

DEVELOPMENT REPORT AND TECHNICAL DESIGN DOCUMENT

DEFENDER WS2

7 OCTOBER 2022

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1 Introduction

The aim of DEFENDER WS2 is to build a tool (or set of tools) that build on existing WPD processes to assess the long-run cost-effectiveness of energy efficiency (EE) compared with traditional reinforcement and flexibility services. The previous deliverable (D0.2 – Energy efficiency investment appraisal tools: specification) set out a summary of WPD’s existing optioneering process for reinforcement and flexibility, based on user research. It presented a high-level design specification for a set of tools to incorporate EE into this existing process.

The tools have been developed in agile fashion by creating and testing prototypes with the WPD DSO Team. As part of this, a number of changes were made to the initial specification. These were documented in a “key requirements update” note, and are summarised here.

This document describes the results of this development process, and constitutes the following deliverables:

- D2.1-3: Technical design document
- D2.1-4: Development report

It is structured as follows:

- **Section 2 (D2.1-4): What do the tools do?** A walkthrough in non-specialist language of how the tool functions
- **Section 3 (D2.1-4): How can the tools be applied?** A description of how the tool will inform the analysis in WS2.2
- **Section 4 (D2.1-3): How do the tools work?** A detailed user guide with step-by-step instructions for how to run the tool, including its build design and each of its functions

2 What do the tools do?

The objective of the development phase of the project was to create a suite of tools for constraint management optioneering, capable of assessing the value of energy efficiency retrofit, while accounting for uncertainty in investment outcomes. The suite was developed for WPD's network, with a view to ensuring these building blocks are reusable. This section of the development report describes the various tools' functionality in non-specialist language, specifically:

- Section 2.1 describes the **EE assessment process**, which assesses the Energy Efficiency (EE) benefit in an individual Constraint Management Zone (CMZ).
- Section 2.2 describes the **WPD-wide EE analysis tool**, which assesses the potential EE benefit across the full WPD licence area.
- Section 2.3 sets out the key changes in the model development relative to the initial scoping document.

2.1 EE assessment process

The '**EE assessment process**' is a set of tools that allow WPD to assess the potential benefit of a user-specified EE intervention in a Constraint Management Zone.

The '**EE intervention**' refers to actions taken by WPD to ensure that thermal efficiency measures (such as wall and loft insulation) are installed in domestic dwellings. For example, this could take the form of a capital grant designed to cover some, but not all, of the cost of insulation. It is assumed that WPD's provision of these measure will be carried out shortly before the customer installs a heat pump (which would be financed separately to WPD's EE scheme). We note that government support for heat pumps is expected to ramp up in the coming years making it reasonable to assume that large portions of the housing market would start to install heat pumps.¹ The EE intervention will therefore be compared to a world where at least some households within the chosen area are installing heat pumps *without* also upgrading their thermal efficiency.²

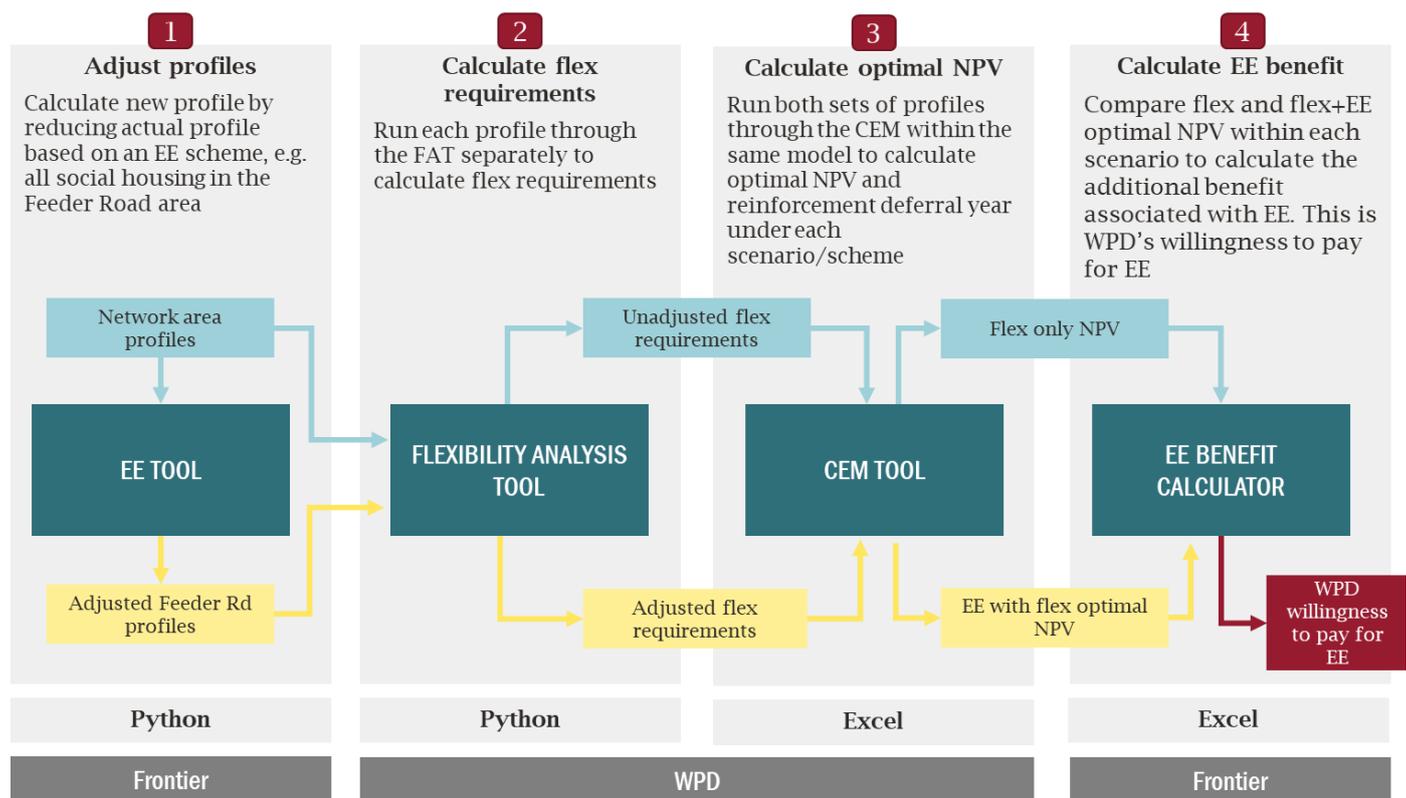
This assumes that WPD is able to target interventions at properties which: a) will install a heat pump; b) would not install insulation without the intervention from WPD; and c) will install insulation following the intervention. This is clearly a significant uncertainty, and one which will be explored in the next phase of this work.

The process is integrated with existing WPD network planning processes, and makes use of existing WPD tools wherever possible. Figure 1 sets out the four tools that make up the EE assessment process, with a brief description of the function of each tool. The following sections describe each tool in further detail.

¹ National Grid's FES 2022 describes some the currently committed policies (p76), and under the "Customer Transformation" and "Leading the Way", scenarios, heat pumps are projected to make up close to 50% of the home heating technology mix by 2035 – see National Grid ESO (2022), [Future Energy Scenarios](#).

² The demand profiles that WPD feed into the EE suite of tools will reflect this, specifically, that there will be a likely increase in load due to households moving from gas to electric heating.

Figure 1 EE assessment process

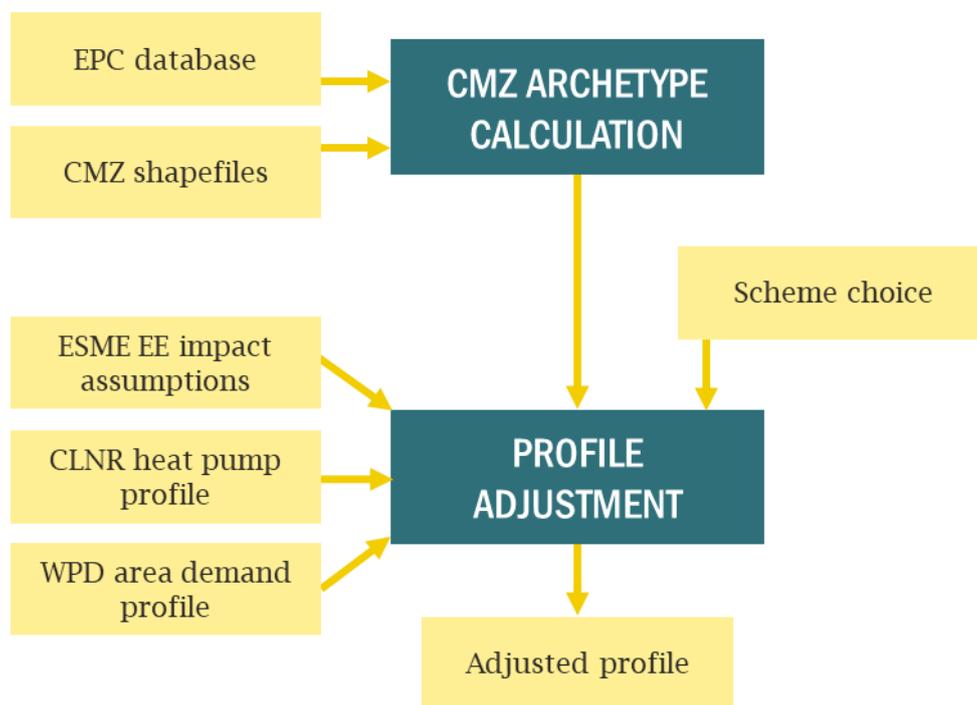


Source: Frontier Economics

2.1.1 EE tool

The Python-based EE tool, developed for this project, is the first step in the EE assessment process. Its purpose is to adjust demand profiles downwards based on an EE intervention. Figure 2 below sets out each conceptual part of the EE tool.

Figure 2 EE tool



Source: Frontier Economics

EE scheme design

The first step of the tool is to design an EE scheme by selecting a sub-set of dwellings from the network area. For example, the scheme could consist of all social housing in the CMZ. Each dwelling is allocated to an ‘archetype’ based on the building properties such as current thermal efficiency and house type (detached, semi-detached, etc.). The total volume of homes per archetype in the scheme is then calculated.

Profile adjustment

The EE tool then calculates the change in the demand profile associated with the EE scheme. To do this the individual household heat pump demand profiles must be derived along with the efficiency increase resulting from any thermal efficiency retrofits.

For the thermal efficiency increase, the tool currently uses Energy System Modelling Environment (ESME) data³ on space heat requirements before and after EE. Specifically, the space heat demand savings resulting from installing the Retroplus insulation technology.

For the individual household heat pump demand profiles, the tool currently uses the 2014 Customer-Led Network Revolution (CLNR) heat pump electricity demand profile.⁴ This is then scaled to the annual electricity

³ We note that both the ESME and CLNR data are placeholders for the forthcoming demand profiles derived from the DEFENDER WP1 workstream.

⁴ See “Enhanced profiling of domestic customers with air source heat pumps” here:

<http://www.networkrevolution.co.uk/resources/project-data/>

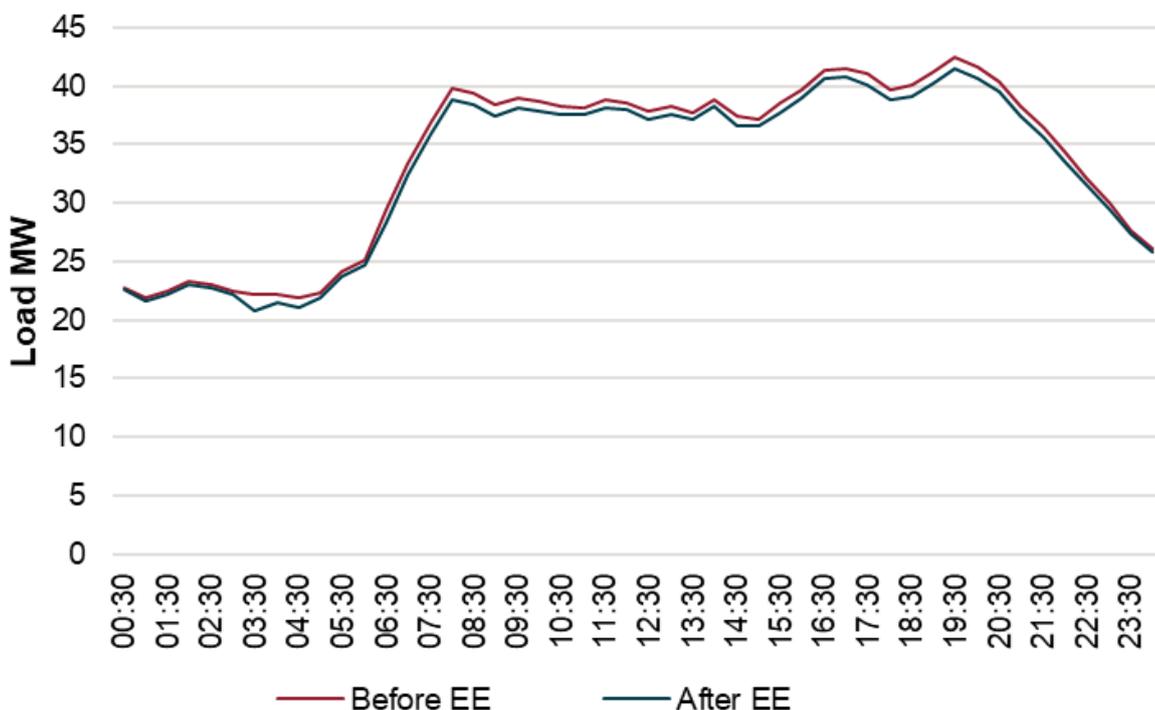
demand for our set of archetypes (the electricity demand for heat pumps without thermal efficiency retrofits, as specified in the ESME data).

We use these demand profiles and efficiency increases to determine the electricity savings profile. For example, the CLNR heat pump profile uses about 2,880 kWh/year. A medium density, medium thermal efficiency home in the ESME dataset uses about 2,075 kWh/year, and saves 41.5% in space heat demand from Retroplus. To achieve a post-intervention electricity demand of heating profile, we first scale down by a factor of 2075/2880 (heat pump with no thermal efficiency upgrade), then further reduced by 41.5% (heat pump with the thermal efficiency upgrade). The difference gives us the savings of **one** medium density, medium thermal efficiency home receiving an EE intervention, in kW per half-hour.

Finally, we take these electricity savings off the aggregate CMZ level electricity demand profile. An aggregate savings profile is arrived at by multiplying each archetypes savings profile with the number of archetypes observed and summing over all archetypes within each hour. This aggregate savings profile is then subtracted from the actual WPD profile for the relevant CMZ (half-hourly, October 2018 – September 2021).

An example of the change in the Bushbury BSP CMZ electricity demand profile is shown in Figure 3 below (for October 1st 2018). The original demand profile is shown in red whereas the adjusted EE intervention demand profile is shown in blue. This is based on a scheme targeting all social housing in the CMZ.

Figure 3 Bushbury_BSP demand profile before and after social housing EE scheme, October 1st 2018



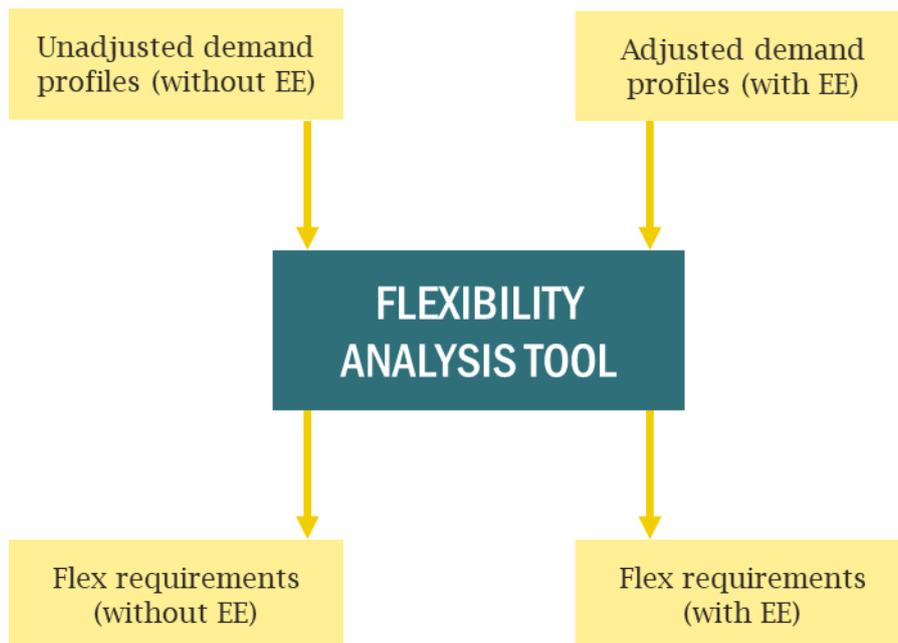
Source: Frontier Economics - CMZ_SP3A_WM_0006

Note: The dip in profile demand at 3.30am is due to the CLNR heat pump profiles having higher demand at this time for hot water. We have not addressed this in the data as it does not affect the peak and will therefore have limited impact on our results, and we expect to receive new profiles from WS1 at a later stage in the project.

2.1.2 Flexibility Analysis Tool (FAT)

WPD’s existing Python-based Flexibility Analysis Tool is used to calculate the flexibility requirements for the network area with and without the EE scheme. Flexibility requirements will typically⁵ be lower for EE adjusted demand profiles.

Figure 4 FAT



Source: Frontier Economics

The analysis is run for five demand growth scenarios: WPD Best View, Consumer Transformation, Leading the Way, Steady Progression, and System Transformation.

Whilst The FAT is (currently) suitable for calculating flex requirements of EE-adjusted demand profiles, we note that it will likely overestimate the effect of the EE interventions. The FAT will take the adjusted CMZ level electricity demand profile we give it and scale it up over time to reflect other loads coming onto the network such as new builds or vehicle electrification. This means that the EE saving identified will also be scaled up over years where it is in reality a fixed saving (assuming that each household’s demand remains constant).⁶ This could be overcome by varying the profiles by year, however the FAT is unable to do this at present.

⁵ There may be circumstances where EE adjusted profiles result in increased flex requirements (as noted in section 2.1.4). This is due to reinforcement being deferred and additional flex being required for those years that were otherwise reinforced. This additional flex requirement can be greater than any flex requirements saved via EE schemes in the years prior to the deferral.

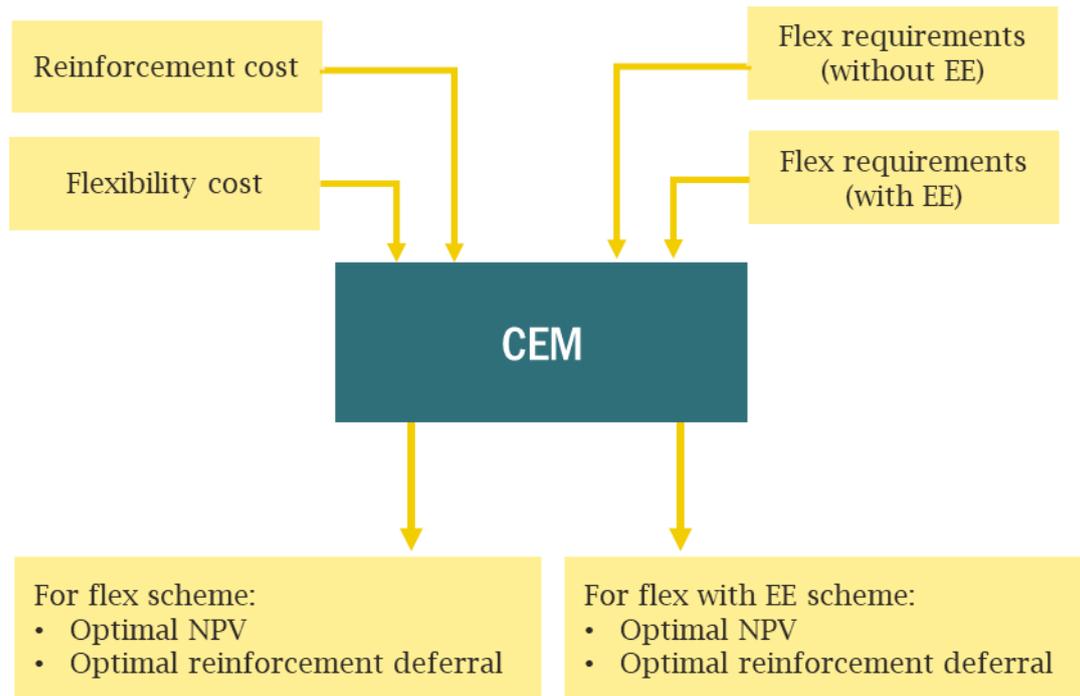
⁶ For example, if a house (in year 1) uses 10 kW in an hour, but only 8 kW after the EE intervention it will have saved 2 kW. If (in year 2) that house purchases an electric vehicle it will add another 4 kW demand in that hour. The FAT model will interpret this as a demand increase of $4/10 = 40\%$ which will be applied to the “with-EE” scenario: $demand_{year\ 2} = (10kW_{demand} - 2kW_{savings}) * 1.4 = 1.4 * 10kW_{demand} - 1.4 * 2kW_{savings}$. i.e. the

2.1.3 Common Evaluation Methodology (CEM)

The existing industry-standard CEM Excel tool is used to assess three options within the same model:

- Baseline reinforcement;
- flexibility only; and
- flexibility with EE.

Figure 5 CEM



Source: Frontier Economics

The CEM compares the cost of delivering each option based on the cost of flexibility required in each year and the cost of reinforcement. It compares the financial benefit of deferring reinforcement with the financial cost of additional years of flexibility. The financial benefit of deferring reinforcement arises from the approach to discounting taken in the model: reinforcement that costs £1m carried out in year 1 has a higher Net Present Value (NPV) than the same reinforcement carried out in year 5 (see box below). Over time, the annual cost of flexibility typically increases as demand in the area increases further above the network capacity (and a higher amount of flexibility is therefore required to keep demand below capacity).

The output of the model is the optimal number of reinforcement deferral years that give the lowest NPV for each option (flexibility only and flexibility with EE) and each demand scenario. The model also reports the NPV broken down into reinforcement cost and flexibility cost.

savings will be scaled along with the increase due to the electric vehicle charging. The desired formula is: $demand_{year 2} = 1.4 * 10kW_{demand} - 2kW_{savings}$.

EE costs are not input directly into the CEM model. Instead, the next step (see 2.1.4 below) calculates the maximum willingness to pay for EE. This means it is not necessary to decide the financial contribution that WPD would make to an EE scheme in advance. Rather, we calculate the maximum it would be for a beneficial outcome, over which it is not economic to do so. If the actual cost of such a scheme exceeds this then it would be uneconomic to implement it.

Box 1 The benefit of deferring reinforcement

There is a financial benefit to deferring expenditures since money spent tomorrow can be invested in other ventures today.

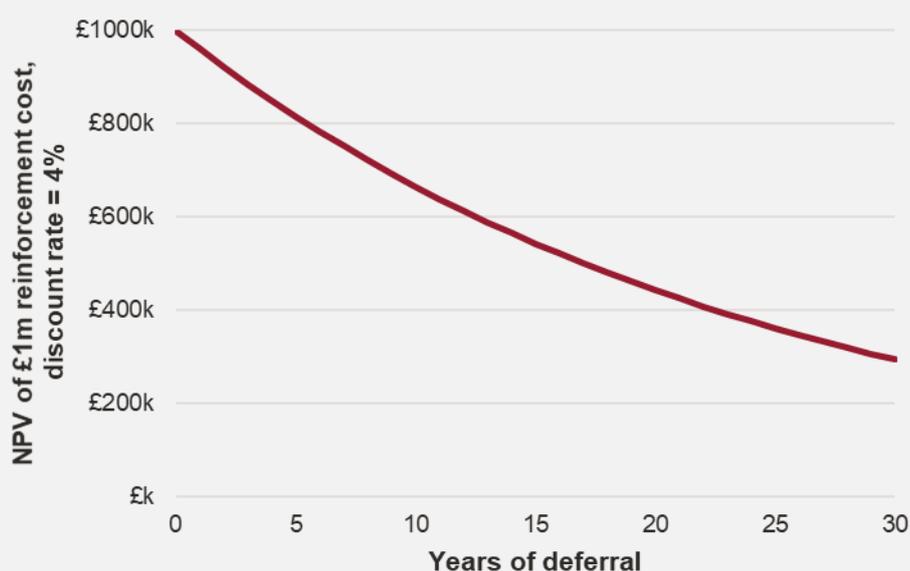
For example, if interest rates are at 4%, deferring an expenditure of £100 from now to next year means you can invest the £100, spend the £100 next year, and keep the additional £4 earned from interest. Conversely, you only need to invest £96.15 today to ensure you can cover the £100 next year ($£96.15 * 1.04 = £100$).

Economists use **discounting** to approximate this – dividing the expenditure from next year by $(1 + \text{the chosen discount rate})$. The discount rate reflects interest rates, but also risk – if there's, say, a 20% chance the expenditure may turn out to not be necessary next year, you'd on average spend £80 next year ($£100 * 80\% + £0 * 20\%$), and so deferring it to next year means you'd only need to budget £80 today, reducing its NPV.

So, if our discount rate is, say, 4%, a £100 reinforcement next year would cost us $£100/(1.04) = £96.15$ today – that is its **Net Present Value (NPV)**. A £100 reinforcement in two years would have an NPV of $£100/(1.04)^2 = £92.46$, and so on. The figure below shows this graphically. A 4% discount adds up to a 25% reduction in the NPV within 7 years, and a halving within 17. If the reinforcement cost is large, a deferral can add up to a large saving in pound terms fairly quickly.

In the CEM, the applied rate (the cost of capital) is around 3 – 3.5% depending on the timeframe.

NPV of £1m at 4% discounting



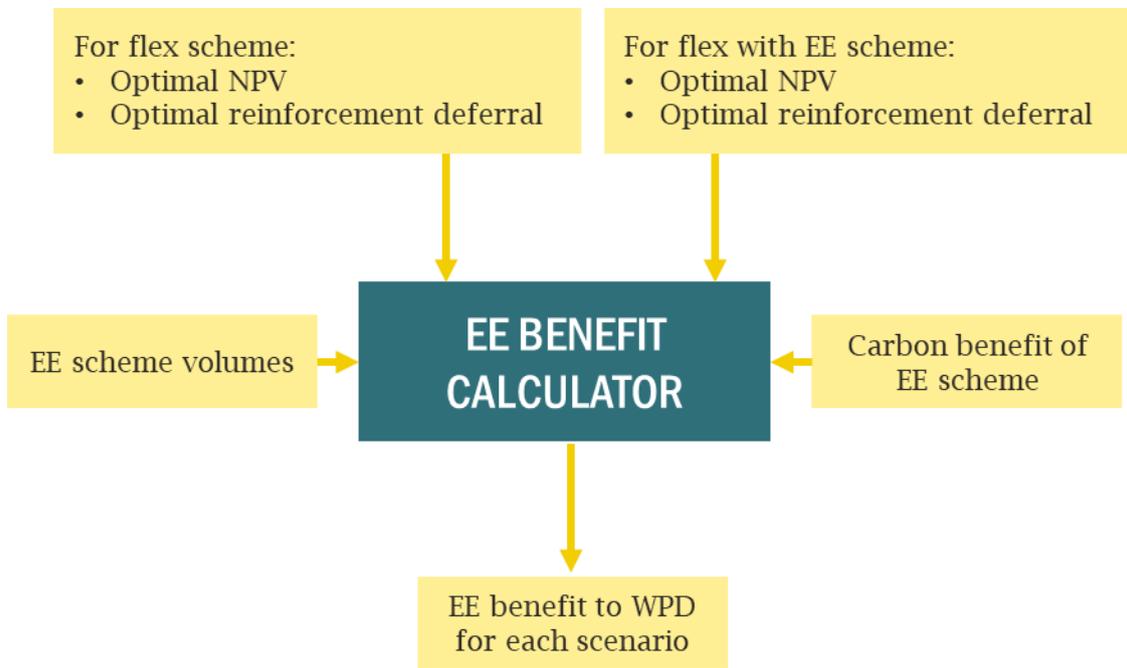
Note: this assumes we are talking about £ in today's terms and disregards inflation.

[Insert Source here]

2.1.4 EE benefit calculator

The EE benefit calculator is a simple Excel spreadsheet that takes outputs directly from the CEM using a VBA macro. The purpose of this calculator is to organise the results in an easy-to-read format because the CEM is not designed to explicitly compare options against each other. It also cannot by itself quantify the reduced carbon emissions of EE interventions.

Figure 6 EE benefit calculator



Source: Frontier Economics

The EE benefit calculator works out the financial benefit to WPD and wider benefits such as the carbon benefit of the scheme. All results are presented in terms of total £ NPV, and separately in terms of £ per dwelling NPV (where the dwelling numbers relate to the number of houses involved in the EE scheme rather than the total number of houses in the CMZ). The key result is the £/dwelling benefit, which can be interpreted as the average amount that WPD would be willing to contribute to installing EE measures in each dwelling.

Financial benefit

The EE financial benefit to WPD is calculated as the difference between the optimal NPV for the flexibility-only option and the optimal NPV for flexibility with EE option. For example, in Mullion, under the “Best view” scenario, the flexibility-only option has an optimal deferral of 4 years and an NPV cost of ~ £3,520,000, and the flexibility-with-EE option has an optimal deferral of 5 years and an NPV cost of ~ £3,500,000. In this case,

the EE benefit is ~ £20,000 total and has achieved an extra 1 year deferral of reinforcement, through an EE intervention in 188 homes = £118/dwelling⁷.

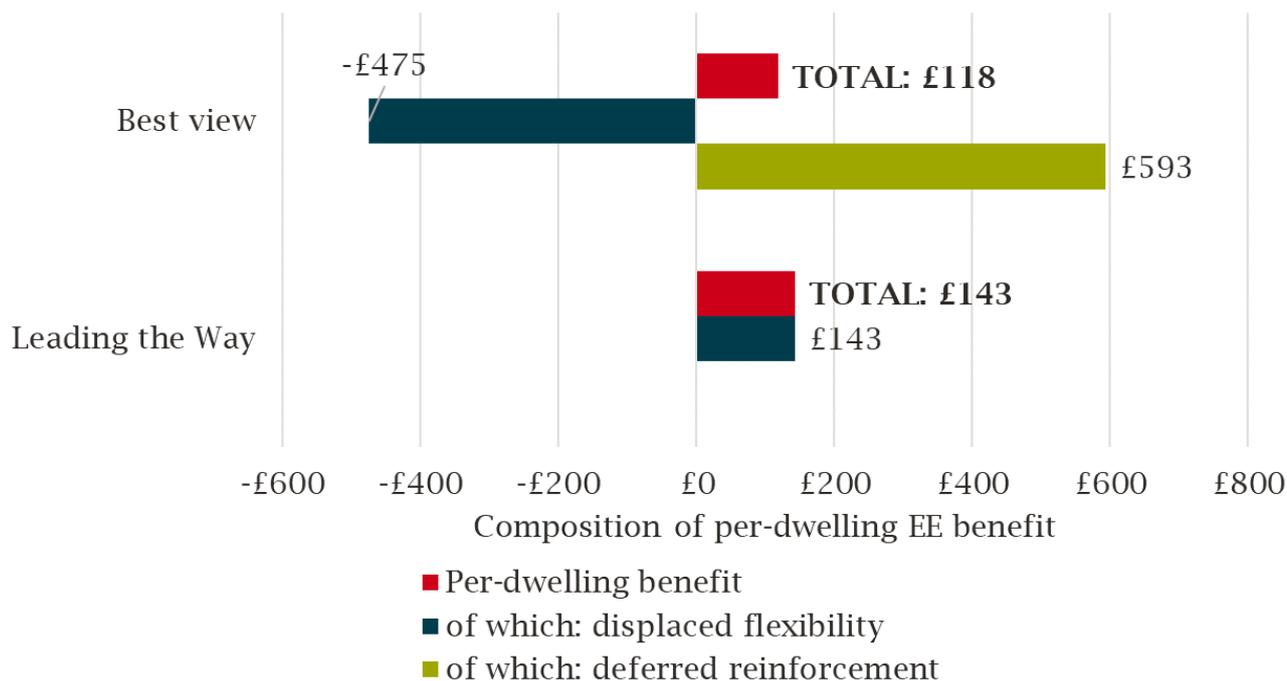
The financial benefit of this “Best view” scenario is shown as the red bar in Figure 7 below along with that of the “Leading the way scenario” (£143/dwelling). A key difference between these two scenarios is that the “Best view” scenario achieves an extra 1 year deferral of reinforcement whereas the “Leading the Way” scenario does not.

To better understand the factors driving this financial benefit, we have broken it into reinforcement benefits (green bar) and flexibility benefits/costs (blue bar). These add up to the total financial benefit (red bar).

- **Reinforcement benefit (green bar).** The EE scheme can result in additional years of reinforcement deferral if it reduces demand sufficiently. This results in a positive financial benefit because the NPV of reinforcement decreases as it is pushed further into the future. In the case of Mullion under the “Best view” scenario (where one extra year of deferral is achieved), this is worth £593/dwelling. In the “Leading the Way” scenario, there is no deferral and hence no reinforcement benefit (note the absence of a green bar in Figure 7 on the bottom row).
- **Flexibility benefit or cost (blue bar).** EE schemes can reduce or increase the amount of flexibility required depending on whether it achieves additional reinforcement deferral or not:
 1. EE can reduce the amount of flexibility required. All else held equal, EE schemes will reduce the need for flexibility. In the “Leading the way” scenario there is no additional reinforcement deferral attributable to the EE scheme, therefore any EE scheme will purely displace a portion of the flexibility requirement (i.e. flexibility benefit of £143/dwelling).
 2. EE can increase the amount of flexibility required. If EE schemes result in additional reinforcement deferral (say reinforcement occurs in 2025 instead of 2024) then additional flexibility will likely be required within the years that are no longer reinforced (2024 will require additional flexibility). This is the case in the “Best View” scenario where EE results in 1 additional year of flexibility being required. This extra year of required flexibility, combined with the reduced flexibility requirement in the 4 years prior results in a net cost of £475/dwelling (that is, the cost of additional flexibility in the deferred year is greater than the benefit of the displaced flexibility in the 4 years prior).

⁷ The NPV values are an approximation; the EE benefit is about £22k.

Figure 7 Example: Mullion CMZ



Source: Frontier Economics

Note: Based on a scheme with 188 social homes

Wider benefits

In addition to the financial benefit that accrues directly to WPD, there are also social benefits associated with EE schemes. These include:

- Social benefits arising from carbon savings; and
- bill savings for consumers.

Whilst the existing CEM includes the functionality to assess the carbon benefits of flexibility schemes, it does so for EE schemes (where the carbon benefits endure longer than the scheme costs are incurred). The CEM user guide includes two workarounds for these benefits,⁸ however both of these workarounds require calculations outside of the CEM, and may not appropriately apply the carbon price in each year. The carbon benefit calculation is therefore included in the EE benefit calculator, using inputs taken directly from the CEM (carbon prices, discount rates, etc.).

⁸ The first workaround is to run the model twice over two time periods and compare NPVs outside of the model. The user must ensure that the cost of the scheme is not double counted. The second workaround is to calculate the long-lasting carbon benefit outside of the model and include it in the final year of the model run. This approach may not use the correct carbon price, because it will apply the carbon price in the final year to the long-lasting carbon reduction (rather than applying future year-specific carbon prices).

2.2 WPD-wide EE analysis tool

In addition to the **EE assessment process** tool (described above in section 2.1) we have also developed a **WPD-wide EE analysis** tool which looks at WPD’s entire network to determine locations most likely to benefit from EE interventions.

Initial testing using the EE assessment process showed that the case study Feeder Road primary had low EE benefits. To better understand these results, we ran sensitivities and found that reinforcement costs were a particularly important driver. We then sought to develop a tool that could predict in which types of CMZ EE benefits could be high, given reinforcement costs and a number of other metrics. These CMZs could then be examined in more detail using the EE assessment process described above (as this involves manual steps such as running the FAT, it would not be practical to run the full EE assessment process for all CMZs).

As a result, the tool development plan was modified to include this additional “WPD-wide EE analysis” tool. Its intended use is to assist in the selection of which areas to run through the EE tool, based on their likely EE benefits.

Figure 8 WPD-wide EE analysis tool



Source: Frontier Economics

The tool matches a number of data sources together to provide a richer set of statistics for a given CMZ. Data is taken from WPD and public sources including the Census and the Energy Performance Certificate (EPC) database⁹ (see Figure 8 above), as well as outputs from the EE tool (which are independent of any chosen scheme, and provided in the zip file). It matches these on the CMZ-level and calculates a set of summary statistics for each CMZ including:

- Reinforcement cost per peak MW.¹⁰ Our sensitivity analysis of the Feeder Road CMZ showed that reinforcement cost is a strong predictor of the benefits (to WPD, per dwelling) of EE. All else equal, we would expect a doubling of reinforcement costs to double the savings from EE.

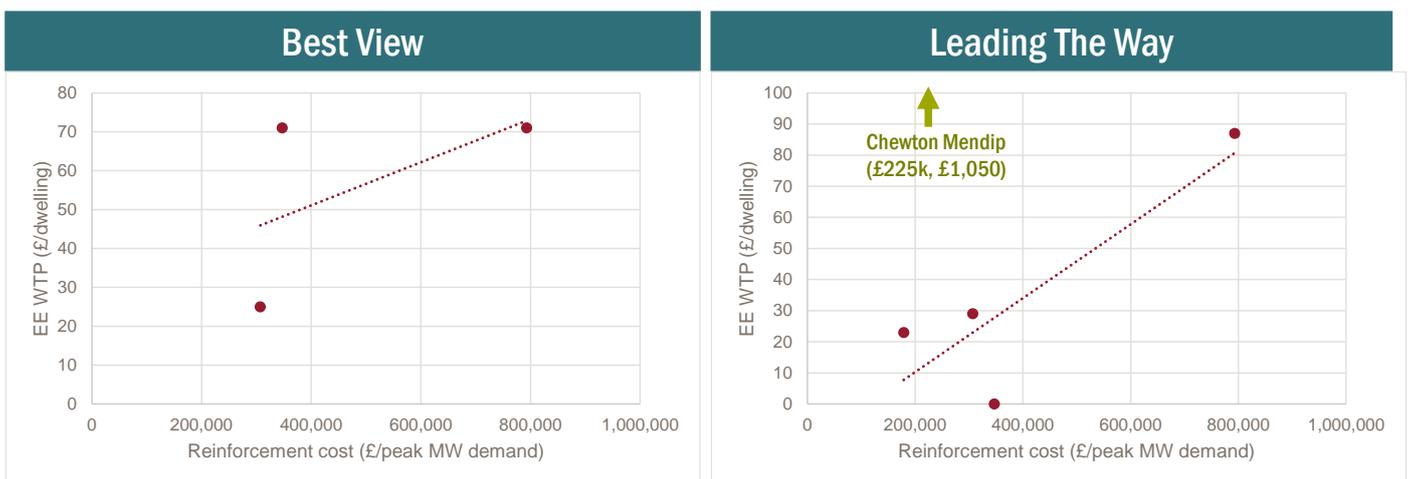
⁹ <https://epc.opendatacommunities.org/>

¹⁰ Peak MW per CMZ is calculated by averaging the three-year profile of the CMZ across each half-hour, to generate an average profile, averaging the half-hours into hourly loads, and then taking the peak of this year-long average profile.

- Approximate peak reduction from EE scheme, in kW per dwelling retrofitted. All else equal, we would expect that a doubling in the peak savings per dwelling would double the benefits to WPD.
- Area characteristics including proportion of low density housing, proportion of thermally inefficient housing, and average income levels. This allows us to understand which types of areas score most highly in terms of the metrics above, and may therefore have the highest benefits from EE.

We have not duplicated the full functionality of the FAT and CEM, and so the areas we identify as having the highest potential for EE may not necessarily be those that the full EE assessment process would flag. To validate how well we are able to predict EE benefits, a small number of CMZs with particularly high or low reinforcement costs¹¹ were ran through the entire EE assessment process. As shown below, there is evidence of a weak positive relationship between the reinforcement cost (on the x-axis) and the Willingness To Pay (WTP) for EE (on the y-axis). However there is one very significant outlier: the Chewton Mendip CMZ has a relatively low reinforcement cost (£225k/MW) but an extremely high willingness to pay for EE. We will examine the reasons behind this as part of the next phase of our work.

Figure 9 Comparison of EE benefits and reinforcement cost



Source: Frontier Economics

In the following subsection we describe the initial results of applying this tool.

2.2.1 Initial outputs from WPD-wide EE analysis tool

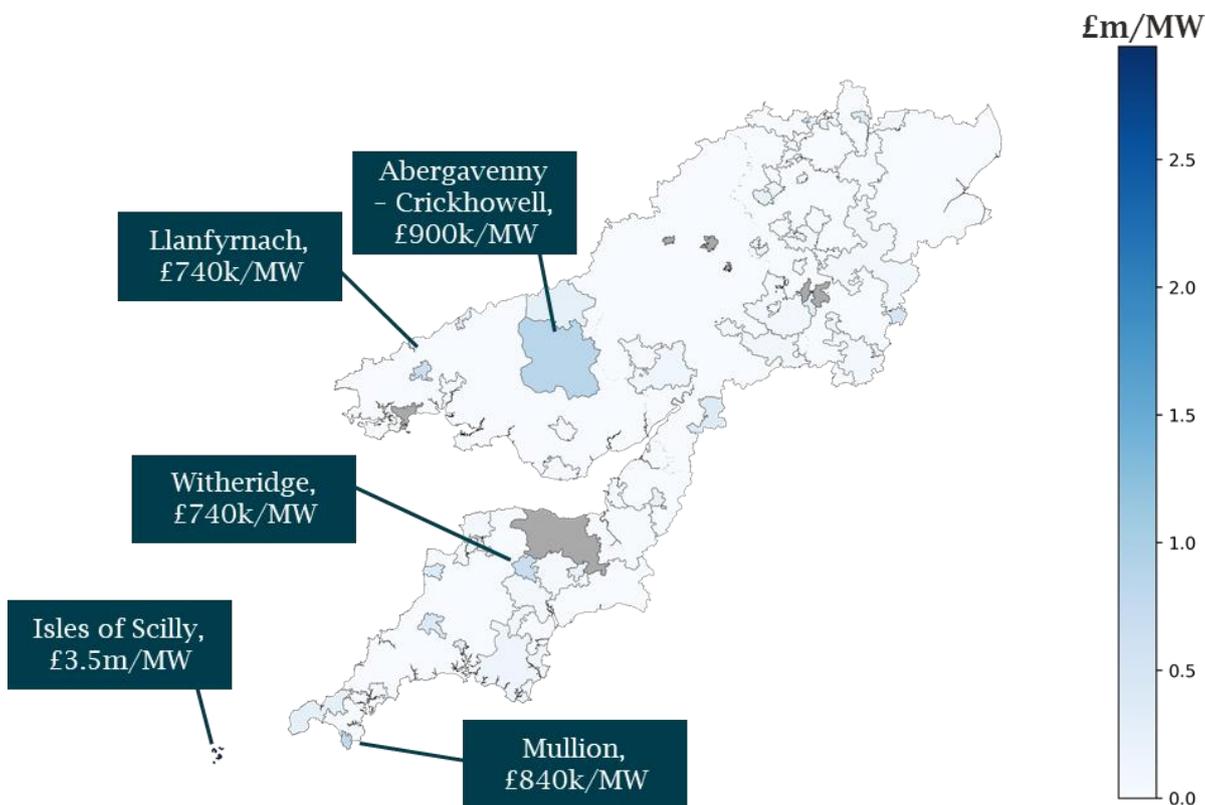
Reinforcement costs vary considerably between CMZs, a heatmap of which can be seen in Figure 10. We analysed all CMZs within WPD’s network area.¹² Reinforcement cost is calculated for each CMZ by the WPD Planning System Development (PSD) team. Costs vary from £9k to £3,500k per MW of peak demand. As

¹¹ We obtained similar results – not shown here – if the reinforcement costs on the x-axis are divided by peak reduction per dwelling retrofitted. This is since there is more variation across CMZs in terms of reinforcement costs than peak reduction per dwelling retrofitted. We have therefore focussed on reinforcement cost here, as it is both a more simple metric, and is independent of the particular properties chosen to be retrofitted.

¹² We note of the 68 CMZs in WPD’s are, complete data was only available for 61 of these. Analysis was run on all CMZs which had data for each relevant question.

described above we have normalised reinforcement cost using peak MW¹³ to control for differences in area size.

Figure 10 Reinforcements costs across WPD’s service area



Source: Frontier Economics

Table 1 below shows the results of several regressions we ran to determine the factors associated with reinforcement costs (£/peak MW). As above, the key insights are that areas with higher reinforcement costs also tend to have more low density and thermally poor dwellings with electric heating. These areas tend to be less densely populated, with a lower annual income after housing costs. Below we expand on these insights in more detail.

¹³ See footnote 10.

Table 1 High reinforcement cost area characteristics

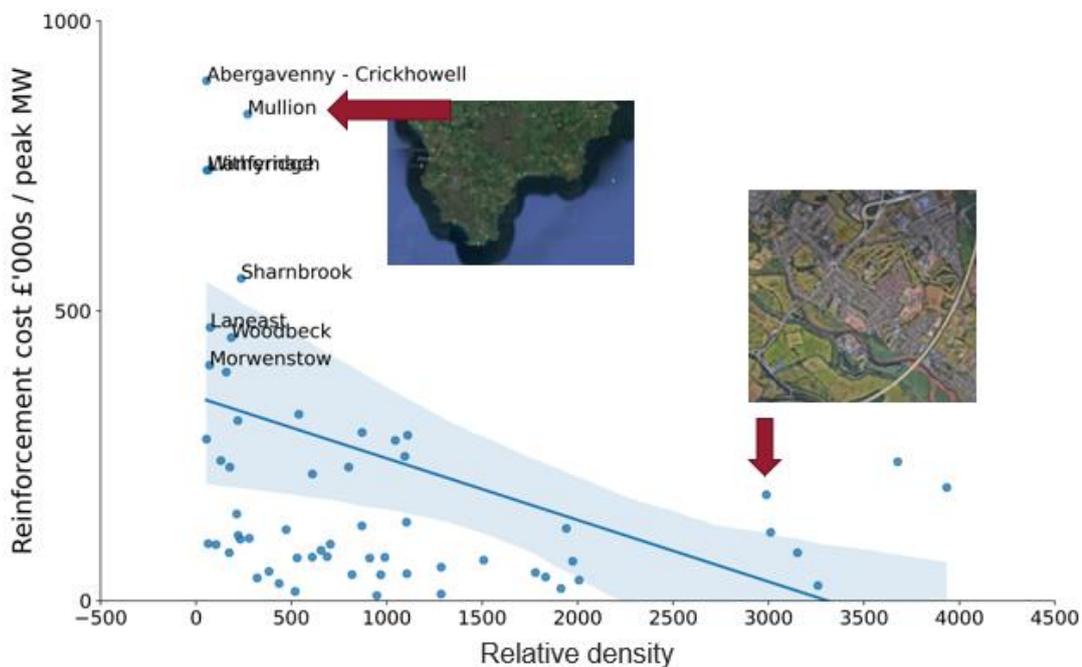
METRIC	RANGE	CORRELATION WITH REINFORCEMENT COST/PEAK MW
Housing density / urbanity – number of homes per square km	Some CMZs with 100 times more homes per km ² as others	-22%
Low density homes - share of homes that are classed as low density (Bungalow), in %	1% - 39% (Pembroke BroadField, Mullion)	31% (1% when including medium density homes)
Thermally poor homes – share of homes with EPC rating or E, F, or G) in the CMZ, in %	6% - 62% (Isles of Scilly, Llanfyrnach)	53% (-47% for thermally medium homes)
Income – net annual income after housing costs	17k – 37k	-24%
Social homes – share of homes that are social housing, in %	4% - 33% (Chesterfield Main)	6% (low correlation)
Electric heating – share of homes using electric heating (and no additional main fuel), in %	1% - 40% (Isles of Scilly)	63%
Off-grid - share of homes using a main fuel other than gas	2% - 98% (Isles of Scilly, Mullion, Stokenham, Witheridge all have 94%+)	50%

Source: Frontier Economics

Figure 11 shows that reinforcement cost is negatively correlated with housing density (calculated as the number of homes in an area¹⁴ divided by the area of the CMZ). This is distinct from low-density homes (e.g. bungalows as opposed to flats). We understand this is likely driven by the characteristics of rural networks – e.g. long cable distances and single transformer feeders.

¹⁴ as per the EPC data

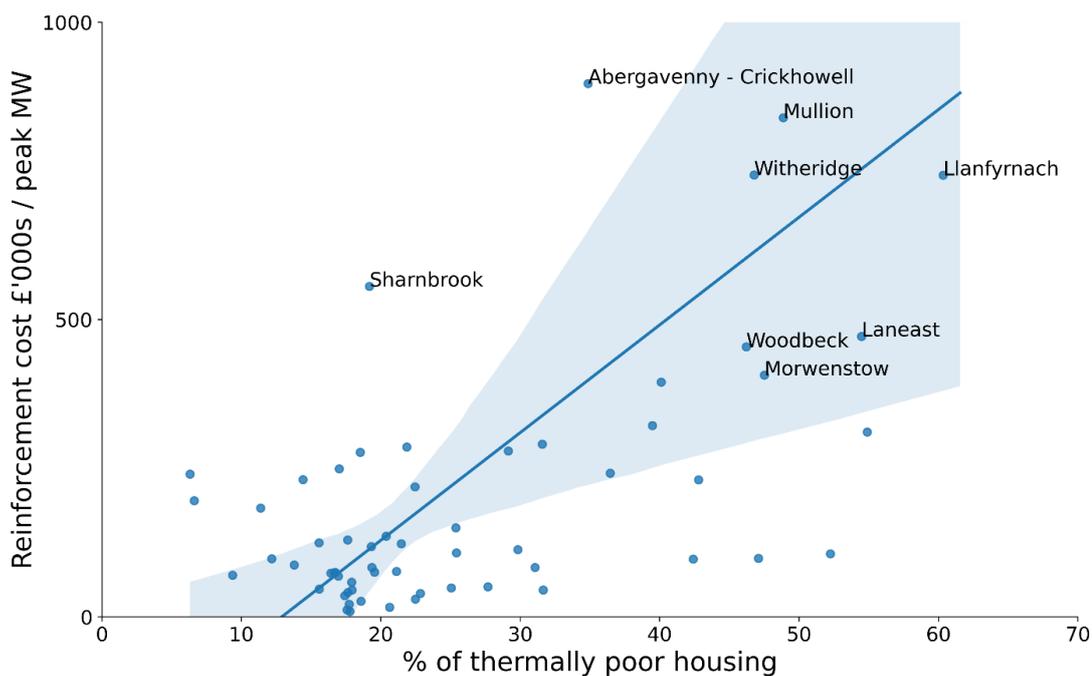
Figure 11 Reinforcement costs vs housing density



Source: Frontier Economics

Figure 12 shows that reinforcement cost is positively correlated with the percentage of thermally poor housing in an area. Housing rated as 'thermally poor' has the greatest benefit from EE measures. Most of the CMZs have a high proportion of thermally poor housing, above 50% in Llanfyrnach.

Figure 12 Reinforcement costs vs proportion of thermally poor housing



Source: Frontier Economics

Figure 13 shows that reinforcement cost is negatively correlated with household income (after housing costs). This suggests that, if money was provided for EE measures in areas with high reinforcement costs, this would on average benefit less well-off households. However we note that the EE schemes might not be representative of the whole area (e.g. focussing on larger houses). We will examine these issues as we use our tools further.

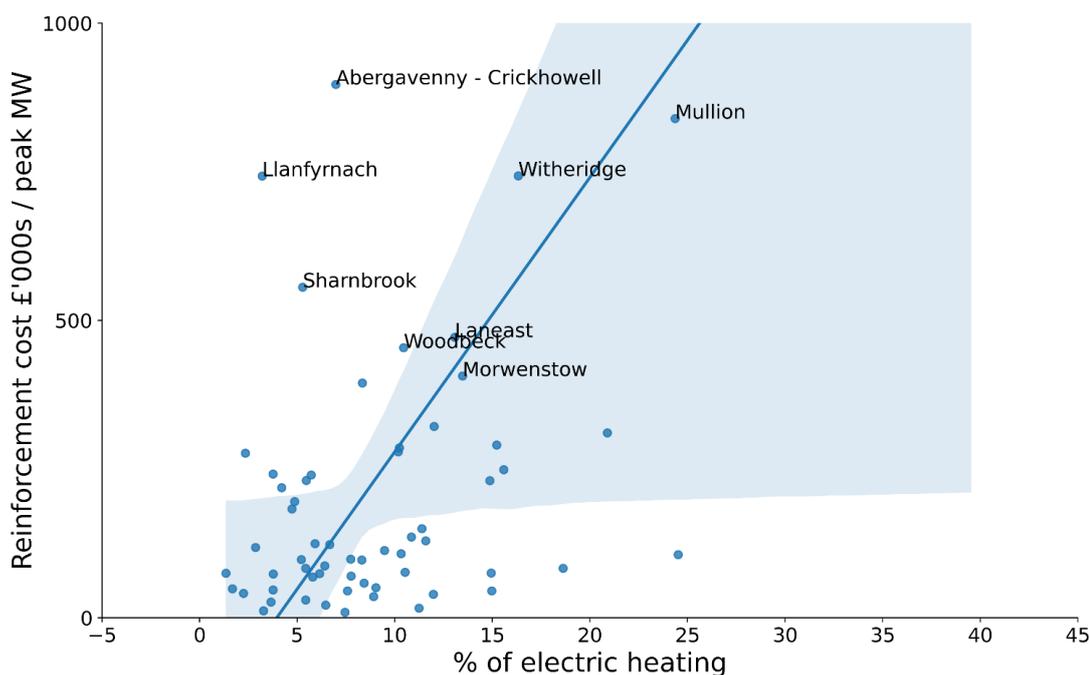
Figure 13 Reinforcement costs vs household income



Source: Frontier Economics

Figure 14 shows that reinforcement cost is positively correlated with the share of homes using electric heating as their main heating source.

Figure 14 Reinforcement costs vs proportion of electric heating



Source: Frontier Economics

Section 3 describes how this tool will be used for the analysis we will carry out as part of deliverable 2.2.

2.3 Key changes from initial specification

Since this project was undertaken in an agile format (to allow the project to be flexible in response to interim findings), specific outputs were not pre-determined. Rather, a series of key requirements to fulfil and a set of key questions to answer were set out in the scoping document¹⁵.

The following key changes were made over the course of the development stage:

- Originally, the 'Requirement and Specification' section of the initial scoping document envisaged that the tool would be developed for a limited area of WPD's network. Feeder Road 11kV was selected as the case study primary. However, the initial findings from Feeder Road showed a relatively low EE benefit. In response to this, throughout the rest of the development phase the tool was run over multiple different WPD CMZs. In addition, the model development was extended to include the additional 'WPD-wide EE analysis tool' that was not part of the original specification.
- Originally, the 'Requirement and Specification' section of the scoping document envisaged developing a real-options assessment tool to assess the importance of uncertainty when assessing EE interventions. It was agreed in the updated requirements document *not* to develop a real options analysis model because this is being developed by the ENA. However, part of the next phase of work

¹⁵ Investment appraisal tool specification - final - clean - 110522 – stc.docx

will use the existing 'least worst regrets' functionality in the CEM to explore the risks associated with paying for EE measures up-front.

- The 'Requirement and Specification' section of the initial scoping document also envisaged possibly making amendments to the FAT to better capture costs and benefits of EE – for example, a longer time horizon. As the FAT is proprietary WPD software and the source code was not available, as set out in the updated requirements document we instead worked closely with a member of the WPD team to run profiles through the FAT and make adjustments.

3 How can the tools be applied?

Section 3 of the WS2 key requirement document¹⁶ specifies the key questions that will be answered through modelling work using the tools described above. We will address these questions and what insights the model gives us in the next phase of the project: WS2.2 Analysis and insights. Here we set out each question and show how the tools were developed to assist us in answering them. The tools we have developed, as described above in section 2, are:

- The **EE assessment process** (made up of the **EE tool**, the **FAT**, the **CEM tool**, and the **EE benefit calculator**), which can be run across CMZs to assess the value of EE in that CMZ, and
- The **WPD-wide EE analysis tool**, which contains statistics across all CMZs. This can be used to analyse the conditions under which the value of EE is likely to be highest, and tell us the proportion of WPD CMZs in which EE is likely to have a meaningful benefit.

3.1 Are current optioneering tools suitable for assessing EE interventions?

The existing suite of WPD tools (the **FAT** and **CEM tool**) was not suitable for assessing EE interventions by themselves. We have augmented that suite with our own tools (the **EE tool** and the **EE benefit calculator**), enabling an approximation of the effects of EE interventions.

Whilst the WPD tools did not require any changes to achieve this approximation, they could be improved with further development of the WPD tools, specifically:

- Demand profiles are static in the CEM (we are unable to specify a different one for each year, addressed in 2.1.2 above); and
- The FAT and CEM cannot be automatically run across multiple areas to find the best candidates for EE. The WPD-wide assessment tool only approximates this, and is not currently able to identify all areas with high benefits from EE.

3.2 What are the main factors that make EE interventions more or less cost-effective from the network's point of view?

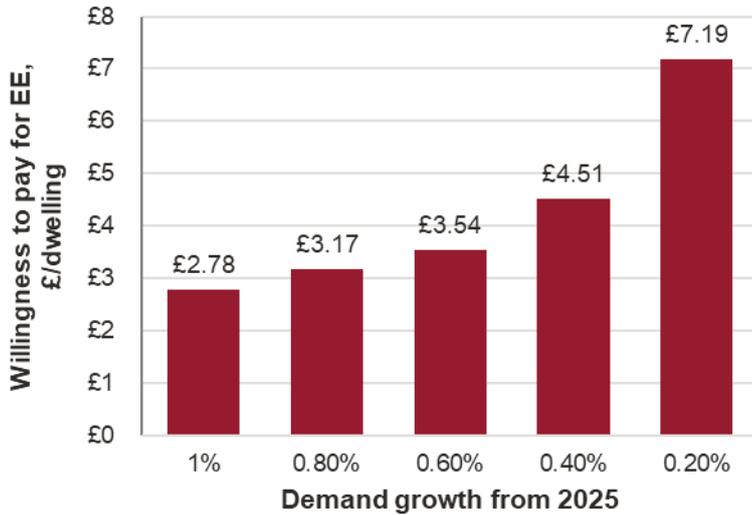
We have used the **EE assessment process** to run sensitivity tests, for example: testing the impact of different demand growth rates, reinforcement costs, and scales of EE schemes. We will carry out further sensitivity tests and document these as part of the next workstream, but summarise initial results below.

- **Lower demand growth:** The network has a set amount of capacity, and reinforcement occurs when demand exceeds that capacity. EE gives additional “head room” to this, as demand is lowered, and so this capacity is reached later. However, this benefit only applies when growth is sufficiently slow. If demand growth is too high, demand exceeds this threshold almost immediately, and so EE does not permit any additional deferral. Conversely, when demand growth is lower, this “head room” is useful for

¹⁶ DEFENDER WS2 Key requirements update - 210722 - stc.docx

longer. By reducing Best View growth rates from 2025 onwards, the value of EE in Feeder Road can be augmented from £0.49/dwelling to up to £7.19/dwelling (see Figure 15 below).

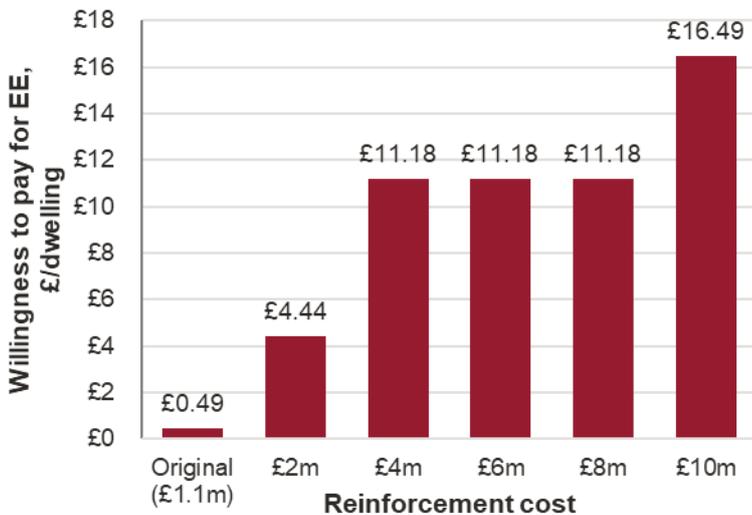
Figure 15 Impact of demand growth after 2025 – Feeder Road



Source: Frontier Economics

- Higher reinforcement costs:** increased reinforcement costs from £1.1m to £10m (x9) increases the willingness to pay significantly, by a factor over x30 in this instance. Under assumptions with lower growth, even smaller increases in reinforcement costs yield high willingness to pay. Reinforcement costs vary significantly across areas and so this is an important factor. As described in section 2.2, we have used the WPD-wide EE analysis tool to explore the characteristics of areas with highest reinforcement costs.

Figure 16 Impact of increased reinforcement cost – Feeder Road



Source: Frontier Economics

- **Availability of flexibility:** Flexibility is both a complement to and substitute for EE. If availability of flexibility is so low that reinforcement is required regardless of EE, WPD's willingness to pay for EE will be low. However if flexibility availability is very high then this will push out the deferral of reinforcement cause by EE.
- **Property type:** Our sensitivities demonstrated that, all else equal, the willingness to pay for EE is higher where the scheme includes property types which can provide particularly high peak savings. For example, if all homes in the Feeder Road area were medium-density poor thermal performance homes, WPD's willingness-to-pay for EE would increase by 2.5 times.

Given the importance of reinforcement cost, the WPD-wide EE analysis tool was used to examine the types of CMZ where these are highest. This highlighted particularly rural areas (which will also be more likely to be thermally poor, low density, off gas grid and lower income) as areas where reinforcement costs tend to be higher.

Work going forward

As soon as they are available, the profiles we use in our tool will be replaced with those developed as part of WS1. In addition to confirming the results of our high-level analysis still hold, homes that currently have electric resistive heating will be included, as there are good reasons to think these may have particularly high benefits to the network from EE coupled with moving to a heat pump. This is as:

- As noted above, the analysis shows that rural off-grid areas (which are more likely to use electric resistive heating at present, and where a heat pump may be more attractive in the near term) tend to have higher reinforcement costs, and therefore higher benefits to WPD from EE.
- Homes with electric resistive heating will have greater gains to EE than those with a HP (as electric resistive heaters will use around 3x the electricity of heat pumps.)
- There would be even greater savings if the intervention includes moving the home from electric resistive to a HP.

The tools will also be used to investigate areas with disproportionately high benefits from EE, such as Chewton Mendip (discussed in section 2.1), compared to their cost of reinforcement.

3.3 Are EE interventions likely to provide sufficient value to WPD, across a broad range of networks, that it is worth further developing the process to bring them forward?

The **EE assessment process** has been used to estimate, in sensitivity tests, the range of potential EE benefits for WPD across all CMZs. Initial results suggest that EE may be useful in a limited number of areas under a specific set of conditions: areas with higher reinforcement costs, which also tend to have more low density and thermally poor dwellings with electric heating. These areas tend to be less densely populated, with a lower annual income after housing costs

Work going forward

The **WPD-wide EE analysis tool** (with updated profiles from DEFENDER WP1) will be used to estimate the proportion of WPD CMZs in which EE may have a meaningful benefit.

The tool tells us WPD's willingness to pay. As part of the next phase of work, the amount WPD might be *required* to pay in order to bring forward EE investment will also be investigated. This will involve considering the cost of EE schemes versus the private benefits in terms of reduced bills – as well as the value that WPD may place on the reduction in carbon emissions.

This will be used, with the **WPD-wide EE analysis tool**, to understand:

- What are the types of areas where EE is likely to be worthwhile? Combined with information on the make-up of the license area as a whole, we can estimate in what % of CMZs EE might – at some point – be useful for the network. We will also combine with information from WPD on procurement of flexibility: We currently believe the types of areas where EE may be most effective are likely to be rural, which may have insufficient sources of flexibility.
- Within these areas, what sorts of homes need focussing on? This will draw on the result of analysis using the EE assessment process to determine whether the scale of the intervention matters. I.e. is it sufficient to focus on a small number of housing types which have particularly high benefits (e.g. large thermally poor properties)? Or is it necessary to have a large scale of scheme to have any impact – in which case the average willingness to pay per dwelling may be lower.

3.4 How significant is the role of uncertainty?

Although the cost of reinforcement is a key driver of benefits from EE (and this cost should be relatively well understood by WPD) sensitivity testing has shown that the value of energy efficiency is substantially affected by less factors such as the rate of load growth. Our current hypothesis is that it may be the particular rate of load growth which is responsible for the particularly high modelled EE benefit in Chewton Mendip, described above.

Work going forward

It was agreed in the scoping document not to develop a real options analysis model because this is being developed by the ENA.

Instead, part of the next phase of work will use the existing 'least worst regrets' functionality in the **CEM tool** to explore the risks associated with paying for EE measures up-front. The different sources of uncertainty that may affect an EE scheme will be considered – for example:

- future load growth;
- how many people will take up the scheme; and
- how many would have insulated their homes without the scheme.

We will use the least-worst regrets functionality to understand to what extent these uncertainties affect the case for EE, and describe the types of uncertainty which may be most important for any new version of the CEM to include.

3.5 Given the nature of EE interventions, what types of commercial model might be used to procure it? Are there any blockages that might prevent these models being deployed?

We have so far used the **EE tool**, and the **WPD-wide EE analysis tool** to answer the following questions:

- What types of property will give the greatest value for EE interventions?
- What proportion of properties may be required in an area (e.g. to obtain a high value from EE, will it be necessary to engage with virtually all properties, or just a targeted subset)?
- Are the types of available property different in areas where the value of EE is highest (e.g. where reinforcement costs are relatively higher)?

Work going forward

As described above, the tools will continue to be used to investigate these questions, as well as others such as:

- Is a large scale of scheme (i.e. many houses) required to obtain meaningful benefits per dwelling?
- What are the risks for WPD? For example, what might the costs be if an EE intervention is carried out by no longer needed (e.g. due to demand growing faster than expected)? How likely might this be?

The answers to these questions will affect the types of commercial model that are viable. For example, commercial model(s) may vary in terms of:

- Amount of funding provided (varying from schemes which do not provide any funding at all – e.g. information campaigns – through to part- and full-funding of EE interventions);
- the form of provision (e.g. loans, one-off grants, ongoing funding);
- the extent to which the scheme is targeted (e.g. available to everyone in the area vs low-income housing, etc.)

We will set out potential commercial model(s) and describe the risks and trade-offs to WPD, and assess potential blockages. We will also include the assessment of what proportion of areas EE interventions are likely to provide value-for-money.

4 How do the tools work?

This section sets out detailed steps for using the tools described in Section 2.

The following conventions will be used when specifying the details of the model:

- Inputs are marked in red (e.g. `shp_wpd_cmz_and_background.shp`)
- Filenames are marked in green (e.g. `01 Combine primaries into CMZ shapefile.py`)
- User input options are marked in orange (e.g. *User can input in line 20*)

4.1 Overview of the tools

The **EE tool** consists of scripts 01 – 06, with script 07 calculating carbon benefits on top of this. It operates in the following steps (further laid out in Figure 17):

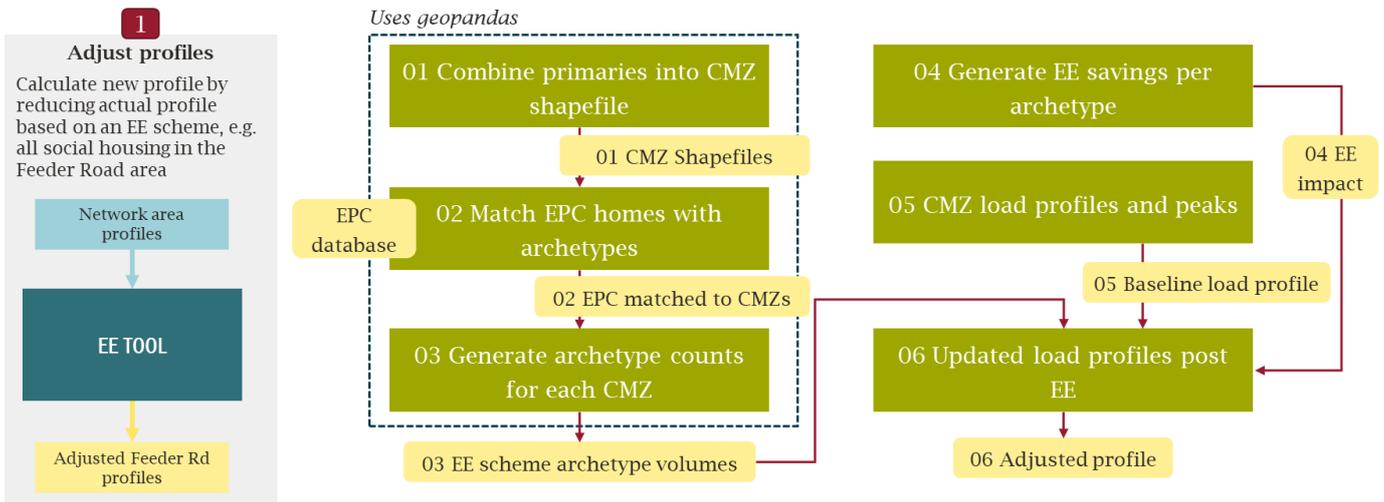
- `01 Combine primaries into CMZ shapefile.py`: this loads in WPD primary shapefiles across the whole operating area, combines them into CMZ areas, and saves this out.
- `02 Match EPC homes with archetypes and CMZs.py`: this loads in the pre-cleaned EPC database¹⁷ (see sub bullet below), assigns archetypes based on EPC variables (high/medium/low density, as well as good/medium/poor thermal efficiency), and then filters the database for homes in the WPD CMZ areas.
 - `R work to create epc data.R`: This script pre-cleans the EPC database.¹⁸ It saves out to the file called `epc_ew_uprn_trim.csv`, which we provide separately in the setup zip. This script is provided in R, rather than in Python – the code is attached for completeness, but we do not anticipate it being need to re-run.
- `03 Generate archetype counts for each CMZ.py`: this counts the number of homes and social homes of each archetype per CMZ, based on which an EE scheme can be designed.
- `04 Generate EE savings per archetype.py`: this calculates savings from EE for each archetype based on data from ESME etc.
- `05 CMZ load profiles and peaks.py`: this loads in load profiles for all CMZs, calculates peak use, and saves these out.

¹⁷ Downloaded June 29th 2022 <https://epc.opendatacommunities.org/login>

¹⁸ Downloaded June 29th 2022 <https://epc.opendatacommunities.org/login>

- **06 Updated load profiles post EE.py**: based on user selection, this loads in the WPD CMZ load profile, selects a scheme, and generates a post-EE profile for each CMZ, which can be loaded into the FAT tool.
- **07 Calculate carbon reduction.py**: this calculates carbon savings from EE interventions.

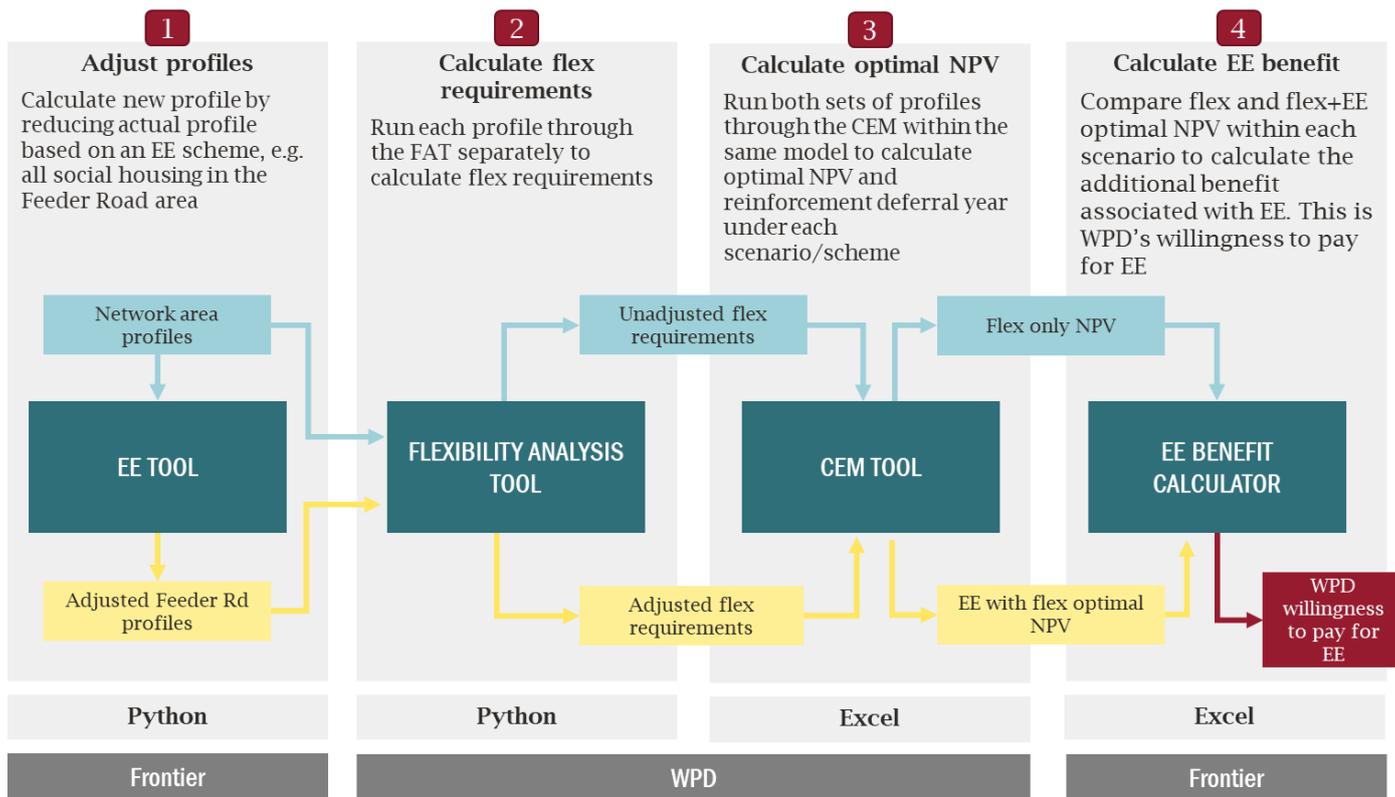
Figure 17 EE Tool Diagram



Source: Frontier Economics

The updated load profiles from script 06 are then loaded into the FAT, then the CEM tool, and then the EE benefit calculator as in Figure 18:

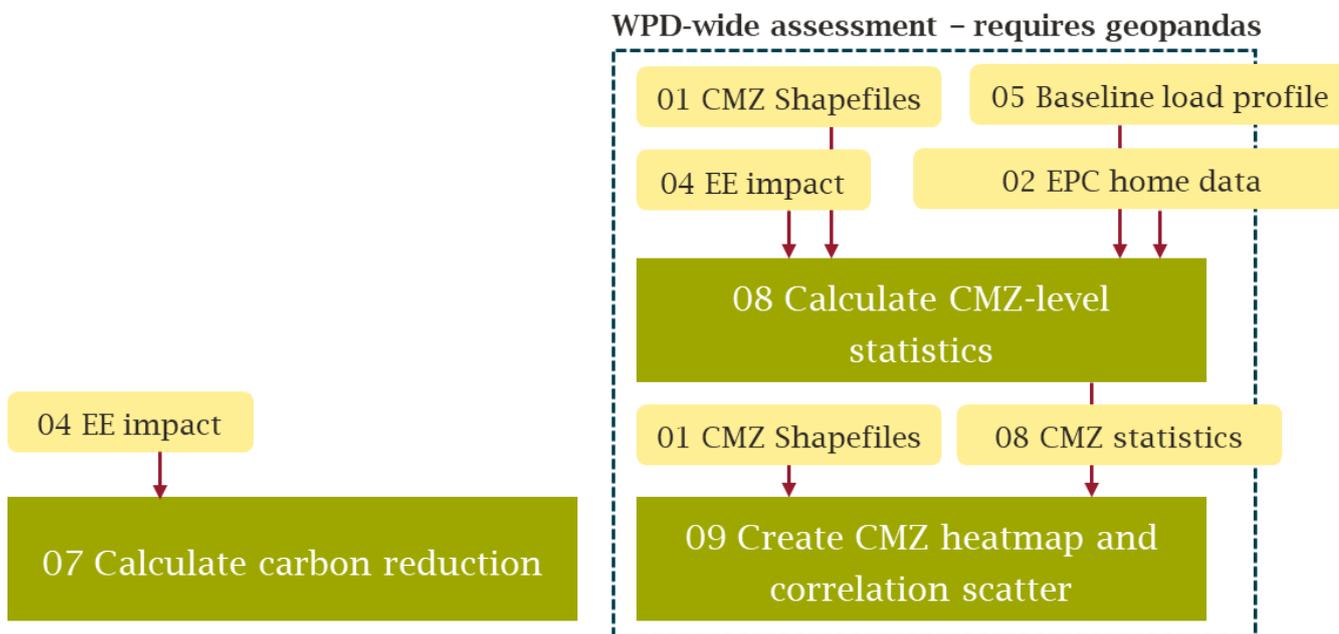
Figure 18 Complete EE assessment process



Source: Frontier Economics

The **WPD-wide assessment tool** consists of scripts 08 and 09, further laid out in Figure 19. This loads in outputs from the EE tool and combines these into a succinct table of statistics across all CMZs. These are then used to create heatmaps and correlation scatters, to investigate the conditions under which the value of EE is likely to be highest, and show in which WPD CMZs EE is likely to have a meaningful benefit.

Figure 19 Carbon reduction, and WPD-wide assessment tool



Source: Frontier Economics

4.2 Example of tool usage

If the user wants to examine the impacts of a scheme in Gunnislake covering all homes (rather than just social homes), they would do the following:

EE tool

- The volume of homes in each archetype across all homes is already calculated, and is available in the output from script 03 *input_wpd_all_cmz_ee_dist.csv*
 - If the user wanted to e.g. apply the scheme to privately rented homes, they would need to step into script 03, which requires geopandas.
 - If the user wanted to apply the scheme to 50% of social homes, rather than all social homes, they would need to also step into script 03, and update the calculation for <social_dwellings> in section 2.3. This requires geopandas. Alternatively, they could load in *input_wpd_all_cmz_ee_dist.csv* and make the edit manually.
- Scripts 04 and 05 do not need to be rerun if they have been run before, as they simply save out EE impacts and load profiles for each CMZ
- The user would step into script 06 and adjust the EE scheme use in line 20, and then rerun the script. The script would output updated load profiles for all CMZs (if this is not desired, the user can amend the loop at the end of script 06).

FAT, CEM and EE benefit calculator

- Then, the user would run the adjusted EE profile (created in script 06) along with the original CMZ profile (created in script 05) through the FAT tool.
- The FAT output would be used to populate the CEM tool¹⁹.
- After running the CEM, the user would run the EE benefit calculator, which takes the CEM output (along with volumes calculated in previous steps) and yield a £ benefit of EE in total, and per dwelling.

This would tell the user the benefit of running this example scheme in the relevant CMZ.

4.3 Detailed instructions: EE assessment process

The following instructions set out, step by step, how to install and run the EE tool.

4.3.1 Set up files

Download and save the accompanying file package '*EE_tool.zip*' in a relevant working folder.

The list of packages required (and the versions used in development) can be seen in the "requirements.txt" file, please install them into the python environment you are using. The tool was originally developed in python 3.9. If another version of python is being used then the specified versions of the packages may be inappropriate nor can we guarantee that the tool will run properly. We therefore recommend that 3.9 is used for the code as delivered.

4.3.2 Calculate archetype counts for the area considered

This calculates the volume of all housing, and social housing, by archetype, in each CMZ. The outputs of this section are provided in the zip file, specifically:

- *input_wpd_all_cmz_ee_dist.csv* - this contains archetype counts for all CMZs used to calculate the post-EE load profiles; and
- *shp_wpd_cmz_and_background.shp* – the associated shape file which is used to generate maps (see script 08)

The user therefore **does not** need to run the code detailed in this section unless they wish to make changes to the archetype tabulations for each CMZ. The data is complete as long as you are running the analysis for a WPD CMZ area (not a Primary), and would like to apply the scheme to either a specific share of social homes or all homes. *If you would like to adjust the tabulation, e.g. splitting out homes that are rented privately, or applying the scheme in a non-CMZ area, you would need to edit the script as follows.*

Note that each script is designed to be run in isolation. You can either run all lines in an IDE or run "python <script_name>" on the command line.

¹⁹ Using the internal 'WPD process for using the CEM CBA tool' user guide

4.3.2.1 Make a shapefile of the CMZ areas

File: '01 Combine primaries into CMZ shapefile.py'

No user input required.

This script combines the WPD primaries into a shapefile which contains the 68 CMZ areas²⁰. The code performs the following steps:

- Combine the primaries into CMZs. This is done based on the file "PRIMARY_SUBSTATIONS.csv", provided by Hannah Lewis (28.07.22);
- Merge these CMZs with the shapefiles. This is done via the Primary ID variable (PRIM_NRID).²¹

This outputs two shapefiles: `shp_wpd_cmz_only.shp`, and `shp_wpd_cmz_and_background.shp`, which contain the shapes of the 68 CMZ, and the shapes of the 68 CMZs plus the entire non-CMZ WPD service area, respectively. The non-CMZ WPD service area has the CMZ_CODE variable set to "CMZ_none", and is retained to allow map generation.

4.3.2.2 Assign homes to a CMZ and an archetype

File: '02 Match epc homes with archetypes and CMZs.py'

No user input required.

This script loads in the EPC data for England and Wales²² which has been cleaned and reduced to one line per UPRN (Unique Property Reference Numbers).²³ The file is called `epc_ew_uprn_trim.csv`.

The script then loads in the UK postcode data from May 2022, `ONSPD_MAY_2022_UK.csv`.²⁴ The postcode & longitude/latitudes are retained and merged onto the EPC data to provide an approximate geocoding for each home.

Each home in the EPC dataset is then allocated an archetype, in line with ESME, as follows:

²⁰ Downloaded from the WPD data portal <https://connecteddata.westernpower.co.uk/dataset/spatial-datasets> on July 21st 2022

²¹ Note: the shapefiles were missing the primary 314314 Calvert, and the primary substation mapping was missing the primary 491018 Rugby Gateway

²² Downloaded June 29th 2022 <https://epc.opendatacommunities.org/login>

²³ This is done in a separate R script, see its description in 4.1 above. The script deduplicates the EPC data, where dwellings are uniquely identified by their UPRN. Duplicates are due to homes having had multiple EPC inspections/certificates in the database period (since October 2008). where there are multiple observations per home, the most recent observation is kept. If there are multiple lines for the same day, the observation with the highest EPC score is retained. Records are dropped where an UPRN has not been made available.

²⁴ Downloaded from the ONS data portal <https://geoportal.statistics.gov.uk/datasets/ons::ons-postcode-directory-may-2022/about-published-May-25th-2022>. Note: the August 2022 postcode directory is now available

Table 2 **Archetype allocation**

ESME: DENSITY	EPC: "PROPERTY TYPE"	ESME: THERMAL PERFORMANCE	EPC: "CURRENT ENERGY RATING"
High (HD)	Flat	Good (ThG)	A, B
Medium (MD)	House, Maisonette	Medium (ThM)	C, D
Low (LD)	Bungalow, Park home	Poor (ThP)	E, F, G

Source: Matching was done based on ESME documentation [<https://ukerc.rl.ac.uk/ETI/PUBLICATIONS/ESME-v4.3-Dataset.pdf>]

Note: Two homes with a missing energy rating had a score of zero, and so were allocated to "poor". One home had a "invalid" energy rating and had a score of >= 92, and so was allocated to "good". The ESME data also contains a classification of "thermally excellent", applying to new builds only, but for both thermally excellent and good homes, EE measures have no impact, so it is not necessary to differentiate these.

This is combined into archetypes such as Dwelling_HD_ThP.

Social housing can be identified in the EPC variable "Tenure". It should be noted that some homes have no clear tenure, and as such the number may be a slight undercount.

The script loads in the shape of the WPD CMZs using the output from script 1, `shp_wpd_cmz_only.shp`. Using the geopandas function 'intersect', each home in the EPC data is allocated to a CMZ, and the homes not in any CMZs are dropped. The file is saved out as `epc_ew_wpd_areas_cmz_only.shp`.

4.3.2.3 Calculate summary table with archetype counts

File: '03 Generate archetype counts from EPC for each CMZ.py'

No user input required.

This script calculates the number of social and total homes in each CMZ, split by archetypes, scales this up to account for EPC incompleteness (more detail below), and outputs this as `input_wpd_all_cmz_ee_dist.csv`.

First, the list of homes in CMZ areas is loaded in, `epc_ew_wpd_areas_cmz_only.shp`. The code provides summary statistics for each archetype in each CMZ including total homes and total social homes²⁵ (homes where "tenure" = "rented (social)"). For example, in the Mullion CMZ, we have the following tabulation:

²⁵ If a user wishes to tabulate archetypes for a different scheme, e.g. one covering private renters, they would need to amend the code in section 2.3, adding on a tabulation for the desired tenure type, calling it e.g. total_private, scaling this up (total_private_scaled), and outputting it to this table. The relevant column is then specified at the start of script 06 (see below).

Table 3 Example archetype count: Mullion CMZ

ARCHETYPE	TOTAL DWELLINGS	SOCIAL DWELLINGS	SCALED: TOTAL DWELLINGS	SCALED: SOCIAL DWELLINGS
Dwelling_HD_ThG	1		1	
Dwelling_HD_ThM	29	11	46	17
Dwelling_HD_ThP	10		16	
Dwelling_MD_ThG	71	1	115	1
Dwelling_MD_ThM	358	56	579	90
Dwelling_MD_ThP	350	4	566	6
Dwelling_LD_ThG	11		17	
Dwelling_LD_ThM	179	47	289	76
Dwelling_LD_ThP	260	6	421	9
	1,269	125	2,050	199

Source: Frontier Economics

Note: “Scaled” means the count has been multiplied by x1.62 to account for the EPC covering only 61.7% of homes in England and Wales, and then rounded down. Mullion CMZ_CODE is CMZ_T5B_SWE_0019

The “... scaled” columns account for the fact that the EPC is an incomplete list of homes in the UK. Overall, the EPC²⁶ contains complete data on 15.68m homes in England and Wales (based on the number of unique UPRNs). ONS data tells us that there are 23.96m homes in England and 1.44m homes in Wales, meaning the EPC is 61.7% complete. To get from the homes in the EPC to the total number of homes, the EPC figures (after being split by CMZ and archetype) are scaled up by a factor of $1/61.7\% = 1.62$, and rounded down to be conservative (e.g. 2.8 is rounded to 2)²⁷.

This is saved out as `input_wpd_all_cmz_ee_dist.csv`.

The script also calculates the total number of homes and social homes per CMZ, for use in script 08 (which uses CMZ characteristics to identify areas with high benefits from EE). This is saved out as `count_of_homes_all_cmzs.csv`.

4.3.3 Adjust profiles

If the user has skipped section 4.2.2 (scripts 01 – 03), they need to ensure they have the file `input_wpd_all_cmz_ee_dist.csv` from script 03, which contains archetype counts for all CMZs.

²⁶ Downloaded June 29th 2022 <https://epc.opendatacommunities.org/login>

²⁷ We are assuming that our sample is representative, i.e. that a fairly constant 62% of homes have EPC scores across the country.

4.3.3.1 Calculate EE savings per archetype

File: '04 Generate EE savings per archetype.py'

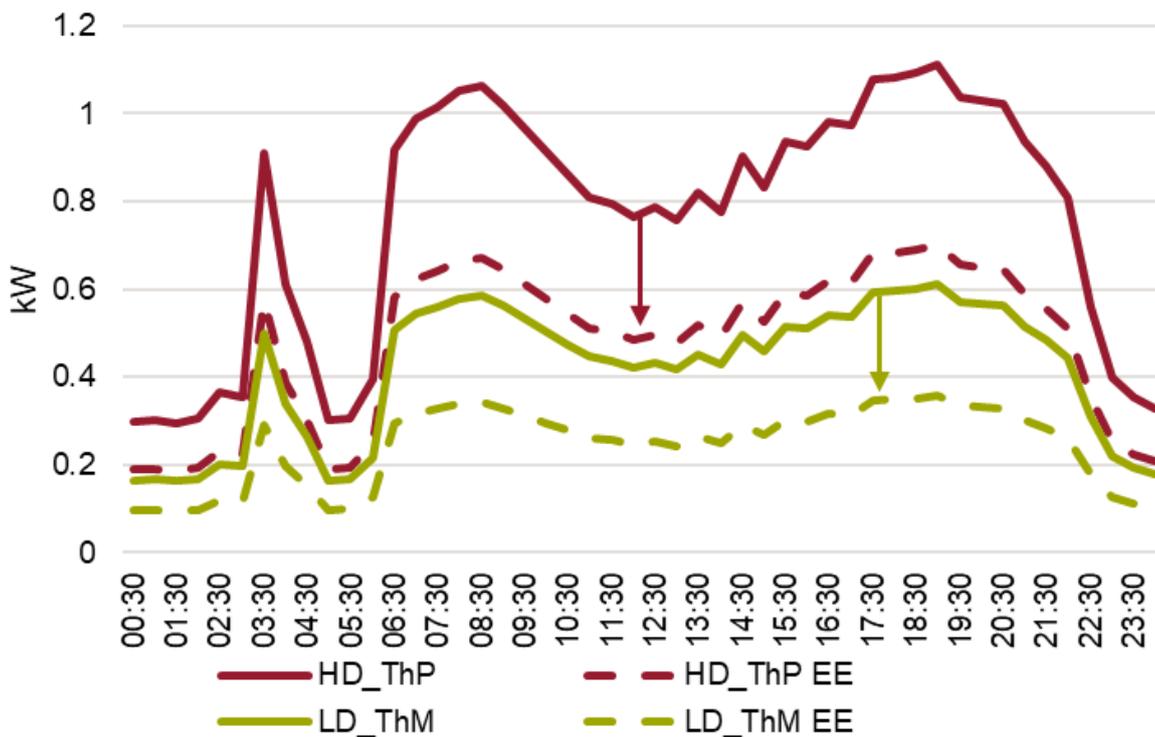
No user input required.

This file calculates a set of half-hourly profile changes for each dwelling archetype (e.g. Dwelling_MD_ThM). This is not based on WPD profiles, unlike script 05. It loads in data from ESME, [input_ESME_v4.4.xlsx](#)²⁸, which contains space heating data in the form of kW per Heating Degree Days (HDD), as well as % savings and investment costs of retrofitting energy efficiency²⁹.

The script also loads in a heat pump profile from [CLNR input_CLNR_TC3_Dec2014.xlsx](#)³⁰, which contains half-hourly demand across all twelve months.

The script calculates annual electric demand in kWh per archetype, applies the appropriate saving, and then, using the heat pump profile, creates an updated half-hourly demand profile for each archetype. For two example homes (high density thermally poor and low density thermally medium), in a day in January, this looks as follows:

Figure 20 Example profiles in January pre- and post-EE



Source: Frontier Economics

²⁸ Energy System Modelling Environment (ESME) data, <https://ukerc.rl.ac.uk/ETI/PUBLICATIONS/ESME-v4.3-Dataset.pdf>

²⁹ We use the figures for “Retroplus”, to amend this to “Retrofit”, amend the selection in line 45.

³⁰ See “Enhanced profiling of domestic customers with air source heat pumps” here:

<http://www.networkrevolution.co.uk/resources/project-data/>

Note: The dip in profile demand at 3.30am is due to the CLNR heat pump profiles having higher demand at this time for hot water. We have not addressed this in the data as it does not affect the peak and will therefore have limited impact on our results, and we expect to receive new profiles from WS1 at a later stage in the project.

It outputs three files:

- `heat_pump_profile_archetypes.xlsx`, which contains the updated heat pump profiles
- `heat_pump_profile_archetypes_change_only.xlsx`, which is a subset containing only the change in profile, and
- `archetype_annual_stats.xlsx`, which contains annual demand in kWh before and after EE, and investment costs, per archetype, amongst other columns.

4.3.3.2 Tidy up CMZ load profiles

File: '05 CMZ load profiles and peaks.py'

No user input required.

Unlike script 04, which works with hypothetical load profiles pre- and post-EE, this script works with CMZ-level load profiles. It loads these in and saves them out in a more easily usable naming convention, and calculates the peak hour and usage.

This script loads in actual load profiles across 2018 – 2021 for all WPD CMZs (data is available for 66 of 68), merges on the CMZ_CODE based on `CMZ Name Matching.xlsx`³¹, and saves them out in the format "`load_profile_without_EE_<CMZ_CODE>.csv`" for use in script 06.

It then calculates an average profile across the years and identifies the peak hour of this averaged profile. It loads in the heat pump profile `CLNR input_CLNR_TC3_Dec2014.xlsx` and calculates what % of annual usage the heat pump profile uses at that peak hour. It saves this information out, with one row per CMZ, as `all_areas_hourly_peak_and_pump_share.xlsx` for use in script 08. This is to estimate the reduction in peak load (as opposed to total load), as well as to calculate reinforcement costs per peak MW³².

4.3.3.3 Adjust WPD profiles using EE scheme

File: '06 Updated load profiles post EE.py'

This script brings together outputs from the previous script to output load profiles post-EE, for use in the FAT, in the file `DEFENDER_wpd_profile_with_ee_<CMZ_CODE>.csv`. By default, it outputs load profiles for every CMZ³³.

The user can adjust the following in the "config.yaml" file:

³¹ This file matches up CMZs across various files, based on CMZ Name, Code, and load data file names. It was created by Frontier Economics and approved by Peter Gaskin on August 12th 2022.

³² Peak MW per CMZ is calculated by averaging the three-year profile across each half-hour, to generate an average profile, averaging the half-hours into hourly loads, and then taking the peak of this year-long average profile.

³³ Two CMZs do not have load profiles and hence are excluded: Pembroke – BroadField, and Pembroke – Tenby (CMZ_T4A_SWA_0003_P1 and CMZ_T4A_SWA_0003_P2)

- which EE scheme to use (social housing or total housing) – item “ee_scheme_social”.
- whether to use scaled figures (which increase the number of homes in the EPC data by ~60% to account for incomplete EPC data) or not – item “scaled”.
- Which retrofit type to use (Retroplus or Retrofix where Retroplus is more effective but more expensive), based on the types seen in the ESME data – item “tech_name”.
- Scaling to be applied to each archetype (this is a proxy for selecting a proportion of households of a given archetype) – item “ee_archetype_scaling”.
- A list of CMZs (or specify “all” for all CMZs) to calculate the updated load profiles for – item “ee_cmz”

The script loads in `input_wpd_all_cmz_ee_dist.csv` from script 03, which contains archetype counts for all CMZs, `heat_pump_profile_archetypes_change_only.xlsx` from script 04, which contains half-hourly EE savings per home for each archetype, and `archetype_annual_stats.xlsx` from script 04, which contains statistics for each archetype.

The number of homes per CMZ is merged onto the archetype statistics, to produce a dataframe with a row for each CMZ-archetype combination. The number of homes (e.g. 100 medium density, thermally poor homes in Mullion CMZ) is multiplied by the relevant kWh savings (e.g. 2,212 kWh annually). This is done for total homes and social homes, and also for investment costs. This is saved out as `Archetype_annual_stats_with_ee_schemes.xlsx` (see sample extract below).

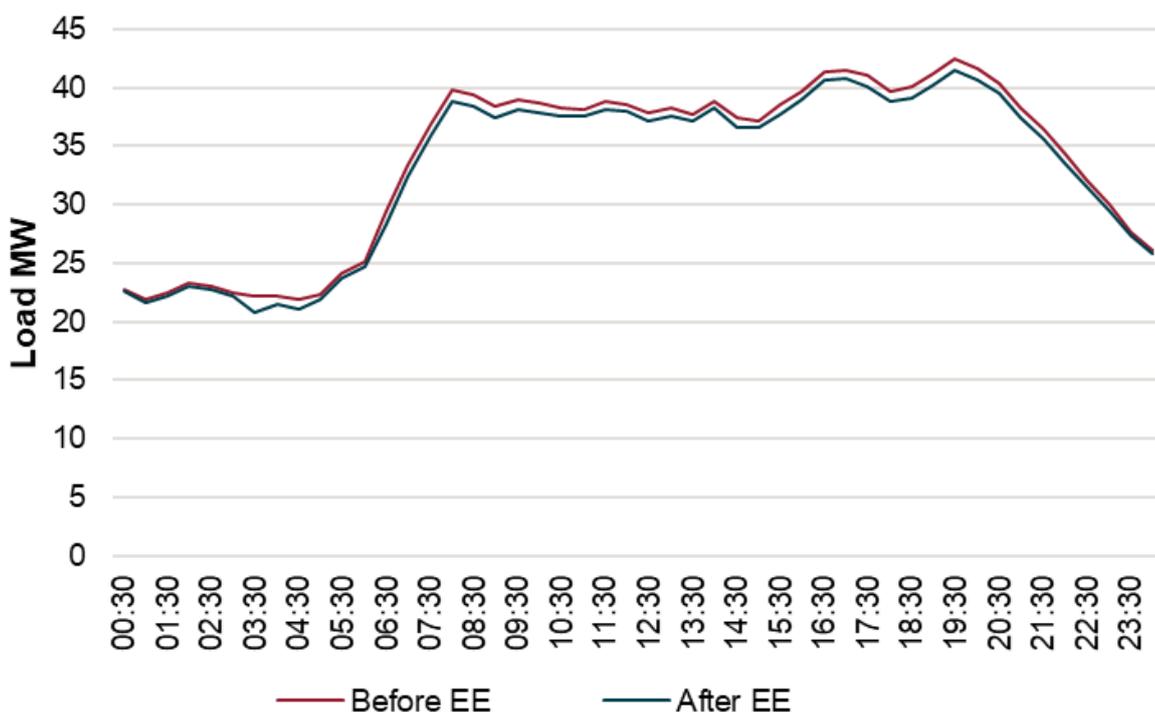
Table 4 Example archetype annual stats for CMZ_SP3A_WM_0006 (Bushbury_BSP)

ARCHETYPE	EL. DEMAND (KWH, ANNUAL)	% SAVINGS	CHANGE (KWH, ANNUAL)	# SOCIAL HOMES (SCALED)	CHANGE IN SOCIAL HOMES (KWH, ANNUAL)
HD_ThG	649	0%	-	130	-
HD_ThM	1,516	37%	558	1,933	28,533,927
HD_ThP	3,768	37%	1,386	147	2,176,519
LD_ThG	886	0%	-	3	-
LD_ThM	2,075	42%	861	551	14,041,761
LD_ThP	4,915	42%	2,040	100	2,560,557
MD_ThG	815	0%	-	3	-
MD_ThM	1,913	49%	934	4,680	88,796,142
MD_ThP	4,533	49%	2,212	237	4,487,448

Source: Frontier Economics

Then, the code loops over each CMZ for which we have load and EPC data, loading in the relevant profile before EE from script 05 ('load_profile_without_ee_<CMZ_CODE>.csv'), and subtracting the heat pump profile changes multiplied by the number of homes, based on the month and time of day, for each archetype. This generates a new load profile for that CMZ, which is saved out as 'DEFENDER_wpd_profile_with_ee_<CMZ_CODE>.csv' which can be used in the FAT.

Figure 21 Example load profile, October 1st 2018, CMZ_SP3A_WM_0006 (Bushbury_BSP)



Source: Frontier Economics

The script also saves out a version called 'before_after_<CMZ_CODE>.csv' which contains both pre- and post-EE profiles, as well as the change applied, for reference.

File: '07 Calculate carbon reduction.py'

The user can adjust the following in the "config.yaml" file:

- The scheme name – item "ee_scheme_name"
- the start year for the carbon calculation – item "start_year"
- The number of years for the carbon calculation – item "years"

This script calculates the carbon reduction, outside of the CEM, from the EE measures. The script loads in Archetype_annual_stats_with_ee_schemes.xlsx (from script 06) as well as

`input_grid_carbon_intensity.xlsx`³⁴, which contains domestic carbon intensities to 2100. The script multiplies the change in demand from EE with the relevant carbon intensity, and then summarises this across the chosen timeframe. It is saved out as `total_carbon_reduction_<start_year>_to_<end_year>_all_areas.xlsx`. The yearly statistics are saved out as `carbon_reduction_byyear_all_areas.xlsx`.

4.3.4 Calculate flexibility requirements

Run the following through the Flexibility Analysis Tool (FAT), ideally over a 10 year time horizon³⁵:

- Unadjusted WPD actual demand profiles for the network area from script 05
(`'load_profile_without_ee_<CMZ_CODE>.csv'`)
- Adjusted WPD actual demand profiles for the network area from script 06
(`'DEFENDER_wpd_profile_with_ee_<CMZ_CODE>.csv'`)

This will output flexibility requirements for the network area based on a flexibility-only scheme (unadjusted profiles) and a flexibility-with-EE scheme (adjusted profiles). For each scheme 5 scenarios³⁶ are created based on different demand growth rates assumptions³⁷. The flexibility requirements for the flexibility-with-EE scheme should be lower.

4.3.5 Assess options using the CEM

The Common Evaluation Methodology (CEM) is a Cost Benefit Analysis (CBA) tool. The primary purpose of CEM is to allow the user to assess the merits of deferring reinforcement by employing flexibility solutions for one or more years. The model allows the user to test different flexibility strategies under different load growth scenarios. The outputs flow into the EE benefit calculation tool.

The following are user instructions for the CEM.

Open a blank Common Evaluation Methodology (CEM) template and set up the two schemes ('Flexibility' and 'Flex with EE') in the 'Control' tab. Click the 'Update Configurations' button. There should be 10 'Config' tabs at the end of the model, one for each scenario-scheme combination.

³⁴ Green Book supplementary tables, <https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal>

³⁵ This would extend the time horizon of the CEM tool in the next step and increase the chance for the optimal reinforcement deferral to be captured by the model.

³⁶ Best View, Consumer Transformation, Leading the Way Steady Progression and System Transformation

³⁷ Set internally by WPD

Figure 22 Example 'Control' tab of CEM

Reference Year (for discount and index)	2021/22
Reference Calendar Year (for discount and index)	2022
Start Year	2022
Baseline exceedance directly or via peak load	Directly
Flexibility Cost Input Type	Flex Costs from Volumes

Potential long list of scenarios and strategies (user-defined)	
Market scenario	Strategy
Best view	Flexibility
Consumer Transformation	Flex with EE
Leading the Way	[3]
Steady Progression	[4]
System Transformation	[5]
[6]	[6]
[7]	[7]
[8]	[8]
[9]	[9]
[10]	[10]

Configuration id	Scenario	Strategy	First year where availability requirement exceeds flex availability	Configuration name
Config1	Best view	Flexibility	2034	Flexibility under Best view
Config2	Consumer Transformation	Flexibility	2034	Flexibility under Consumer Transformation
Config3	Leading the Way	Flexibility	2034	Flexibility under Leading the Way
Config4	Steady Progression	Flexibility	2034	Flexibility under Steady Progression
Config5	System Transformation	Flexibility	2034	Flexibility under System Transformation
Config6	Best view	Flex with EE	2034	Flex with EE under Best view
Config7	Consumer Transformation	Flex with EE	2034	Flex with EE under Consumer Transformation
Config8	Leading the Way	Flex with EE	2034	Flex with EE under Leading the Way
Config9	Steady Progression	Flex with EE	2034	Flex with EE under Steady Progression
Config10	System Transformation	Flex with EE	2034	Flex with EE under System Transformation
Configuration count			10	

Source: CEM tool received from WPD

In tab 'Baseline Reinforcement' set the Basis for identifying intervention year star year to "Manual Input", and the Intervention start year then set as the first year flexibility will be required under the WPD Best View scenario. The reinforcement cost should be entered in the same year as the Intervention start year under BASELINE REINFORCEMENT AND UPLIFT CAPEX (TO BE DEFERRED). All costs should be put in the same year in the absence of a full spend profile.

Figure 23 Example 'Baseline Reinforcement' tab of CEM

Basis for identifying intervention start year	Manual input
Intervention start year (for manual input)	2022
Scenario driving intervention requirement (if selected)	Best view
Intervention start year	2022

Exceedance per year (MVA) - Manual Entry		2022	2023	2024	2025
1	Best view				
2	Consumer Transformation				
3	Leading the Way				
4	Steady Progression				
5	System Transformation				

Exceedance per year (MVA)		2022	2023	2024	2025
1	Best view			0.00	0.00
2	Consumer Transformation			0.00	0.00
3	Leading the Way			0.00	0.00
4	Steady Progression			0.00	0.00
5	System Transformation			0.00	0.00

BASELINE REINFORCEMENT AND UPFRONT CAPEX (TO BE DEFERRED)		2022	2023	2024	2025
Cost 1	£	1,000,000			
Cost 2					
Cost 3					
Total	£	1,000,000			

Source: CEM tool received from WPD

In tab 'Flex Volume and Cost Input' under Initial price assumptions the Availability price should be set to £125 and the Utilisation Price should to be set to £175. The Availability price trend assumption should be left as 100% for every year. Under Fixed Costs the Annual Fixed costs should be filled out with £7,500 for every year except the first year (as the first year costs are sunk costs) for every scenario.

The Availability Volumes should be filled out by dividing the ESTIMATED_AVAILABILITY_ENERGY by the hours from the FAT outputs to populate the Average capacity of availability procured each year (MVA) and then populating the Hours per day of availability required with the hours from the FAT outputs. The Days per year of availability required should all be set to 1. After the first five years the Average capacity of availability procured each year (MVA) should be set to an arbitrarily high value (101) to exceed the Maximum flex availability (MVA) from the Additional inputs and control tab. This cuts off the results past the ten years being studied. The Utilisation Volumes should be filled out using the STIMATED_UTILISATION_ENERGY from the FAT outputs.

Figure 24 Example 'Flex Volumes and Cost input' tab of the CEM

Availability and Utilisation Price Assumptions

Initial flexibility price assumptions													
Availability Price (£/MW/h)	£125.00												
Utilisation Price (£/MWh)	£175.00												
Availability price trend assumption													
Availability price trend	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Effective availability price (£/MW/h)	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Effective utilisation price (£/MWh)	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00

Fixed Costs

Upfront Costs (incurred regardless of strategy duration) (£/yr)													
1	Flexibility under Best view												
2	Flexibility under Consumer Transformation												
3	Flexibility under Leading the Way												
4	Flexibility under Steady Progression												
5	Flexibility under System Transformation												
Annual Fixed costs (incurred only if strategy is still being pursued) (£/yr)													
1	Flexibility under Best view		7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
2	Flexibility under Consumer Transformation		7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
3	Flexibility under Leading the Way		7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
4	Flexibility under Steady Progression		7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
5	Flexibility under System Transformation		7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500

Availability Volumes

Average capacity of availability procured each year (MVA)														
1	Flexibility under Best view	0.11	0.13	0.13	0.15	0.19	0.2	0.3	0.5	0.8	1.1	1.3	1.6	101.0
2	Flexibility under Consumer Transformation	0.12	0.12	0.13	0.14	0.19	0.2	0.2	0.3	0.4	0.5	0.7	1.0	101.0
3	Flexibility under Leading the Way	0.12	0.13	0.14	0.16	0.22	0.2	0.3	0.5	0.8	1.1	1.3	1.6	101.0
4	Flexibility under Steady Progression	0.11	0.10	0.10	0.09	0.10	0.1	0.1	0.1	0.2	0.2	0.3	0.4	101.0
5	Flexibility under System Transformation	0.11	0.11	0.10	0.11	0.11	0.1	0.1	0.1	0.2	0.1	0.2	0.2	101.0
Hours per day of availability required														
1	Flexibility under Best view	1090.05	1130.9	1283.55	1606.05	2186.55	2702.55	3672.2	4760.1	5572.8	5753.4	5903.9	5934	
2	Flexibility under Consumer Transformation	1087.9	1210.45	1322.25	1578.1	2128.5	1915.65	2339.2	2868.1	3717.35	4745.05	5527.65	5753.4	
3	Flexibility under Leading the Way	1180.35	1358.8	1532.95	1978	2543.45	2702.55	3672.2	4760.1	5572.8	5753.4	5903.9	5934	
4	Flexibility under Steady Progression	769.7	666.5	582.65	574.05	632.1	915.9	1100.8	1350.2	1616.8	2218.8	3044.4	3777.55	
5	Flexibility under System Transformation	900.85	857.85	855.7	879.35	870.75	855.7	855.7	915.9	982.55	1216.9	1578.1	1874.8	
Days per year of availability required														
1	Flexibility under Best view	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Flexibility under Consumer Transformation	1	1	1	1	1	1	1	1	1	1	1	1	1
3	Flexibility under Leading the Way	1	1	1	1	1	1	1	1	1	1	1	1	1
4	Flexibility under Steady Progression	1	1	1	1	1	1	1	1	1	1	1	1	1
5	Flexibility under System Transformation	1	1	1	1	1	1	1	1	1	1	1	1	1

Utilisation Volumes

Expected annual volume of utilisation dispatched (MWh)													
1	Flexibility under Best view	124.2	142.9	171.6	233.8	419.4	669.5	1252.0	2483.8	4517.0	6079.0	7831.3	9700.0
2	Flexibility under Consumer Transformation	127.2	139.9	167.7	225.1	397.1	371.1	543.3	758.6	1337.6	2470.1	4020.6	5975.5
3	Flexibility under Leading the Way	139.9	171.0	220.4	317.7	568.4	669.5	1252.0	2483.8	4517.0	6079.0	7831.3	9700.0
4	Flexibility under Steady Progression	83.1	67.4	55.8	48.9	60.4	99.1	133.5	185.6	255.8	492.2	860.4	1394.1
5	Flexibility under System Transformation	99.0	92.4	89.6	94.7	92.8	92.9	93.6	97.6	111.1	161.1	237.4	353.8

Source: CEM tool received from WPD

None of the other input tabs would require user input.

In tab 'Additional inputs and control' set the Maximum flex availability (MVA) to a high value (100) below the value used for Average capacity of availability procured each year (MVA) after ten years in the 'Flex Volume and Cost Inputs' tab. Minimum initial contract length should be set to 1 year and the discount functionality left off (select No Discount). The Scenario for intrinsic value calculation should be selected as Best View.

Click the 'Calculate Benefit' button to run the CEM tool and update the results in the 'Benefit by strategy' tab.

Save the CEM with the results in the '2. Outputs' folder.

4.3.6 Calculate EE benefit

The EE benefit calculation tool allows the user to interpret the results from the CEM tool. The main outputs of this tool are the total and per-dwelling EE benefit under each of the five CEM scenarios.

The following are user instructions for the EE benefit calculation tool.

Open the blank template '*EE benefit calculation – template.xlsm*'.

In the 'Input' tab fill in the following filepaths in the 'Inputs' tab:

- CEM filepath for the CEM (saved in 4.3.5)
- EE scheme volumes filepath (saved in 4.3.2)
- EE scheme summary filepath (saved in 4.3.3.3)
- EE scheme name
- CEM cut-off period (years)³⁸

Click the 'Update model' button to update the model inputs.

Figure 25 The 'Inputs' tab in the EE benefit calculation tool

Update filepaths here and click 'Update model'

CEM:
EE dwelling volumes:
EE scheme summary:
EE scheme name:
CEM cut-off period (years):



Source: Frontier Economics

The EE benefit (total and per-dwelling) is presented in the 'Results' tab for each scenario. Charts are also included in this tab and the 'Carbon savings' tab.

³⁸ Set either to 5 or 10 years depending on the FAT output time scope.

Figure 26 Example of ‘Results’ tab of the EE benefit calculation tool

Scenario	Optimal length of deferral in years		NPV of Total costs		Reinforcement deferred beyond CEM scope?		WPD willingness to pay for EE (total)	WPD willingness to pay for EE (per dwelling)
	Flex	Flex with EE	Flex	Flex with EE	Flex	Flex with EE		
Best view	6	6	£992,203	£983,418	No	No	£8,785	£26.22
Consumer Transformation	5	6	£997,235	£990,894	No	No	£6,342	£18.93
Leading the Way	4	4	£1,026,608	£1,021,095	No	No	£5,514	£16.46
Steady Progression	9	9	£935,693	£923,983	No	No	£11,711	£34.96
System Transformation	9	9	£922,561	£913,256	No	No	£9,305	£27.78

Source: Frontier Economics

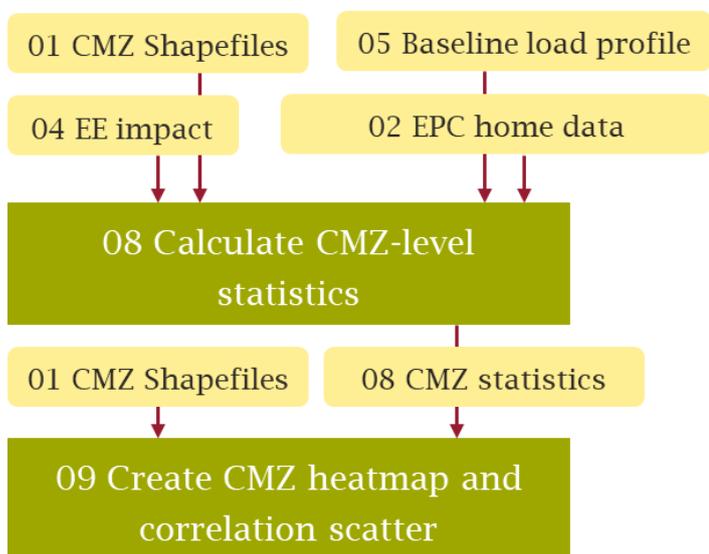
4.4 WPD-wide EE analysis tool

This tool is not part of the EE assessment tool, but requires some outputs from it:

- The CMZ shapefile `shp_wpd_cmz_and_background.shp` from script 01
- The dataset with EPC homes in WPD CMZ areas `epc_ew_wpd_areas_cmz_only.shp` from script 02
- The impact of EE by archetype `archetype_annual_stats.xlsx` from script 04
- CMZ peak load data `all_areas_hourly_peak_and_pump_share.xlsx` from script 05

These outputs are all independent of the scheme design and will be provided with the zip file.

Figure 27 WPD-wide assessment tool



Source: Frontier Economics

The tool loads in data on all CMZs and produces comparison statistics, maps, and scatterplots. This is intended to investigate the relationship between reinforcement costs and characteristics of CMZs to

determine where EE is likely to have a high benefit. For example, do areas exist with high reinforcement costs (and hence likely high benefits of deferring this through EE) and also poorly insulated homes?.

File: '08 Calculate CMZ-level statistics.py'

No user input required.

This file loads in all information on CMZs and combines this into a CMZ-level table, which is saved out as `cmz_statistics.csv`.

It loads in:

- The CMZ shapefile `shp_wpd_cmz_and_background.shp` from script 01
- The dataset with EPC homes in WPD CMZ areas `epc_ew_wpd_areas_cmz_only.shp` from script 02
- Archetype statistics `archetype_annual_stats.xlsx` from script 04
- CMZ peak load data `all_areas_hourly_peak_and_pump_share.xlsx` from script 05
- Data on reinforcement per CMZ (received from Peter Gaskin from WPD) called `Flexibility Areas Data.xlsx`
- The CMZ matching file `CMZ Name Matching.xlsx`³⁹
- Shape file from the ONS `Output_Areas_(December_2011)_Boundaries_EW_BGC.shp`⁴⁰
- Data on heating type per area `heating_type_clean.csv` from Census data⁴¹
- Data on income from the ONS `ons_income.csv`⁴² as well as a matching aid `ons.csv`⁴³

Based on this, it calculates a number of statistics and combines them into a single dataframe, such as

- Reinforcement cost per peak MW⁴⁴ (simply dividing reinforcement cost in each CMZ by that CMZ's peak, in MW)
- % of homes that are social housing
- % of homes that are thermally poor
- EE savings in kWh and %, for all homes and all social homes
- Average demand change per dwelling in kWh
- % of homes that are electrically heated

³⁹ This file matches up CMZs across various files, based on CMZ Name, Code, and load data file names. It was created by Frontier Economics and approved by Peter Gaskin on August 12th 2022.

⁴⁰ <https://geoportal.statistics.gov.uk/datasets/output-areas-december-2011-boundaries-ew-bgc-1/explore?location=53.648931%2C-1.567456%2C7.77>, downloaded August 2022

⁴¹ <https://www.nomisweb.co.uk/census/2011/QS415EW>, downloaded August 2022

⁴² <https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/datasets/smallareaincomeestimatesformiddlelayersuperoutputareasenglandandwales>, downloaded August 2022

⁴³ https://geoportal.statistics.gov.uk/datasets/fe6c55f0924b4734adf1cf7104a0173e_0/explore, downloaded August 2022

⁴⁴ Peak MW per CMZ is calculated by averaging the three-year profile across each half-hour, to generate an average profile, averaging the half-hours into hourly loads, and then taking the peak of this year-long average profile.

- Average net annual income after housing cost

This is saved out as `cmz_statistics.csv`.

File: '09 Create CMZ heatmap and correlation scatter.py'

This script creates heatmaps and correlation scatterplots based on the output of script 08, `cmz_statistics.csv`. It also loads in the CMZ shapefile `shp_wpd_cmz_and_background.shp` from script 01.

These are outputted for *selected variables which the user can select in the code, in the object plot_list, for both maps and scatterplots*. They are saved out as `varname_heat_map.png`, and `varname_scatter.png`.

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