of the potential benefits to networks from increased penetration of domestic retrofit interventions.	✓	An economic analysis has been published which uses a suite of tools developed in the project to assess the value of energy efficiency to the networks.

Table 6-2: Status of project success criteria

Success Criteria	Achieved	Performance
A profiling tool will be delivered which is capable of generating archetype demand profiles for domestic buildings pre- and post-retrofit, including transference from gas to electric heating.	✓	A tool has been developed which is capable of generating demand profiles for a set of house archetypes, with sub-archetypes dependent on level of house retrofit. Heating demand is derived from gas smart meter data, and through modelling can be mapped onto a variety of electrified heating sources.
An investment appraisal tool will be delivered which is capable of supporting analysis of the business case for WPD investing or promoting energy efficiency as constraint management option.	✓	A suite of tools have been developed which integrate energy efficiency into optioneering processes to identify the maximum value of an energy efficiency solution in managing an identified constraint.

Success Criteria	Achieved	Performance
The economic assessment will identify what, if any, are the most certain potential benefits to networks from energy efficiency.	✓	The published document “D2.2-1. Analysis and Insights Report” includes assessment of the most certain potential benefits to networks from energy efficiency using a Least Worst Regrets methodology
The economic assessment will identify what, if any, are the opportunities to pursue these benefits within the existing regulatory and commercial landscape.	✓	The published document “D2.2-1. Analysis and Insights Report” identified potential schemes that could be pursued to benefit from investment in energy efficiency, within the context of the existing regulatory and commercial landscape.
The profiling tool will be reusable and can be re-run with updated data.	✓	The Glow Simulator is modular and can be run using any smart meter data set filtered into the correct format.
The outputs of these tools can be integrated into distribution network forecasting and planning.	✓	A methodology has been developed and demonstrated for using the profiles in Distribution Future Energy Scenario modelling.
The methodology for the tools will be replicable across all distribution networks.	✓	The tools do not require any inputs unique to NGED, and its outputs are easily adjustable for use in any distribution network area or modelling environment.

7. Required Modifications to the Planned Approach during the Course of the Project

Real options analysis

In the initial scope, it was intended that the tool for appraising the value of EE investment would follow a "real options" approach. Real options analysis uses a process of backwards induction, where the model first finds the optimal decision at the final decision point of various scenarios. Given a probability for each scenario occurring, the model can then work backwards to arrive at an optimal decision today which minimises the expected cost.

If the likelihood of different scenarios occurring can be quantified, then this process will maximise the value for a risk-neutral investor. However, the results may be sensitive to the probabilities chosen for each scenario, and the development of such probabilities has been outside the scope of this project. In addition, the Open Networks Project is currently considering whether to include a more complex variant of this decision rule within the CEM, and this project has sought to avoid duplicating that work.

As a result, this project has adopted a 'least-worst regrets' framework. This approach attempts to minimise the worst error that could be made. In LWR analysis, the 'regret' for a given scenario and decision is calculated as how much extra cost is incurred compared to this optimal decision. This is effectively a measure of error: Given the scenario that occurred, has the decision led to the DNO incurring more costs than it would otherwise have faced? The approach then chooses the strategy which overall will cause the least worst regret across all possible scenarios.

Scope of Workstream 2 case study

Originally, the Workstream 0 scoping document for Workstream 2 envisaged that the EE tool would be developed for a limited area of NGED's network. The 11kV network fed from Feeder Road primary was selected as the case study. However, the initial findings from Feeder Road showed a relatively low EE benefit. In response to this, the model development was extended to include the additional 'NGED-wide EE analysis tool' that was not part of the original specification.

The NGED-wide EE analysis tool was an interim measure which contains statistics across all NGED Constraint Management Zones (CMZs). This was used to analyse the conditions under which the value of EE is likely to be highest, and tell us the proportion of NGED CMZs in which EE is likely to have a meaningful benefit and were therefore worth running through the full EE assessment process. As such, in the rest of the development phase the tools were run over multiple different NGED CMZs.

Investment appraisal tools

In the initial scope it was envisaged that a singular tool would be developed to carry out the analysis necessary for Workstream 2. However, owing to the factors above, and an inability to access the proprietary code of the FAT, a suite of tools with different functions have been developed to achieve the required results, including:

- EE intervention tool
- EE benefit calculator
- NGED-wide EE analysis tool

8. Project Costs

Table 8-1: Project Spend

	Budget (£)	Actual (£)	Variance (£)*
NGED Project management	£45,795.00	£61,752.53.00 (=£45,795 + £15,957.93)	-£15,957.93
Carbon Trust Subcontractor project management, model development, building and efficiency scenario methodology development and implementation	£423,730.00	£423,725.00	+£5.00
GHD Validation of outputs, case study power system modelling	£89,442.00	£81,466.00	+£7,976.00
Frontier Economic analysis, investment appraisal tools development	£275,000.00	£295,000.00 (=£275,000 + £20,000 from contingency)	-£20,000.00
Contingency	£83,447.00	(£35,957.93)	+£47,489.07
Total	**£917,914.00**	**£861,943.53**	+£55,970.47

*Negative values indicate an exceedance of stated budged. Positive values indicate spend is less than stated budget

The project was delivered for £862k, £56k less than its £918k NIA budget.

NGED costs increased due to extended duration of the project and additional comms expenses over and above original budget.

The costs for Frontier Economics were increased to include a re-run of the analysis carried out using the investment appraisal tools using the profile outputs from the Workstream 1 profiling tool. This was scoped out in the original project plan, but was stage gated pending the validation of the profile outputs. The alternative plan was to produce outputs using data such as the Energy System Modelling Environment database and Customer Led Network Revolution heat pump profiles. However, these are less robust data sources as that produced in Workstream 1.

Variance in Carbon Trust costs is a consequence of a rounding difference between budgeted and invoiced spend.

9. Lessons Learnt for Future Projects and outcomes

The learning from the DEFENDER project has been captured and shared in a variety of ways:

1) An open-source tool with integrated help guides for generating heat demand profiles for network planning and at the household level
2) As-built design documents for the household and network planning levels of the profiling tool modules
3) A validation report of the household and network outputs of the tool
4) A methodology document on the approach to creating house archetypes and integration energy efficiency transitions into DFES scenarios
5) A CBA report on the per-household benefit of energy efficiency
6) A network investigation report on analysis of the impact of the newly developed profiles on growth forecasting of three 11kV feeders
7) A technical design document on the EE assessment tools developed to appraise investment in energy efficiency
8) An analysis and insights report on the outcomes of using the EE assessment tools to assess the value of EEE investment to DNOs
9) The final project dissemination webinar

Learning from the project undertaking is presented in Table 9-1 below.

Table 9-1. Learning from DEFENDER

Workstream	Learning Detail
WP1.1. Producing house archetypes from smart meter and EPC data	House archetypes are critical to the analytic method as they reduce the number of dimensions and provide selection criteria for scenarios. However, the EPC data must be transformed or cleaned so that it can be used to lookup house archetypes from a geographic boundary box. When looking at the samples from the Hildebrand data set and EPC data, there is a reduction of about 50% of the usable data set. This “discount” should be applied in future experimental design if recruitment is required. Once the statistical power is determined, recruiting double the amount of homes will ensure the data set is suitable.
WP1.1. Data set limitations	There appears to be a bias in Hildebrand data towards high users or users with solar, batteries etc. It may be possible to use more of a mass market data set or as the Hildebrand data set gets larger, filter properties to remove the bias.
	From the Hildebrand data set that was available from April, some house types were under represented. It makes sense that certain house types may not easily be found, such as modern flats with gas. In these cases, additional work may need to be done to disaggregate heating loads from overall electricity consumption.
	Improvements would likely rely on training the models with a larger data set. Hildebrand’s data set is now at least 5 times larger than the one that was used. No major issues are foreseen in running the models with this new data, however there is considerable time that would go into extracting and preparing data for a new model run.

WP1.1. Bayesian vs top down methodology	Comparatively the Bayesian approach for estimating heat demand outperforms a state of the art top down approach for a single household where actual heating performance is known. However, the analysis showed the Bayesian method has a maximum likelihood that is over-estimating heating energy consumption by 22%.
WP1.1. Probabilistic modelling	Baseload and heat demand parameters are stochastic and therefore multiple running of the tool will not always give the same result.
WP1.1. Energy to power conversion	The input data from smart meters is recorded as energy in kilowatt hours (kWh) occurring within the half hour. To convert to power in kilowatts (kW), the kWh are multiplied by 2. This means the average power for the half hour is represented instead of the instantaneous peak during this time period.
WP1.1. EV and night storage influence on baseload	Electric vehicle (EV) and night storage heaters have a distinct usage signature, with very large and disproportionate electricity demand overnight. This is due to low cost electricity at those times. EV and storage heater properties were filtered out of the electricity baseload data set as these dramatically skewed. The method that was used to identify properties that has EV or night storage heaters was based on the assumption that overnight electricity demand would be disproportionately high as compared to day time usage. For each property, half hourly data was grouped as night time or daytime, and for each day a ratio of night time to total usage was calculated. Night time was defined as midnight to 4am, and to simplify, UTC time was used rather than transforming to local time. Furthermore, each household's average percentage of night time use was taken, resulting in a list of properties and their average use over a period. 30% night time consumption or below was found to be a good cutoff point.
WP1.1. Browser execution	The execution of the model to generate data is currently done on the web browser to simplify import into NGED forecasting tools. Moving the model execution to the server should give more control over sampling functions and allow for more detailed Bayesian calibration with sub-archetype information.
WP1.1. Representing effects of weather	The model only considered a single day in the profile generation. A study of the effects of longer periods such as prolonged cold weather should be done to understand the effects of the preceding days' weather.
WP1.1. Heat pump power factor	It is currently assumed in DFES that heat pumps will have a unity power factor. This is actually unlikely to be the case. As such, 600,000k non-unity additional loads on the network are likely to impact voltage. This was outside the scope of the project but warrants further investigation in a forecasting context.
WP1.2. Approaches to defining a housing mix	A middle ground approach between manual definition and the not yet implemented Geographical Information System (GIS) import methods for generating housing mix had to be devised in order to enable Carbon Trust to create multiple scenarios in a timely fashion to enable the network investigation. The "Import Numeric Archetypes" allows a spreadsheet of archetype numbers by numeric tag defined by the methodology created in WP1.4. This allows users to quickly generate multiple

	scenarios as long as the underlying building stock is known and sorted into the archetype set used in the Glow Simulator.
WP1.2. Profile outputs	Network planning relies on the construction of scenarios defined by a mix of housing stock. Data is generated by the models for the individual houses and then combined as a network model. The Network Planner should be able to generate realistic feeder and substation level data given the same conditions.
WP1.2. Validating network profiles against real data	The results have shown that model estimates are higher than the real data, although the shape and dynamics of the consumption look similar between model and real data. This is likely due to bias in the training data (generally higher users) or housing stock selection (overestimating the number of occupied homes connected to a feeder.)
WP1.2. Representing scenarios within the GUI	Scenarios are driven from the front-end tool. Adding another software layer and parameterising the scenario would enable more scenarios to be generated with the ability to study the effects of small changes in energy efficiency and heating technology.
WP1.3. Constraints on issue tracking	NGED have limited access to external web sites, which meant that an Excel spreadsheet was used to track issues through to completion, sharing the spreadsheet via email with external testers on an ongoing basis as the testing and bug fixes progressed and using the same spreadsheet to request confirmation of issue closure from the original issue Reporter. This approach was outside of Hildebrand's standard procedure for system development, which uses the web-based JIRA tool for managing the UAT process; JIRA is a collaborative, interactive tool that requires the issue reporter to close issues they raised.
WP1.3. Main issues	Specific challenges that arose during the testing phase included: • Tagging and managing scenario names in a way that reflected the forecast year (2030, 2040 and 2050) - permutation management became a challenge quite quickly due to the number of scenarios • Splitting scenarios up into feeders • Reliance on offline selection of housing stock
WP1.3. Functional requirements capturing	For the network planning tool, the testing process highlighted that some of the requirements articulated for the network planner were not initially defined clearly enough. This resulted in some mis-matched expectations between the delivered and expected user interface. This likely due in part to the combination of this project involving brand new partnerships and the short timescales of Workstream 0. This scenario can be avoided by ensuring timescales include leeway for the learning curve of any new partnerships involved.
WP1.4. Archetype framework	The archetype structure is comprised of base archetypes and sub-archetypes. Base archetypes are defined by a combination of largely immutable factors of property type, built form, age, floor type, roof type and wall type. Sub-archetypes are defined by mutable fabric factors of floor insulation, roof insulation, wall insulation and window glazing. There are 68 archetypes with up to 54 sub-archetypes. The total number of valid combinations is 2,904. This is not the same as 68 time 54 as there are some factors unique to flats and not houses, and vice versa. Some of the combinations are not found in EPC

	records. For instance having single glazing and full insulation in walls, roof and floor is very unlikely. In looking at EPC records, 1,017 combinations were found. This is not to say that more combinations would not emerge as homes are retrofitted in the future.
WP1.4. Using the archetype framework	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
WP1.4. EPC coverage	EPC coverage is typically around 60%. Therefore, an extrapolation method was used to complete the building stock database. The extrapolation was done by assigning the most common sub-archetype in each Output Area (OA) to the unknown properties within the OA. 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.
WP1.4. EPC records	A significant amount of EPC data for Wales is stored only in Welsh, requiring translation and matching with English language sets of the same data.
WP1.4. Categorising efficiency within archetypes	Each sub-archetype was assigned into one of three efficiency 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. 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.
WP1.4. Optimising transition	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.
WP1.4. Limitations of modelling from historic patterns	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 was chosen to include in the analysis as it reflects new flexible working practices.
WP1.4. Linking scenarios to DFES heat pump uptake rates	The rate of EE interventions was linked to the DFES rates of heat pump installations, as the demand reduction is only observed on the grid when the heat technology is electrified. It was therefore

	assumed that energy efficiency measures are installed at any time between the baseline year and the year of heat pump. The top-down approach of linking the scenarios to DFES rates of heat pump installations fulfils a core objective of this modelling task by tying energy efficiency scenarios to DFES scenarios. However, it does not 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.
WP1.4. Effect of efficiency on half-hourly peaks	The difference between the demand profiles for the low, medium and high EE scenarios in the case study areas investigated was small in 2030 and 2050 (less than 4% in 2050). This is a characteristic of the modest differences in the EE measures that are applied in the different scenarios. This limited reduction is mainly due to the high efficiency of a heat pump in converting electrical energy input into thermal output, effectively reducing heat demand by a factor of 3. This means that the impact of any reduction in heat demand as a result of energy efficiency measures is observed significantly less on electrical load than if the demand was being met by direct electric or natural gas. Consequently, electricity base load remains a much higher proportion of the overall electricity consumption, and is not affected by energy efficiency measures. This low reduction in peak load is exacerbated in the three case study areas investigated, due to the relatively high thermal efficiency in the existing building stock reducing the potential for energy efficiency measures to reduce load.
WP1.4. Effect of profiles on profile shape	The demand profiles assessed in the network investigation can generally be characterised as having a late afternoon peak demand (with a few exceptions), and shifting upwards throughout the day in later years as higher HP uptake is manifested in additional continuous demand. The average load factor for all distribution substations considered increases by 25.9% from 60.9% under the baseline profiles to 76.7% under the 2050 profiles. This increase, corresponding to flattening of the profile shape, should be noted as it represents a loss of cyclic capability. The above points should not be considered in isolation. In assessing upgrade options, the increase in the peak demand may be the dominant factor, but the suitability of cyclic ratings should be reviewed in light of the reduced time for transformers to recover from overload periods.
WP1.4. Implications for modelling approaches	The project has demonstrated that a range of profiles can be applied effectively to PSS SINCAL models of individual HV feeders, and this approach could be adopted to assess the impact of different profiles that account for a broader range of technology uptake (e.g. alternative assumptions for uptake of HPs, EE measures, EVs and rooftop solar PV in combination). Futhermore, the assessment undertaken in the project looks to complement the DFES analysis by providing additional detail at a greater spatial resolution (profiles for individual distribution substations based on building stock analysis that enable network modelling at the HV feeder level).
WP1.5.	The house-level CBA categorised the existing 100 most prevalent house sub-archetypes in NGED's area into low, medium and high

100 most common archetypes	energy efficiency categories, based on the current levels of thermal energy efficiency measures installed. Across the population of homes that falls within these 100 sub-archetypes, almost half the homes are classed as 'medium' thermal efficiency. A further 37% of homes are of a low energy efficiency standard, with only very limited levels of insulation present. Only 15% of homes have high levels of building fabric, largely consisting of new-build homes and a small number of retrofits.
WP1.5. Most impactful retrofit measures	Loft insulation, cavity wall insulation, and double glazing are the most cost-effective measures for reducing peak loads on the network on a £Capex per kW reduction in peak load basis
WP1.5. Most impactful transitions	The effect on house-level peak loads as a result of upgrading from low to medium thermal efficiency has a maximum of 600W reduction per house. This is a similar impact to upgrading from medium to high thermal efficiency, which has a maximum of 750W peak load reduction, but the latter comes at much higher capital cost.
WP1.5. Scope limitations and further study	The technical CBA concluded that there is very limited benefit for NGED to invest in energy efficiency measures as a method for reducing network reinforcement costs based on the modelling completed. However, the scope of this project was limited to the impacts of thermal energy efficiency on the low voltage distribution network as heat pump deployment increases. However, this change will not happen in isolation and the findings will be affected by wider system dynamics. Further modelling in two main areas could be pursued: • Identification of the wider impact of energy efficiency deployment on individual stakeholders across the sector to identify where greatest benefits are seen and hence which organisation outside of the DNOs should be engaged in pushing forward deployment of thermal energy efficiency retrofits. • Interactions between energy efficiency deployment and the flexible operation of heat pumps and batteries on the investment case for these assets and their impact on the distribution network.
WP2.1 Understanding EE's value through existing evaluation mechanisms	The EE tool designs an EE intervention by selecting a sub-set of dwellings to be targeted. The user can design an intervention to target: • particular CMZs; • particular tenure types (e.g. either social housing or all households); • particular types of properties; and • the level of thermal efficiency upgrade (whether to include 'low to medium', 'low to high', and 'medium to high' interventions, as defined by Workstream 1. The result of the modelled intervention is a change in the demand profile of a selected set of dwellings within a given CMZ. These profiles can be fed through the existing FAT and CEM tools to calculate the optimal level of flexibility procurement, timing of reinforcement and the resultant Net Present Value (NPV) of the investment if the EE intervention is carried out.

	The EE benefit calculator takes the output from this process and separately, the FAT and CEM tool outputs if they are run without the EE intervention. The financial benefit to the DNO is then calculated as the difference between the optimal NPV for the flexibility-only option and the optimal NPV for the flexibility with EE option. This is the ‘Ceiling Price’ of an EE intervention – i.e. the maximum amount that a DNO could pay for the EE intervention without costs outweighing the benefits.
WP2.1. Future scenarios	This way of calculating the Ceiling Price is based around a single scenario, similar to how NGED currently uses its ‘Best view’ scenario when deciding whether to procure flexibility. However, uncertainties around factors like future demand may affect the value of EE interventions.
WP2.1. Limitations of existing tool suite	Whilst the FAT is currently suitable for calculating flex requirements of EE-adjusted demand profiles, it will likely overestimate the effect of the EE interventions. The FAT will take the electricity demand profile and scale it up over time to reflect overall load growth (such as from new builds or vehicle and heat electrification). However this also means that the EE saving identified will be scaled up where it is in reality a fixed saving (assuming that each household’s demand remains constant).
	The profiles used in the FAT are based on scaling historic load profiles and so may be inconsistent with the heating technologies assumed to be the source of the EE savings. Greater consistency and accuracy could be obtained if the load profiles used in the FAT were based on a ‘bottom-up’ analysis like that developed in DEFENDER Workstream 1, based on individual load profiles for technologies such as heat pumps and EVs. This could still be calibrated so that current load profiles used in the modelling match the load profiles currently observed on the network, but may allow a more accurate forecast of future load profile shape.
	The DFES load growth scenarios used within the CEM may not present a complete view of the uncertainty in demand that could manifest over the medium-term. This is since technologies like heat pumps and electric vehicles may be expected to cluster on specific parts of the distribution network (e.g. because a certain area has physical or demographic characteristics that are likely to lead to a particularly high take-up, or feedback effects where the take-up of these technologies by some consumers may prompt take-up by others nearby). Local demand is therefore likely to be even less certain than the national demand used to create the DFES scenarios.
WP2.2. Drivers of EE effectiveness	Reinforcement costs per megawatt (MW) are the key driver of variations in Ceiling Price between CMZs: areas with higher reinforcement costs tend to have higher Ceiling Prices. Areas with high reinforcement costs are typically in more rural areas. To a lesser extent, the Ceiling Price is also affected by: • The scale of the intervention – in some areas (typically where reinforcement is likely to occur sooner) a larger intervention may have a higher Ceiling Price per dwelling, although this does not hold everywhere; • The type of property or retrofit – some types of retrofit, such as suspended floor insulation, provide a greater

	reduction in peak demand and so are associated with a higher Ceiling Price. • The rate of demand growth – as long as demand is high enough to require flexibility, slower demand growth will extend the duration of the benefits from EE; and • The availability of flexibility – if flexibility is available but still somewhat limited this can increase the Ceiling Price, although the amount of flexibility required to see this effect varies widely by CMZ.
WP2.2. Features of CMZs with highest return	Examining the characteristics of CMZs with the highest return has found that these tend to be rural areas with higher reinforcement costs, likely due to factors such as long conductor distances and a greater propensity to single transformer primaries. In addition they also typically have: • A higher share of off-grid houses using electric heating • Lower average incomes • More thermally 'poor' houses (and fewer thermally 'medium' houses) • A lower proportion of social housing
WP2.2. Value present on NGED's network	In one case study area, the EE measures were modelled as being cost-effective for consumers to install regardless of the DNO's intervention, and in all other areas the gap between the Ceiling Price and net cost to consumers was so high that the maximum amount the DNO could pay would not make any difference. There are a vast number of uncertainties, not least the value that consumers place on non-monetary benefits or costs, and so these results should only be seen as highly illustrative. However the general finding – that the DNO value is small compared to the other costs and benefits – is likely to hold. It may be possible for a DNO to obtain greater value for money by focussing on retrofits that would have been installed by consumers, but too late to make a difference to the network. To illustrate a best-case scenario, the net cost to consumers if the EE intervention only needed to bring forward installation of measures by two years was considered, assessed using the social discount rate of 3.5%. Under this scenario the DNO payment of the Ceiling Price would be sufficient and necessary to cover consumer net costs of the EE intervention within 15% of all CMZs.
WP2.2. Future value of EE	The LWR Ceiling Price tends to be higher for CMZs which are closer to the point where flexibility would be uneconomic in the absence of EE. Over time, demand growth will mean that all of NGED's CMZs will move towards this point. Therefore, while it may not be economic to carry out an EE intervention now for many CMZs, it might be in the future. The LWR analysis indicated that, in an area that is close to requiring reinforcement the LWR Ceiling Price might be around 50% higher than the Best View Ceiling Price. Applying this 50% uplift, the analysis suggests that the DNO might have sufficient value to incentivise this intervention in around 24% of CMZs. As shown below these are typically in more rural areas (e.g. concentrated in NGED's South West and South Wales license areas), due to the higher reinforcement costs.
WP2.2.	It is unlikely that capex-based energy efficiency grants that are similar to or less than the DNO's Ceiling Price will make a

Ways to implement EE interventions	significant difference to consumer behaviour in most instances where the consumer would not have ever installed measures. Instead, take-up would be more efficiently incentivised by attempting to bring forward EE investment that would otherwise occur too late for the DNO's purposes. Such interventions may involve: • Providing funding in the form of low-interest loans rather than grants. If consumers have a high effective discount rate then loans may be sufficient to encourage the installation of EE measures, at much lower cost to DNOs than grants. • Having funding that is only available for a limited time. If the DNO can credibly commit to funding for a specific area only being available for a limited time, the 'use it or lose it' nature may encourage more homeowners to bring forward retrofits. • Sharing information on intervention timings with local partners. Given the limited window within which the DNO can obtain value from EE interventions, it may be worthwhile priming the local supply chain to respond. • Targeting those properties most likely intend to invest in EE, but not yet.
WP2.2. Timing and scale of installations	It may often be optimal to defer EE rather than implementing it right away. However, larger interventions have a greater impact, due to either the inherent imperfections of the planning process or the presence of fixed costs. Implementing a larger intervention will likely take longer, and so there is a trade-off between these two concerns. The speed of which large interventions can be implemented could be improved by targeting housing types that could be upgraded at scale, such as engaging with housing associations or social landlords (though it is noted that social housing is less prevalent in high value, i.e. rural, areas).
WP2.2. Impact on vulnerable customers	While EE interventions may help meet DNO vulnerable consumer strategies, this is not always the case. Rural areas with higher reinforcement costs also tend to have lower average incomes, and so implementing EE interventions may tend to benefit areas which are less well-off on average. EE measures may also meet other needs of vulnerable consumers, such as enabling those who are underheating their homes to benefit from healthier levels of heat. This may also lead to cost savings for the health system, another potential source of value. However, within a given CMZ, vulnerable consumers may offer less value to the DNO in terms of cost effectiveness. This is due to: • The presence of the rebound effect (if consumers who are currently underheating their home turn up their thermostats as a result of the insulation, the reduction in peak demand will be less); • The greater likelihood for low-income households to live in 'low' thermal efficiency homes (which are assumed would never be suitable for a heat pump in the first place); and • Any EE intervention that focusses on a smaller subset of consumers (e.g. those in vulnerable circumstances) will

	have less effect – and may suffer from a lack of economies of scale. DNOs will therefore need to consider the relative importance of their duties to vulnerable consumers and their need to lower network costs when designing EE interventions. This is also complicated by regulation: The RIIO ED2 Final Determination explicitly states that DNOs should not pay for energy efficiency interventions as part of their vulnerability strategies.

10. The Outcomes of the Project

The outcomes of the project are as follows:

- A tool[2] which can produce profiles of baseload electrical demand and electrified and non-electrified heat demand for individual house archetypes or a set of buildings aggregated together to represent a network area.
    - Heat demand can be generated using real temperature data or representative day equivalent temperatures.
- A categorisation method[3] for assigning UK building stock into a series of base archetypes based on static factors, with a series of sub-archetypes representing stages of energy efficiency retrofit.
- A methodology[4] for representing the transition between stages of energy efficiency retrofit for domestic buildings which integrates with representation of low carbon heating uptake within Distribution Future Energy Scenario modelling.
- A suite of tools[5] for assessing the value of energy efficiency investment to managing network constraints alongside flexibility procurement and reinforcement.
- A potential approach for DNOs proportionally investing in energy efficiency retrofit[6] which could be trialled in a follow-on project.
- A set of reports of learning on the impact of energy efficiency on electrified heating demand[7] and the potential value of DNO investment in energy efficiency[8].

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[2] Glow Simulator

[3] Modelling Demand

[4] Forecast Scenario Methodology Report

[5] Technical Design Document

[6] Analysis and Insights Report

[7] Case Study Report

[8] Cost-Benefit Analysis

11. Data Access Details

NGED data can be requested via the National Grid Connected Data Portal (https://connecteddata.nationalgrid.co.uk/).

Hildebrand's smart meter data set was used to develop the Glow Simulator modules. The data was never shared outside of Hildebrand's secure servers to maintain GDPR compliance. The data set cannot be shared with a third party. However, the outputs generated by the data are encoded into the Glow Simulator tool, which is open source and available publically and as such access to the raw smart data is not required enabling background IPR for use of the tool.

Furthermore, the tool is designed such that it can be used with any smart meter data set as long as it is filtered into the correct format. Details on how this can be done can be found in the "D1.1-5 Modelling pre-/post-retrofit demand"[9] report published on the DEFENDER project website.

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 in other areas.

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9 Modelling Demand

12. Foreground IPR

New foreground IPR has been created in the project reports. These are published and freely available on the NGED Innovation website.

As noted above, the Glow Simulator is open-source and may be publically accessed here.

The EE assessment tool suite has been handed over to NGED and can be accessed upon request.

13. Planned Implementation

DEFENDER’s stated end use cases were the integration of pre- and post-retrofit heat demand modelling into existing forecasting processes and identifying where and how a DNO such as NGED could invest in energy efficiency. Next steps in each of these use cases are considered below, as well as discussion of other potential use cases for the Glow Simulator tool.

Integration into forecasting processes

The energy efficiency scenario methodology and Glow Simulator tool were produced in Workstream 1 with an eye each upon the present and the future of Distribution Future Energy Scenario modelling. Currently, NGED does not produce network forecasts more granular than to the Electricity Supply Area (i.e. primary substation HV busbar) level. As such, replication of the kind of investigation carried out in work package 1.4 will first necessitate the development of an HV forecasting process. NGED has set developing this capability as an objective in ED2. In the meantime, the toolset can be used to generate scenarios at ESA level.

BAU implementation would also require developing the underpinning building stock models to allow for generation of base scenarios for energy efficiency modelling. There are various ways to achieve this:

- Develop the proposed GIS automation process. This would use GIS shapefiles and EPC lookup tables to assign archetypes to a network area to generate the current base scenario. A high-level description of how this process would work can be found in the D1.4-2 Scenario Methodology report.
- Generate base scenarios by manually assigning building stock to feeders using GIS maps and the EPC database. This would be a time-consuming process in the initial development, but could be made quicker in the uptake by developing a lookup process to only update buildings that have changed in the EPC database in between DFES model runs.
- Develop a rough estimation model using only commonly occurring sub-archetypes. This would be a quick and easy way to develop a ballpark assessment of energy efficiency related demand impact.

As an interim measure, the outputs of the tool could be integrated into the next DFES round using a single diversified model. This would be created by generating a scenario based on the relative proportions of archetypes across a licence area, then dividing each half hourly value by the number of archetypes used to generate it. This single profile would directly replace any usage of the Elexon domestic customer model in demand estimation.

DEFENDER has already determined a methodology for tying energy efficiency scenarios into the adoption of electrified heating technologies in DFES modelling. However, the low, medium and high retrofit scenarios were developed and tested for the Customer Transformation scenario. Further work is required to determine whether low, medium or high scenarios (or an additional scenario determined to be more applicable) should be used in other DFES scenarios.

Investing in energy efficiency

The findings of Workstream 2 on the value of energy efficiency to DNOs require further exploration before any scheme can be considered for BAU. As such, NGED has launched the PIONEER (Proportional Investment of Networks in Energy Efficiency Retrofits) Strategic Innovation Fund (SIF) project. PIONEER will tackle the remaining gaps in the role of the DNO in funding EE measures, including:

- Validation of the modelled outcomes of EE measures through pre and post metering of installed EE measures in different house types.
- Understanding of the homeowner/landlord customer journeys of heat pump procurement and key touch points in influencing decision making on EE.
- Understanding of the funding landscape for EE measures and commercial models for EE retrofit providers.

- The extent to which EE will be deployed in the absence of DNO intervention.

Additional use cases for the Glow Simulator

The DEFENDER project has generated significant interest outside of its stated remit focusing on demand forecasting and constraint management. Below is a list of additional use cases which could be explored, either by networks through BAU or innovation funded activity or by non-network organisations through their own activities:

- Integrating the sub-archetype profiles into customer facing connections tool (e.g. NGED's Connect Lite tool). This would allow customers to be given information on their projected demand characteristics when installing low carbon heating measures to inform them of the potential benefits to them of energy efficiency retrofit.
- Integrating the outputs of the Glow Simulator into modelling tools used by HV and LV planners, to give planners more granular information on the loads on individual feeders or even phases.
- Developing data-driven advice tools for customers seeking information on managing their electricity demand and decarbonise their own homes.
- Developing a heat pump sizing tool, which uses the calculated heat demand model to allow installers, local authorities, housing associations or other to more accurately choose the most efficient heat pump size to meet demand for the housing stock under consideration.

14. Contact

Further details on this project can be made available from the following points of contact:

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15. Glossary

Abbreviation	Term
ADMD	After Diversity Maximum Demand
BAU	Business As Usual
CBA	Cost Benefit Analysis
CEM	Common Evaluation Methodology
CMZ	Constraint Management Zone
CSV	Comma Separated Values
DEFENDER	Demand Forecasting Encapsulating Domestic Efficiency Retrofits
DNO	Distribution Network Operator
DNOA	Distribution Network Options Assessment
DSO	Distribution System Operator
EE	Energy Efficiency
EPC	Energy Performance Certificate
EV	Electric Vehicle
FAT	Flexibility Analysis Tool
HH	Half Hourly
HP	Heat Pump
HV	High Voltage
LV	Low Voltage
LWR	Least Worst Regret
MD	Maximum Demand
MPAN	Meter Point Administration Number
MVP	Minimum Viable Product
NDP	Network Development Plan
NGED	National Grid Electricity Distribution
NIA	Network Innovation Allowance
PIONEER	Proportional Investment of Networks in Energy Efficiency Retrofits
SIF	Strategic Innovation Fund
WPD	Western Power Distribution

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