ANALYSIS AND INSIGHTS REPORT

DEFENDER WS2

16 FEBRUARY 2023

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frontier economics

Executive summary

Decarbonisation will require gas boilers, currently the most prevalent domestic heating technology in GB, to be replaced with low-carbon alternatives. Under National Grid's Future Energy Scenarios (FES), a large proportion of these boilers (the vast majority in some scenarios) will be replaced by electrically powered heating – mainly heat pumps. The addition of this load will place significant additional pressure on distribution networks, many of which would require costly network reinforcement in the absence of mitigation measures. However thermal efficiency measures may be able to reduce these costs. There is therefore potentially an opportunity for DNOs to reduce their costs (and hence the costs to consumers) by intervening to bring forward such energy efficiency (EE) interventions.

Past projects[1] have demonstrated that there may be value to the DNOs in making these types of investment, but only across a limited proportion of the network. Workstream 2 of project DEFENDER, the findings of which are summarised in this report, has built on this work by:

- Incorporating EE interventions into the optioneering process used by NGED and other DNOs;
- carrying out more in-depth analysis to determine the types of area and property which may have the highest value, and their prevalence;
- considering the cost of installing the measures as well as the benefits received by parties other than DNOs;
- examining the impact of the uncertainties associated with EE interventions, and the resulting business models which may be most effective; and
- assessing (at a high level) the proportion of NGED's network where EE interventions might be viable.

Incorporating EE interventions into NGED's decision investment process

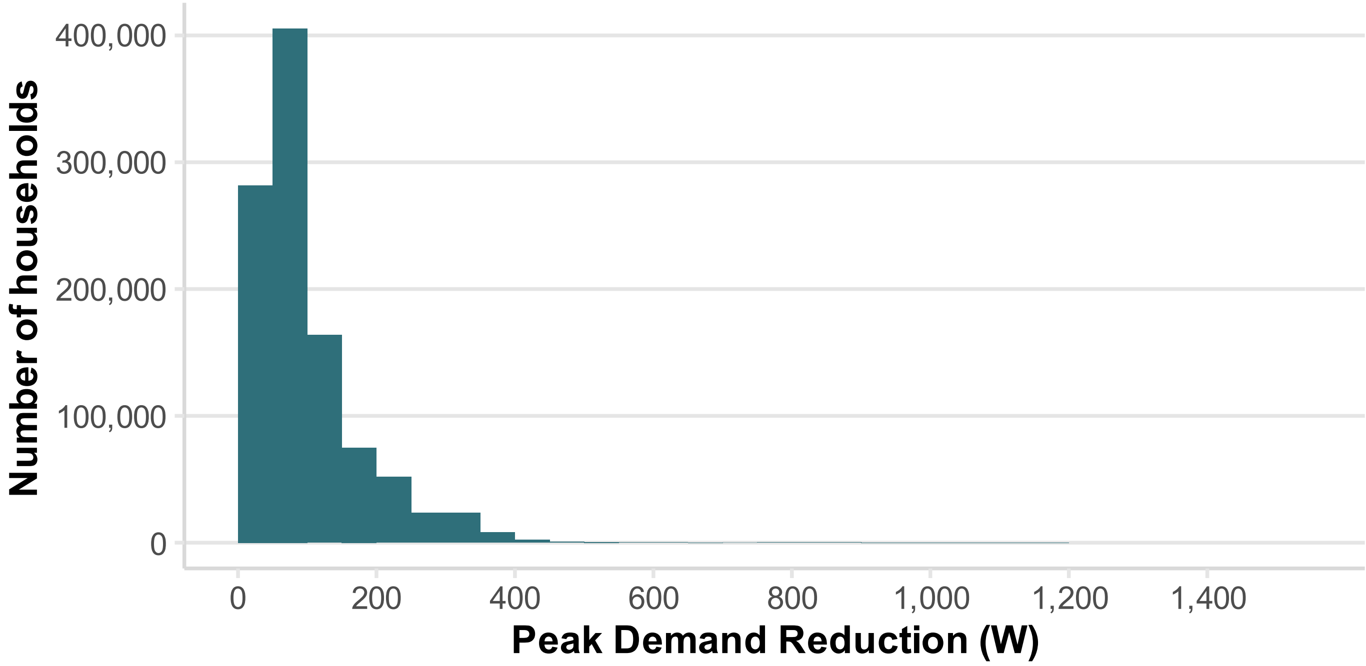
For the purpose of this report, an 'EE intervention' consists of a scheme where the DNO provides funding which facilitates the installation of thermal efficiency measures for a set of dwellings. This funding need not take the form of a grant to consumers, but might be providing loans, or broader activities such as raising awareness.

The profiles developed for DEFENDER Workstream 1 have been used to characterise the types of thermal efficiency measure that can be applied to a given dwelling, and the cost of doing so. By comparing the profiles of heat pump usage before and after the upgrade, it is possible to calculate the reduction in peak electricity usage. Figure 1 below shows the distribution of such peak demand reductions if all 'medium'

1 For example NGED's *Future Flex* and UKPN's *Project Firefly*.

properties[2] within NGED's current constraint management zones (CMZs) had heat pumps and were to be upgraded to 'high' efficiency.

Figure 1 Distribution of per-household peak demand reduction across NGED's current CMZs



Source: Frontier analysis of Carbon Trust data from DEFENDER workstream 1

Currently, NGED has a suite of tools which it uses to determine whether to rely on flexibility to solve a network constraint, or if it is more economical to reinforce the network. In this project, additional tools have been developed to extend this process to consider EE interventions. These tools are capable of modelling the impact of a specific EE intervention on a CMZ's load profile, and then calculating a 'Ceiling Price' for the EE intervention. The Ceiling Price is the maximum amount that a DNO could pay per-household for the EE intervention without costs outweighing the benefits.

Assessing the main drivers of value for EE interventions

These tools have also been used to assess the factors which affect the Ceiling Price. The primary driver is the cost of reinforcement: areas with higher reinforcement costs, relative to the size of the network, tend to have higher Ceiling Prices. Areas with high reinforcement costs are typically in more rural areas. They generally have a higher share of off-grid houses; lower average incomes; more thermally 'poor' houses (and fewer thermally 'medium' houses); and less social housing.

Figure 2 shows how the Ceiling Price per dwelling varies for a particular CMZ (and under all DFES scenarios) as the reinforcement costs are increased or decreased. While the Ceiling Price increases with reinforcement

2 In common with DEFENDER workstream 1, this analysis assumes that a 'low' efficiency property would not be suitable for a heat pump in the first place.

cost, there are diminishing returns, and so increasing the cost of reinforcement ten-fold does not raise the value of EE ten-fold. This is for two reasons:

- First, if the intervention achieves additional deferral years, then increased reinforcement cost will be discounted further the lengthier the deferral is.
- Second, for very high reinforcement costs, it will be optimal to use high volumes of flexibility, which will be called in many hours of the year. As there are fixed costs associated with the availability of flexibility, the average cost per MWh of flexibility called will fall compared to the case when flexibility is only being used for the peak hours. Energy efficiency will therefore, on average, be displacing flexibility which is cheaper per MWh.

Figure 2 Sensitivity tests for increased reinforcement costs – Gunnislake CMZ

Source: Frontier Economics

Note: Reinforcement costs in Gunnislake are £1.70m, which translates to an NPV of reinforcing in year 0 of £1.73m. The costs on the x axis refer to the NPV costs, which are in all cases slightly higher than the upfront cost in 2022. A reinforcement cost of £0 translates to an NPV of £0.

The CMZ we have chosen as an example (Gunnislake) already has relatively high reinforcement costs, but only has a Ceiling Price of £36. There are some CMZs with higher reinforcement costs, and based on the results from Gunnislake they may have Ceiling Prices as high as a few hundred pounds. However these are very much outliers, and the value is still relatively low compared with the cost of installing EE measures.

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.

The value of EE interventions to the wider electricity system and beyond

EE measures can lead to increases or decreases in a wide variety of costs. These can be divided into the direct costs of the measures themselves, impacts on the power system (such as the reduction in DNO costs quantified by the Ceiling Price), and wider impacts on outcomes such as on consumers' health.

Direct costs

As an example of the direct costs, these were calculated for an EE intervention that upgrades all medium-efficiency properties in an area to high-efficiency. The average cost per dwelling (based on the figures provided by DEFENDER workstream 1, and using the housing stock mix in one of NGED's existing CMZs) is £7,483.

Power system impacts

Consumers may expect to recoup some of these costs through reduced bills, which themselves represent reduced costs to the power system. Based on BEIS's retail price projections, the intervention assessed here might lead to bill reductions of £2,309.[3] These bill reductions ultimately come from (but may not be fully cost-reflective of):

- **Displaced generation costs**, as the reduction in demand from EE measures leads to a reduction in the variable costs of producing power. For example, if gas generation can be reduced, this will result in savings through: combustion of a lower volume of gas; production of a lower volume of CO_2[4] (which will in turn require the purchase of fewer UK emission allowances); and a reduction in variable O&M costs such as maintenance. These costs will be passed through to consumers via the wholesale element of their bill (although half-hourly settlement and dynamic time-of-use tariffs would be required to make this fully cost-reflective).

- **Reduced capacity adequacy costs**. This is since a reduction in peak demand will mean a lower generation capacity will be required, which implies lower costs of building and maintaining power stations. Suppliers' bills will generally include an element designed to pass through the cost of funding Capacity Market payments, which will broadly equal this saving.

While there may in theory be savings to the cost of operating the system if the EE intervention is carried out in an area which faces an import constraint on the transmission network, the way the balancing mechanism currently works means that these benefits could not be compensated for.

Taking these bill reductions into account, there is still a net cost to the consumer of £5,174. This is far above the DNO's Ceiling Price (which reflects the value to the DNO of the EE intervention) which for the

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[3] This is based on discounting the future bill savings at the social discount rate of 3.5% used for social cost benefit analyses. In practice, many consumers may apply a higher effective discount rate. Note that BEIS's projections account for the current high levels of bills, but assume that unit rates will fall back towards historic levels.

[4] The intervention might save around 1.2 tonnes of carbon over a 50 year period. However most of the value of this will be in the earlier years when the grid is more carbon intensive.

CMZ and intervention used to quantify the direct costs above is just £36. Even in areas with much higher reinforcement costs (where the Ceiling Price might be £100 or more), and for EE interventions which offer particularly good value-for-money,[5] this gap remains. It is therefore very unlikely that the DNO's value, if paid to the consumer, would be sufficient to incentivise them to carry out an EE retrofit which would not otherwise have been installed.

However, it may be possible for a DNO to obtain greater value for money by focussing on retrofits that would have been installed by consumers at some point, but too late to make a difference to the network. This is since, from the DNO's perspective, an EE retrofit that the consumer would install after the network has already been reinforced has just as little benefit as one that would never be installed at all.

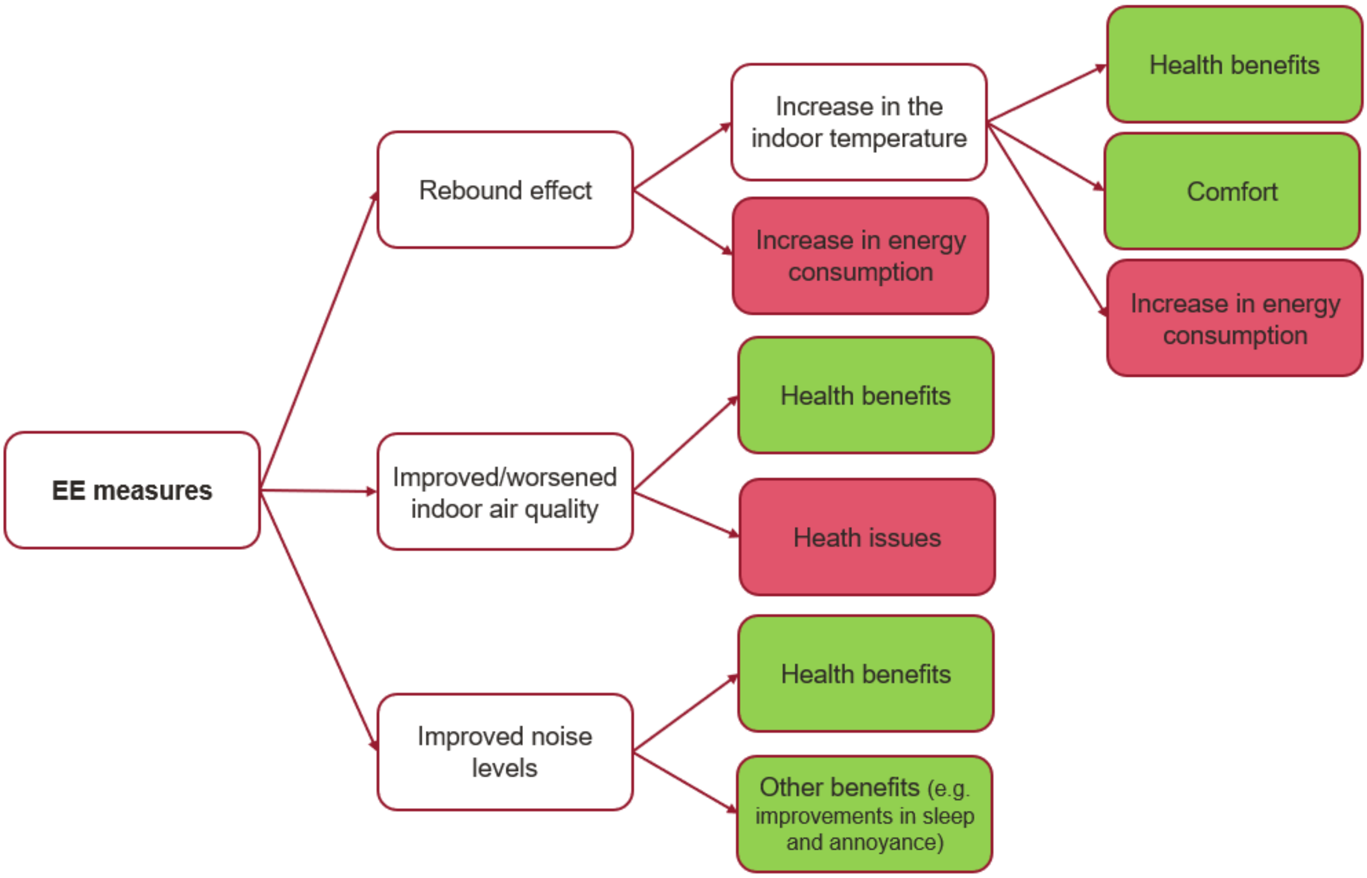
For example, for the same CMZ (and focussing on a subset of EE measures which offer better value-for-money), the cost of bringing forward retrofits by two years might be £323. The discounted reduction in bills is £291, leading to a net cost to the consumer of £32. This is low enough that the DNO's Ceiling Price (which in this case is £52 per property) could cover the gap. There may therefore be some potential for DNO interventions to make the required impact, although there are considerable uncertainties, not least the way in which many consumers may heavily discount future bill savings (which this calculation does not account for).

Wider outcomes

Additional uncertainties relate to the wider benefits and costs of EE measures, which are illustrated in Figure 3. Of particular note are health benefits, which have a value both to consumers, as well as the NHS. If this value was internalised (e.g. if consumers placed value upon the non-monetary benefits, or if DNOs could receive money accounting for reductions in treatment costs) then they could make the installation of EE measures more likely. However these benefits effectively come from a large 'rebound effect', when insulation permits the temperature to be raised. There may therefore be relatively little (if any) impact on energy consumption and avoided network investment costs for such houses. Additionally, many under-heated properties may be low efficiency buildings for which a heat pump would not be viable in any event.

[5] Cavity wall and suspended floor insulation.

Figure 3 Benefits beyond the power system



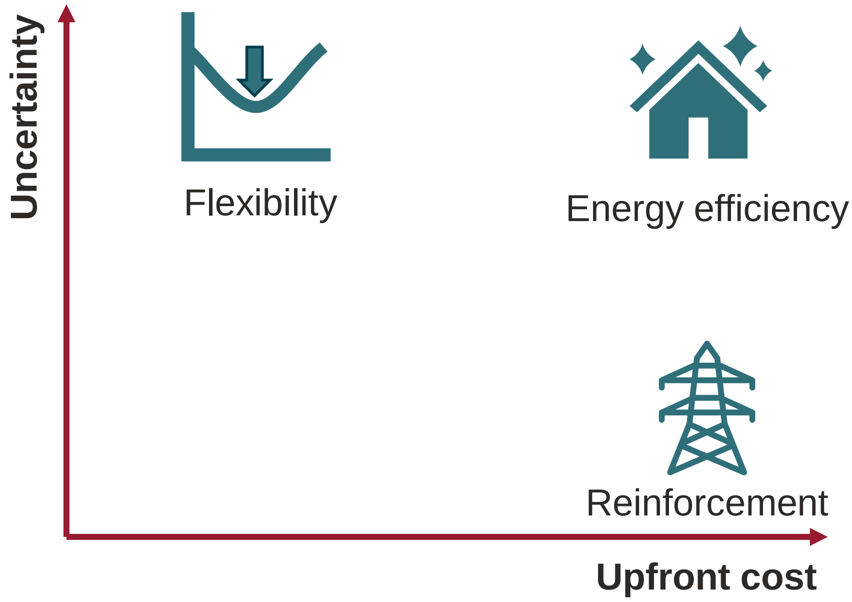
Source: Frontier Economics

Accounting for delays and uncertainties

EE measures have some unique characteristics that present challenges to their use by DNOs. Like reinforcement (and unlike flexibility) they require large upfront investments. However, unlike 'fit-and-forget' reinforcement[6] there is significant uncertainty: If demand grows too quickly then reinforcement may still be required, and so the money spent on EE interventions will to some extent have been 'wasted'. This is illustrated in Figure 4.

6 Where new assets are sized to meet any feasible level of demand.

Figure 4 Characteristics of different DNO interventions



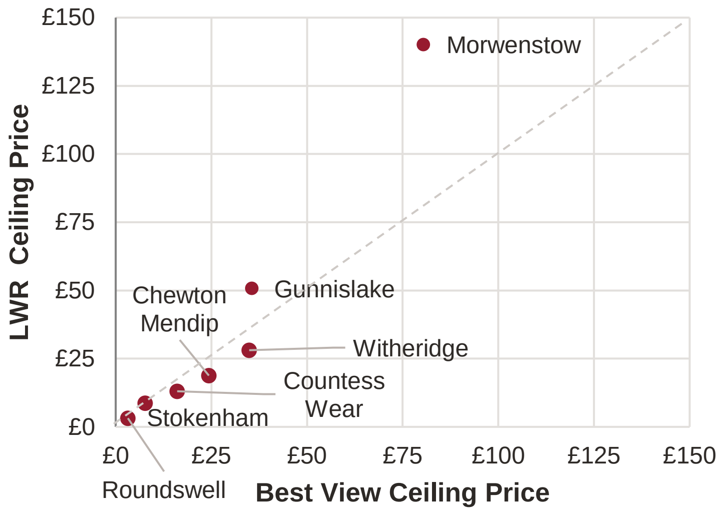
Source: Frontier Economics

To account for the effect of uncertainty, a 'Least-Worst Regrets' (LWR) framework has been applied. This involves selecting an immediate strategy (whether to reinforce, carry out an EE intervention, or to rely solely on flexibility), under conditions where the pay-off is uncertain (reflected by the different DFES scenarios for load growth), and where there is the option to change strategy in the future (for example, initially relying on flexibility to 'buy time', and then choosing whether or not to invest in EE or reinforcement). LWR involves selecting the strategy that minimises the worst 'regret' that could occur, where 'regret' is a measure of how much lower the DNO's costs could have been under the scenario that transpired had it chosen a different strategy.

To determine a Ceiling Price, the model starts by assuming that EE is costless. At this point, investing in EE will generally be the LWR strategy (unless demand is so high that it would make sense to invest immediately in reinforcement). The cost of the EE intervention is then increased until it is no longer the LWR strategy: This point represents the Ceiling Price for EE under LWR.

Figure 5 shows the resulting LWR Ceiling Price for a selection of CMZs, compared to the Ceiling Price calculated under certainty using the 'Best View' scenario. In general, the two Ceiling Prices are closely correlated, since both ultimately depend on the costs of reinforcement. On average, there is no clear difference between them both. However the LWR Ceiling Price tends to be a lower share of the Best View Ceiling Price when the need for reinforcement (without EE) is optimal further in the future. This is as, when reinforcement is not required for some time, flexibility alone can 'buy' a longer delay and therefore has a higher option value. This diminishes the relative value of EE.

Figure 5 LWR and Best View Ceiling Prices for a selection of CMZs



Source: Frontier Economics

Estimating the value present on NGED's network

The Ceiling Price for each current NGED CMZ has been estimated by:

- Taking an EE intervention consisting of the more cost-effective forms of insulation (cavity wall and suspended floor insulation);
- applying the relationship between reinforcement cost and Ceiling Price under 'Best View' shown in Figure 2; then
- assuming, as per Figure 5, that the Ceiling Price calculated using the LWR methodology is approximately equal to this.

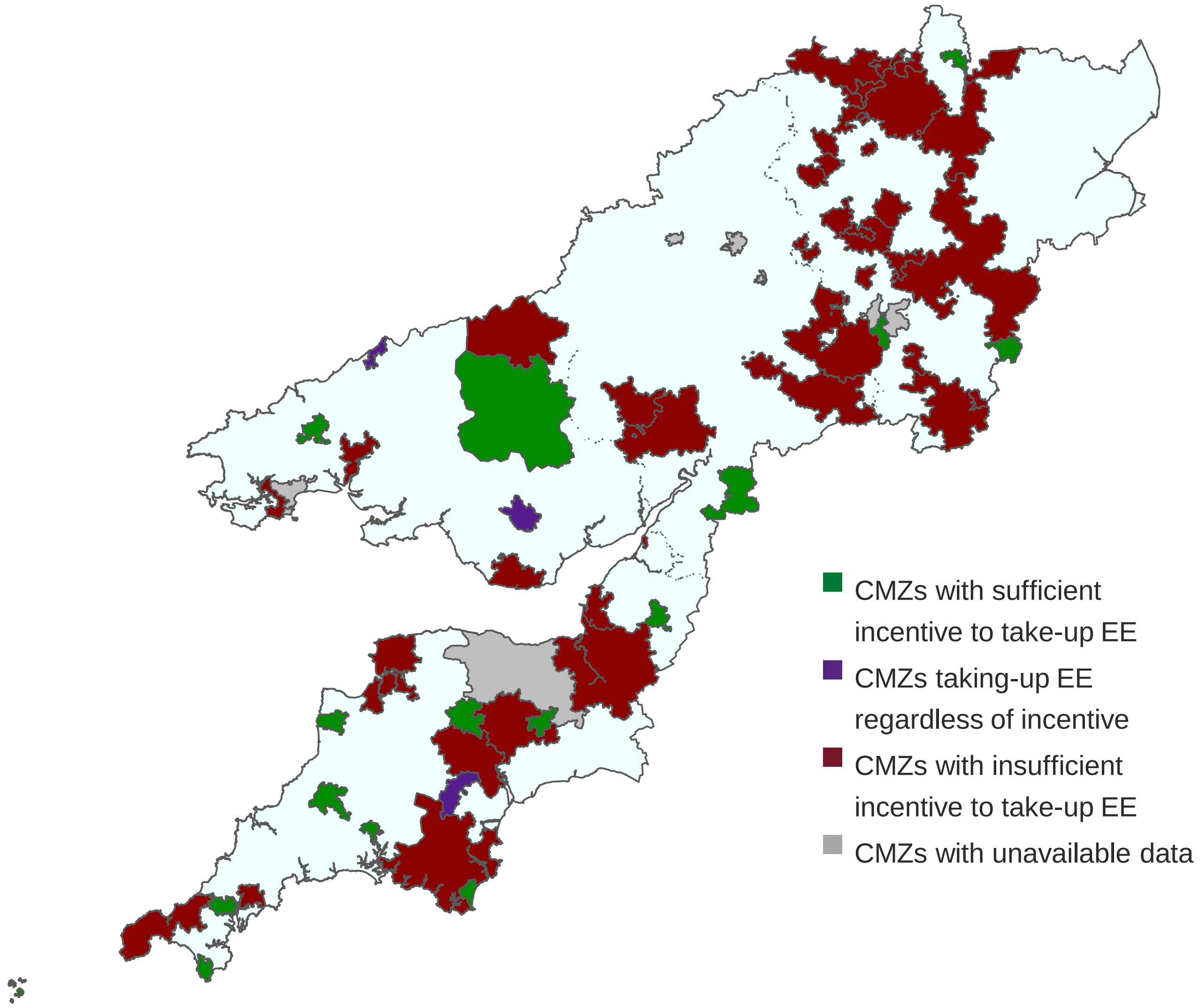
This has then been compared with the net cost to consumers of the EE measures, based on the property archetypes in each CMZ, to determine whether there are any CMZs where the DNO's Ceiling Price might be sufficient to bring forward EE measures that would never have otherwise been installed.

This is not the case for any CMZs: In one area, the EE measures are 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 is so high that the maximum amount the DNO could pay would not make any difference. Clearly, 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.

However, as described above, 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, we have considered the net cost to consumers if the EE intervention only needed to bring forward installation of measures by two years, and where this cost is 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.

As noted above, 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 described above 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.

Figure 6 Map of CMZs by intervention effectiveness (bringing forward EE by 2 years), when close to reinforcement



Source: Frontier Economics

Implementing EE interventions in practice

This shows that there may be some – albeit limited – potential for DNOs to reduce consumer costs by bringing forward EE measures. Based on the analysis carried out for this project, a number of recommendations can be made for how such an intervention could be structured.

It is unlikely that capex-based energy efficiency 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. 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 that most likely intend to invest in EE, but not yet**. This will require further analysis, described in the following section.

Given the relatively low level of the Ceiling Price compared to the capital costs of EE interventions, DNO funding may be more effective if it is targeted at non-monetary barriers to EE take-up. For example, this could involve:

- **Disseminating information regarding the direct benefits of the intervention**. For example providing advice for tradespeople on how to explain the benefits of EE measures and funding available, or financing EPC surveys.
- **Spreading awareness of non-monetary benefits**. For example, initiatives to inform consumers about benefits such as reduced noise levels (when relevant – e.g. for properties which would benefit from double-glazing). This could involve targeting properties in particularly noisy areas.

The DNO will only gain value from EE interventions if properties are electrically heated. There may be a need to design different types of intervention for:

- **Properties that already have electrically powered heating**. EE interventions for properties with direct (non-storage) electric resistive heating may be associated with a particularly high Ceiling Price.
- **Properties that are considering the installation of electrically powered heating**. As the take-up of heat pumps increases, engaging with consumers shortly before or as they are installing a heat pump will

help ensure the appropriate properties are targeted. DNOs could engage with consumers who are about to get a heat pump. This could take the form of co-ordinating with local installers or authorities to ensure that consumers are provided with information regarding any intervention at the point they are planning their installation. However there is a risk that EE interventions which are conditional on heat pump uptake may inadvertently incentivise early heat pump installation in constrained areas and therefore have a *negative* impact on the DNO.

- **Properties which have some prospect of installing electrically powered heating in the future**. At present, the vast majority of homes within GB have gas boilers, are unlikely to upgrade to a heat pump for several years, and are not in currently constrained network areas. However, many of these properties will eventually upgrade their heating system, and as demand rises an increasing proportion of them may be in constrained areas. There is therefore some small value to the DNO to homes carrying out EE interventions now. While this value is likely far too small for direct funding of any measures, it may be sufficient for broader awareness initiatives and similar.

Finally, given the relatively small proportion of CMZs and retrofits for which the DNO may have sufficient value, high-value properties will need to be targeted. Detailed gathering of property characteristics and their potential for EE savings would need to be undertaken to achieve such granular targeting. However there is a tension between the scale of the intervention and its cost effectiveness that will need to be managed, as a smaller intervention targets the most cost-effective properties may suffer from diseconomies of scale.

Next steps and conclusions

This project has demonstrated that existing processes used by DNOs to assess flexibility can be extended to cover EE interventions. However the value of such interventions to the DNO is likely to be relatively low: Even in areas with high reinforcement costs, this value will not exceed a few hundred pounds per property, and will generally be much lower.

A significant number of uncertainties also remain regarding whether it would be cost-effective for EE interventions to form part of BAU processes, and how this would be done, and resolving some of these may involve substantial levels of spend (for example on trials). A prudent course of action is therefore to:

- First carry out less intensive exercises (e.g. desk-based research) to build the case for intervention. This would involve determining the feasibility of different types of intervention (e.g. working with financial institutions if an intervention involving loans is under consideration) and business models in more detail. Further analysis could help more accurately target areas and properties with the greatest value to DNOs.

- Next, carry out randomised control trials to see whether the interventions are cost-effective in practice. This would involve assessing the extent to which they bring forward EE measures, the costs of doing so, and ultimately the impact on the network. Trials might also help better understand other sources of uncertainty, such as the availability of flexibility

- If the results of these trials are positive then further activity (e.g. developing tools for use at scale within DNOs' processes, or standardising the processes used to signal the availability of any DNO funding within an area to the local supply chain) would be needed to implement the measures into Business as Usual.

1 Introduction

Energy efficiency (EE) measures can reduce peaks on the distribution network and potentially save reinforcement costs for DNOs. Thermal efficiency measures will become especially important as more domestic heat demand becomes electrically powered. Standard license condition 31E describes how DNOs may take part in:

"promoting the uptake of measures to improve Energy Efficiency, where such services cost-effectively alleviate the need to upgrade or replace electricity capacity and support the efficient and secure operation of the Distribution System. This may include procuring Energy Efficiency Services, where it is economic and efficient to do so"

National Grid Electricity Distribution's (NGED) Future Flex project has already suggested that such interventions (for example part-funding of insulation), in the right locations, could deliver a network value of up to £1,000 per home based on current constraint management zones. However that project also found that EE would only have such a high value in a small proportion of areas. It is not currently clear whether and how such interventions could be rolled out by DNOs at scale.

Project DEFENDER consists of two workstreams.

- **Workstream 1**, carried out by Carbon Trust, Hildebrand, and GHD, has created an analysis tool which will allow NGED to generate domestic ADMDs[7] and load profiles which take into account the impact of EE measures. The load profiles are based on actual demand data (from smart meters) for a large number of property types, and will be used for network forecasting and planning.

- **Workstream 2**, carried out by Frontier Economics, has used these profiles to assess the long-run cost-effectiveness of EE compared with traditional reinforcement and flexibility services. This has included the development of tools to enable NGED to integrate EE interventions into its optioneering process.

This report describes the results of the analysis carried out as part of Workstream 2. It is structured as follows.

- **Chapter 2** describes how EE interventions can be considered within NGED's processes for making investment decisions. It sets out the scope of EE interventions covered by this project (thermal efficiency retrofits for houses which are or will be electrically heated), and the key challenges in assessing them from a DNO's perspective. A summary of NGED's current optioneering process is provided, followed by a description of how we have built tools to integrate an assessment of EE into this.

- **Chapter 3** uses the tools that have been developed 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 identifies the types of areas where the value is likely to be highest.

- **Chapter 4** considers the broader drivers of value for entities other than NGED. This includes the value of carbon savings, and whole system benefits such as reduced power flows on the transmission network.

[7] After diversity maximum demand – i.e. peak demand for an area of the network with multiple consumers connected to it.

It also quantifies the private costs and benefits of EE measures incurred by property owners, which will affect the level of incentive NGED may need to provide to bring about an EE retrofit.

- **Chapter 5** identifies the risks and uncertainties involved in EE interventions. These uncertainties affect the case for making an EE intervention, and a 'least worst regrets' analysis has been built into the tools described in chapter 3 to show how uncertainties may affect the overall value of EE interventions to NGED.

- **Chapter 6** brings together the analysis in the preceding chapters to estimate over what proportion of NGED's network there might be a positive value from engaging in EE interventions.

- **Chapter 7** suggests some high level ways to implement these interventions, based on the findings above. This includes the types of commercial arrangement which may help maximise value from EE interventions.

- **Chapter 8** identifies 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.

2 How can EE interventions be integrated into NGED's investment decisions?

DNOs currently have processes in place to assess flexibility,[8] but not EE. This chapter first describes the types of EE measures considered by this project and then compares their impact on the DNO to reinforcement and flexibility. It then provides a summary of NGED's existing process for assessing EE, which is built upon industry-standard tools developed by the Energy Network Association's (ENA) Open Networks project.

This project has developed complementary tools that allow EE measures to be considered within this process: These are described, followed by a summary of how these tools could be enhanced further if EE interventions become part of DNO 'business as usual'.

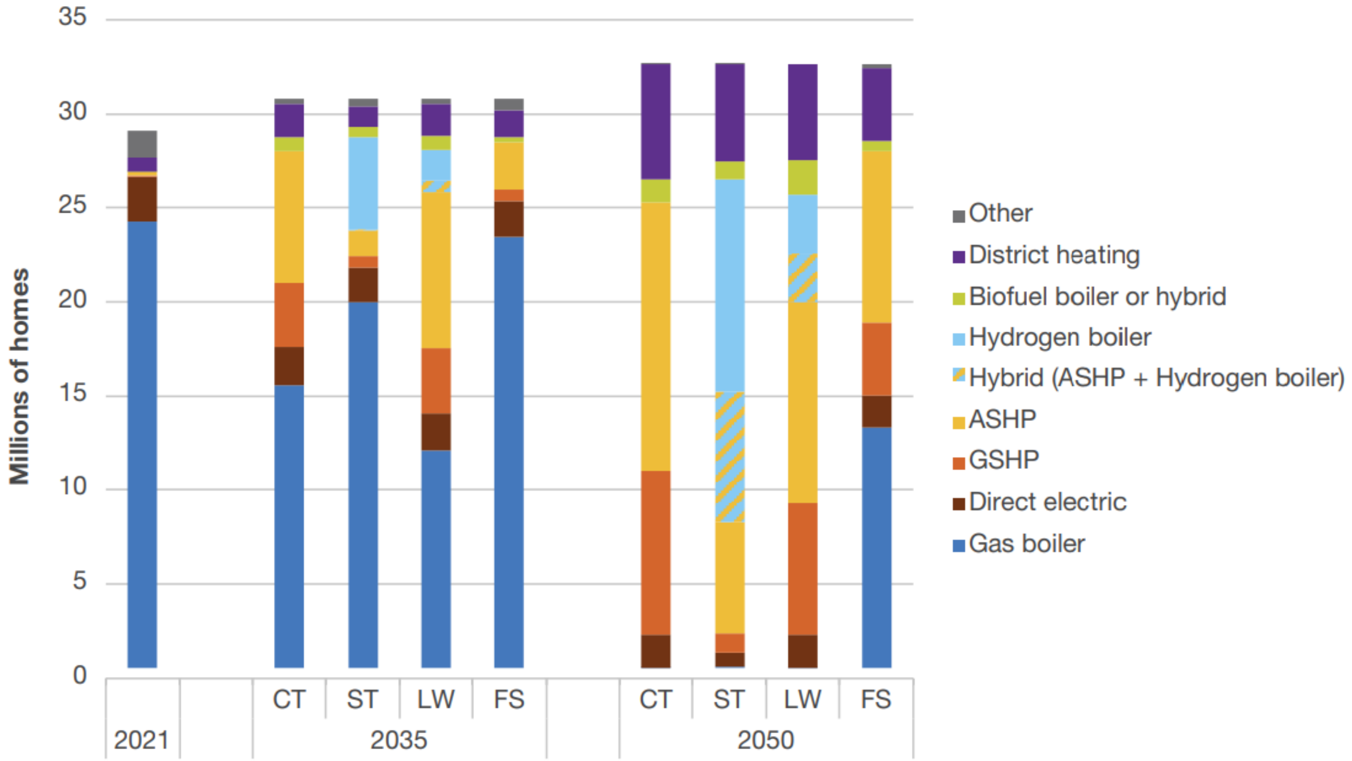
2.1 EE measures considered as part of this project

EE relates to measures which mean less input energy is required to produce the same output on a *permanent* basis. Broad examples of EE interventions include replacing incandescent lights with more efficient LED units, the use of variable speed drive (VSD) motors in industrial applications, and the replacement of domestic appliances with more efficient models. This permanent reduction in demand is distinct from demand-side response (DSR) where demand is *temporarily* shifted or reduced.

The focus of this project is on thermal efficiency measures within the domestic housing stock. As shown in Figure 7, decarbonisation will require domestic gas boilers to be replaced with alternatives. By 2050, heat pumps are envisaged to be installed in the majority of homes under two of the net-zero consistent scenarios (Consumer Transformation and Leading the Way), and nearly 50% of homes under the System Transformation scenario. This will move the domestic heat demand from the gas networks to the electricity networks, which if unchecked could lead to extremely high reinforcement costs. Domestic thermal efficiency measures can help mitigate this, reducing costs for DNOs and ultimately consumers.

8 In this report we use the term 'flexibility' to refer to demand-side response services, distinct from EE interventions.

Figure 7 GB domestic heating technology forecast from FES



Source: Future Energy Scenarios 2022, National Grid ESO

For the purpose of this report, an 'EE intervention' consists of a scheme where the DNO facilitates the installation of thermal efficiency measures for a set of dwellings. As a starting point, it is assumed that the DNO is able to target the following dwellings.

- **Dwellings which are already using, or are about to install, an electrically powered heating system** (the majority of the analysis considers air-source heat pumps). While this analysis uses the current state of the housing stock, it is intended that the techniques developed here could be applied more widely in the future when government policy would mean large portions of the market would start to install heat pumps.[9]

- **Dwellings which would not install the thermal efficiency measures in the absence of DNO intervention**. This does not necessarily mean that they would never install the measures – just that they would not be installed in a timeframe that provides benefits to the DNO.

- **Dwellings which definitely will install the measures following the intervention**. For example, if the intervention involves part-funding of retrofits then this would be conditional on installation.

[9] 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*.

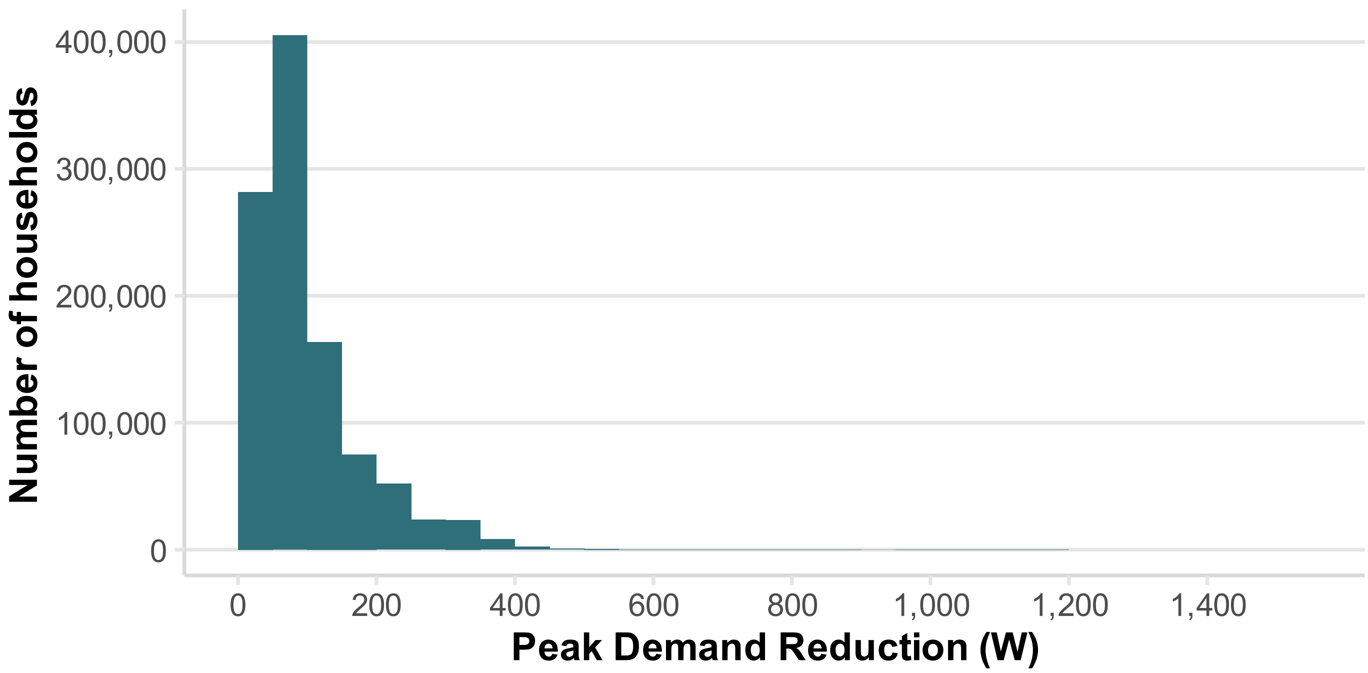
The profiles developed for DEFENDER workstream 1 have been used to characterise the types of thermal efficiency measure that can be applied to a given dwelling, and the cost of doing so. This analysis, described in full in the accompanying workstream 1 report, has divided the England and Wales Housing stock into 2,904 archetypes.[10] For each archetype, differing levels of wall, floor, roof and window insulation have been specified. Each archetype is described as being of overall 'low', 'medium', or 'high' efficiency.

It may be impractical to install a heat pump into a property with a low thermal efficiency. In common with workstream 1, the analysis here therefore assumes that a heat pump could not be installed in 'low' efficiency dwellings. All of the EE interventions considered here therefore involve the upgrading of a dwelling from 'medium' to 'high' energy efficiency.

For example, a relatively common 'medium' efficiency dwelling is a semi-detached house, built after 1930 with cavity walls, solid floors and a pitched roof. It has no floor insulation but it does have roof and wall insulation and double glazing. An upgrade to 'high' efficiency might involve insulating the floor and is estimated to cost £4,104.

By comparing the profiles of heat pump usage before and after the upgrade, it is possible to calculate the reduction in peak electricity usage. Figure 8 below shows the distribution of such peak demand reductions if all 'medium' properties within NGED's current constraint management zones (CMZs) had heat pumps and were to be upgraded to 'high' efficiency.

Figure 8 Distribution of per-household peak demand reduction across NGED's CMZs



Source: Frontier analysis of Carbon Trust data from DEFENDER workstream 1

[10] An example archetype would be a House (Property type), Semi-Detached (Built form), before 1930 (Construction age band), Solid wall (Wall type), Suspended (Floor type), Pitched (Roof type), No insulation (Floor insulation), No insulation (Roof insulation), No insulation (Wall insulation), Single glazing (Window glazing).

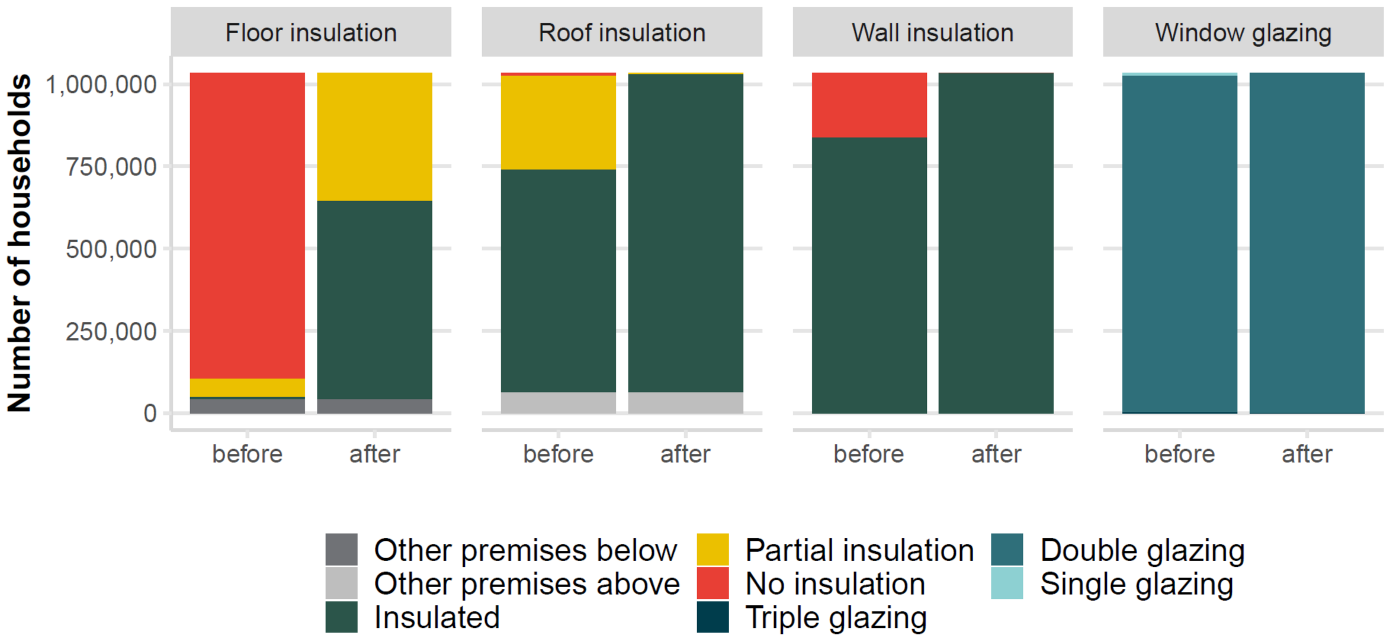
Figure 8 shows that:

- The vast majority of the upgrades result in a reduction in peak demand per dwelling of below 400W. For context, 400W is roughly 20% of a typical after diversity maximum demand figure for a home *without* electric heating.[11]

- A very small proportion (0.5%) of 'medium' efficiency dwellings in this area have a retrofit that would reduce peak demand by between 400W and about 1.5kW. These dwellings typically have less roof and wall insulation than the other 99.5% of properties.

These upgrades are typically an upgrade to floor insulation (from non to fully or partially insulated) and, to a lesser extent, upgrading roof insulation (from partial to fully insulated) and wall insulation (from no insulation to fully insulated), as seen in Figure 9 below. The cost per Watt reduction for these households is typically in the order of £83.

Figure 9 Upgrades for households whose demand reduction is less than or equal to 400 W



Source: Frontier analysis of Carbon Trust data from DEFENDER workstream 1

2.2 The impact of EE interventions on the DNO

EE interventions like those described above will reduce the demand for electricity during all periods of the day in which electrically-powered heating is used. Importantly for the DNO, heating is generally in use during times of peak electricity demand (i.e. winter evenings). By lowering peak demand, an EE intervention may

[11] Northern PowerGrid (2015), '*Customer-Led Network Revolution: After Diversity Maximum Demand (ADMD) Report*'

therefore enable a local network that would have exceeded its capacity to continue to operate safely and securely. This may reduce the need for other interventions in a DNO's toolbox, which include:

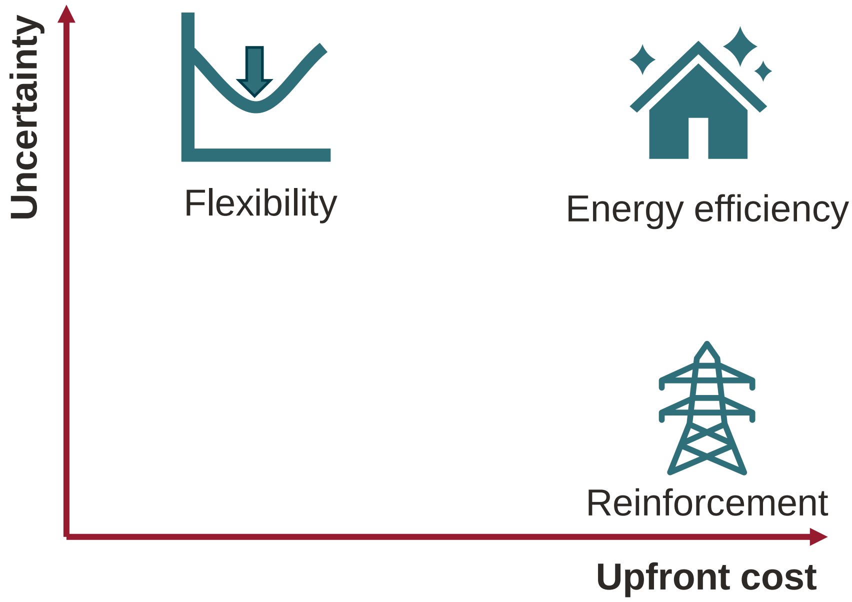
- **Reinforcement**: Upgrading network assets such as transformers and circuits to withstand higher demand.
- **Flexibility**: Paying consumers to shift or reduce demand on a temporary basis.

The reduced (or deferred) need for these other interventions may reduce a DNO's costs. The tools described in this chapter enable a DNO to quantify this reduction in costs, and chapter 3 reports the results.

However, EE interventions have some unique characteristics that present challenges to their use by DNOs. Figure 10 illustrates this, showing the extent to which each type of intervention:

- involves upfront costs (as opposed to ongoing running costs); and
- is associated with uncertainty regarding its costs or benefits.

Figure 10 Characteristics of different DNO interventions



Source: Frontier Economics

Traditional reinforcement is associated with high upfront costs, as physical assets must be replaced. However, once the decision is taken to reinforce part of the network, the new assets are typically sized to cope with any feasible level of demand.[12] This 'fit and forget' approach means that a DNO can be certain that reinforcement will solve the network constraint for the foreseeable future.

12 This is generally the optimal approach as many of the costs associated with reinforcement – such as roadworks – are independent of the capacity of the asset that is put in place.

Flexibility involves the procurement of demand-side response which can be called upon when the network is constrained. There are uncertainties associated with flexibility as before a DNO procures flexibility, it is unclear how much flexibility is available, or at what cost. However, if it is later found to be optimal to reinforce the network, then the flexibility contracts can be allowed to lapse without incurring further costs as the costs of flexibility (availability and utilisation payments) are ongoing rather than upfront. Flexibility is therefore associated with an option value: Given uncertainty regarding whether and when reinforcement is required, flexibility can 'buy time' during which the need for reinforcement will become clearer.

The **energy efficiency** measures that we are considering within this project typically involve high upfront costs (for example, the installation of insulation). However, unlike 'fit and forget' reinforcement, there are significant uncertainties regarding the value to DNOs. For example:

- If EE measures are insufficient to ensure the network remains within its headroom[13] then reinforcement (with an associated additional cost) may be required anyway. This might be due to demand being higher than expected, or the take-up or effectiveness of EE measures being lower than expected.
- Unlike reinforcement (and, to an extent, flexibility), EE measures have significant benefits to property owners, which we discuss in chapter 4. It is therefore possible that the DNO may pay for an EE measure that the homeowner would purchase anyway. While the impact on peak electricity usage is the same, the DNO will have spent money, paid for by its customers, which it need not have.

We describe the impact of these uncertainties further in chapter 5.

2.3 Summary of previous work

Previous innovation projects have already demonstrated that EE interventions may have value to DNOs – albeit this value is typically quite small and not widespread across the network.

NGED's Future Flex project[14] investigated a wide variety of options to enable and encourage widespread domestic flexibility service provision. As part of this, it carried out modelling to assess the benefit to the DNO of EE interventions. The modelling used NGED's existing constraint values for its CMZs to estimate the benefits of an EE intervention over five years.

This work found[15] that, in areas with severe and long-lasting constraints, EE measures for homes with heat pumps could be worth up to £1,000 per home to the DNO. The benefit was greatest for larger homes which would have the highest savings – potentially more than £2,000 per property. However, the areas with high constraint costs were found to be rare, potentially limiting the role of EE interventions.

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13 By 'headroom', we refer to whether power and voltage are within the tolerances of the particular assets such as conductors and transformers. Rather than modelling the electrical flows on the network itself, this project takes the simplified approach by the CEM, which considers whether total power demand will exceed the thermal headroom of the network.

14 https://www.nationalgrid.co.uk/projects/future-flex

15 Everoze for WPD (2021) "*Realising the value of domestic energy efficiency in GB electricity distribution*"

UKPN's Project Firefly[16] modelled the impact of a wide variety of EE interventions (using US data) on six substations. In three of these, some of the EE measures were modelled as being able to cost-effectively defer reinforcement (albeit generally for a year or two at most).[17] The residential energy efficiency measures shown as being cost-effective included measures that reduce the space heating requirements of buildings, although if it is unclear if this relates to homes which would already have had a heat pump, or those with less efficient forms of electrical heating.

Project DEFENDER builds on this work in a number of ways by:

- Incorporating EE interventions into the optioneering process used by NGED and other DNOs. This demonstrates how a consideration of EE interventions could be introduced into business-as-usual operations. The more detailed modelling also accounts for how flexibility may either complement or substitute for EE interventions.
- Carrying out more in-depth analysis to determine the types of area and property which may have the highest value, and their prevalence.
- Considering the cost of installing the measures as well as the benefits received by parties other than DNOs.
- Examining the impact of the uncertainties associated with EE interventions, and the resulting business models which may be most effective.
- Assessing (at a high level) the proportion of NGED's network where EE interventions might be viable.

2.4 NGED's current investment decision process

NGED's current investment decision process takes place over a two year period. At the beginning of the period, demand scenarios are developed and used to produce a list of Constraint Management Zones (CMZs) at the 33kV and 132kV levels of the network. These zones are then assessed every six months via NGED's optioneering process, described below.

An overview of the process of addressing a constraint can be seen in Figure 11 below. The steps taken are:

a. **Forecasting Distribution Future Energy Scenarios (DFES):** Volumes and load surveys of underlying demand on the NGED network are used to forecast demand on the network. The output of this step is a dataset showing forecast demand by half-hour based on NGESO's four Future Energy Scenarios and an additional NGED 'Best View' scenario.
b. **Network impact assessment via modelling in the Network Development Plan (NDP):** Additional modelling in the Network Development Plan is used to identify CMZs that may require intervention. These studies are then passed on to the Primary System Design team to design traditional reinforcement solutions and costs.

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16 https://innovation.ukpowernetworks.co.uk/projects/firefly/

17 The achievable deferral was longer if lighting efficiency measures were included, however these are already implicit in UKPN's load forecasts.

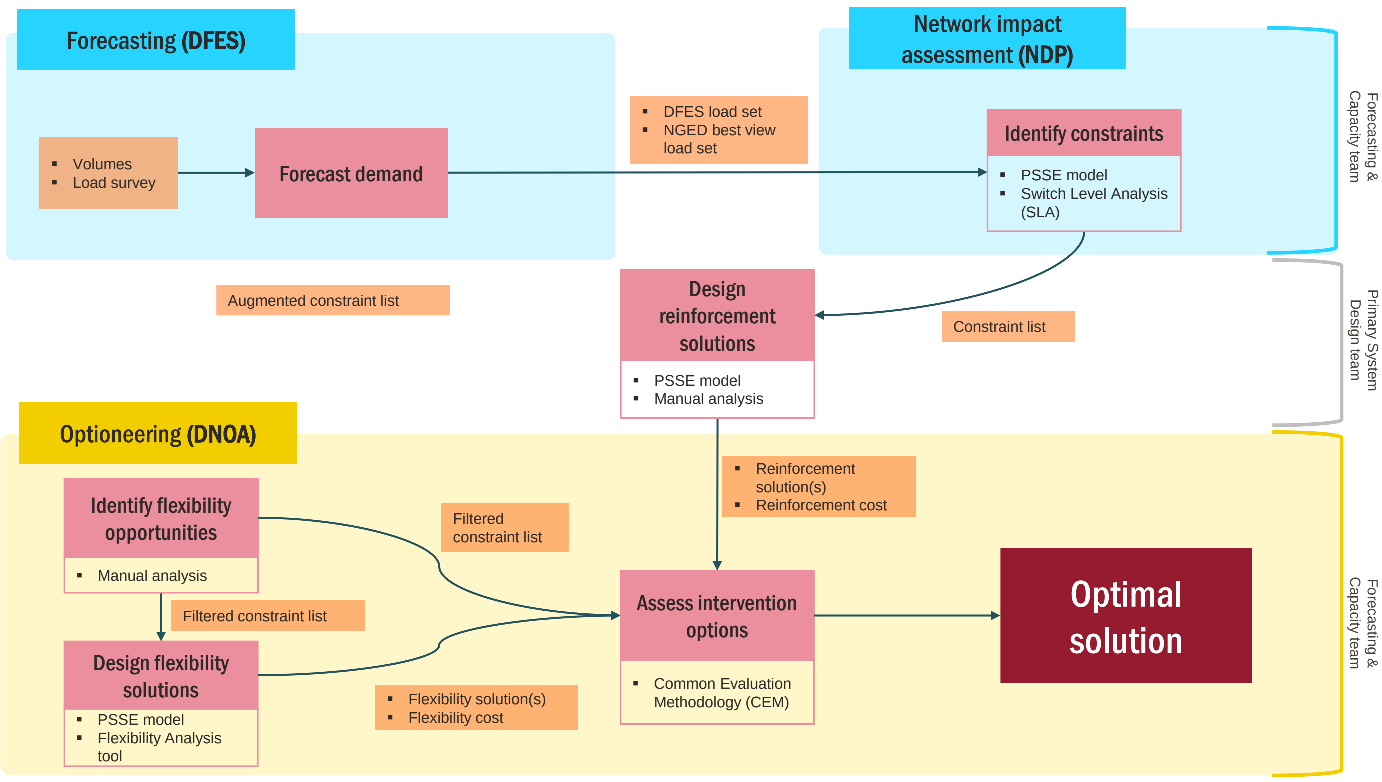
c. **Optioneering using the Distribution Network Options Assessment (DNOA):** Once a set of CMZs and potential solutions is identified, the Forecasting and Capacity team identifies CMZs that may be suitable for flexibility interventions. This set of CMZs is then passed to:

   i. the **Flexibility Analysis Tool (FAT)**, which calculates flexibility requirements and costs for resolving the constraint if flexibility alone was used; and then

   ii. the industry standard **Common Evaluation Methodology (CEM)** tool, which assess the flexibility and reinforcement solutions to determine the economically optimal combination and timing of flexibility and reinforcement.

The full process is described in further detail in Annex A .

Figure 11 NGED Network Planning Process



Source: Frontier Economics based on NGED interviews

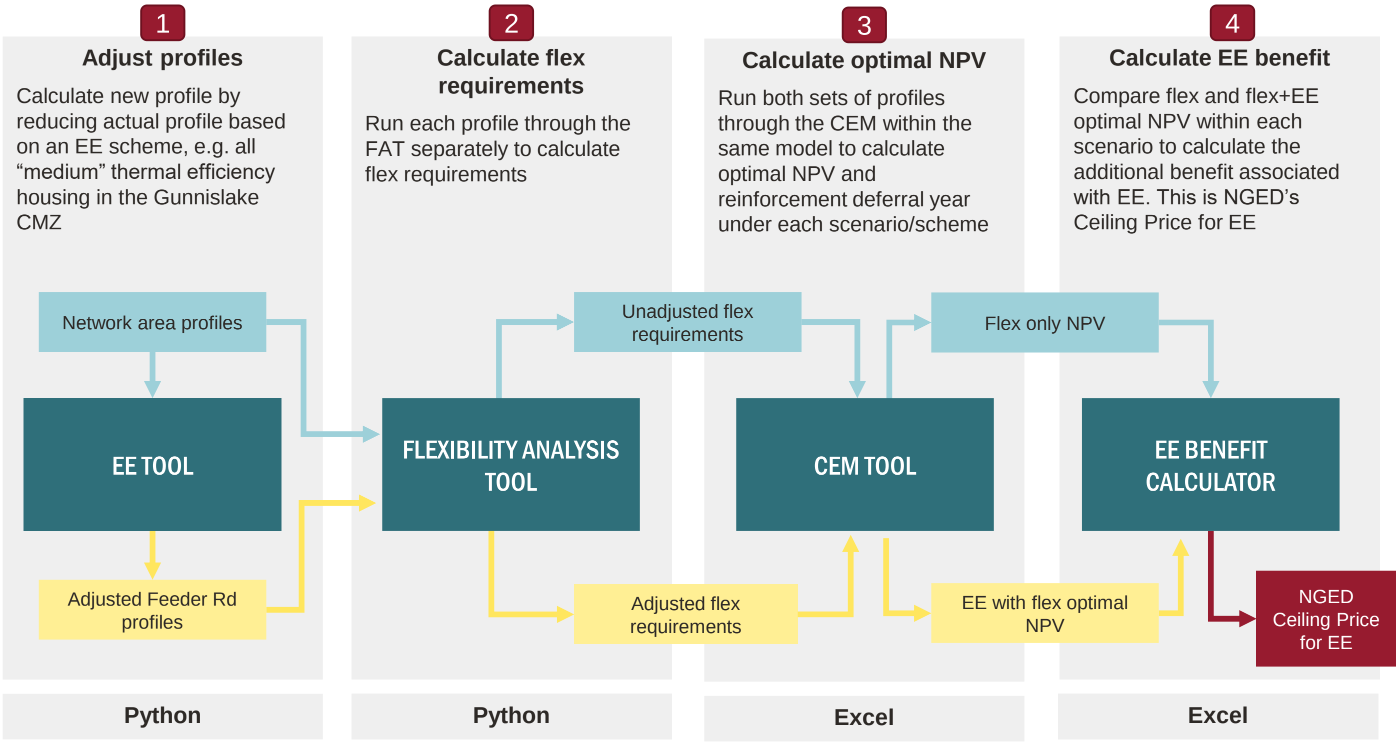
2.5 Integrating an assessment of EE into this process

A set of tools has been developed to assess the costs and benefits to a DNO of domestic EE interventions. These tools have been designed to integrate into NGED's current processes, as shown in Figure 12 below. They 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.

Figure 12 EE assessment process



Source: Frontier Economics

2.5.1 EE tool

The first step of the tool is to design 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 WS1.

The result of the modelled intervention is a change in the demand profile of a selected set of dwellings within a given CMZ.

2.5.2 EE benefit calculator

The profiles described above are fed through the existing FAT and CEM tools, to calculate the optimal level of flexibility procurement, timing of reinforcement and the resultant NPV[18] of the investment if the EE intervention is carried out. Separately, the FAT and CEM tools 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. For example, if the total cost of investments to relieve a CMZ is £5,000 but the costs are reduced to £4,000 if an EE intervention takes place, then that equates to a Ceiling Price for that intervention of £1,000. This calculation is done in a separate 'EE benefit calculator' spreadsheet which uses the CEM outputs.

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, as described in section 2.2, uncertainties around factors like future demand may affect the value of EE interventions. Chapter 5 describes how the Ceiling Price can be modified to take these effects into account, and the EE benefit calculator includes this functionality too.

The EE benefit calculator also allows carbon reduction benefits to be estimated. While the CEM has this functionality, it is not designed to include benefits that endure beyond the point when the network requires reinforcement. However, EE interventions have very long-term benefits, for example if a wall is insulated then this may lead to carbon reductions over the lifetime of the property, which could be 50 years or more.[19]

2.6 Limitations of the current suite of models

The additional tools developed for DEFENDER mean that the existing FAT and CEM are able to assess DNOs' Ceiling Prices for EE interventions. However, there are limitations in the design of the existing tools and the data they are populated with that means the benefits of EE interventions are not fully represented. Specifically, these are:

- The FAT requires a static set of demand profiles which are scaled up each year to account for demand growth. This will also scale the benefit of the EE intervention when it is in fact a constant reduction.
- 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.
- The DFES load growth scenarios used within the CEM may not fully reflect the level of uncertainty in forecasts.

18 Net Present Value. NPV takes account of the opportunity cost of money. A deferred investment means that you need to set aside less for it now, since interest earned in the meantime will make up the difference. An EE intervention that delays reinforcement will therefore reduce the NPV of the investment required.

19 The CEM user guide describes how this issue can be overcome in the way implemented here.

We address each of these in turn below.

2.6.1 FAT demand profiles

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).[20]

This could be overcome by varying the profiles by year, however the FAT is unable to do this at present.

2.6.2 Consistency of load profiles

As described in section 2.3, the future load growth profiles used within the FAT and CEM are based on current monitored demand, scaled up to account for expected growth.

The use of current load profiles means that the overall shape of the profile will remain constant over time. In practice, as gas boilers are replaced with heat pumps (and other changes occur such as electrification of transport), the load profile would be expected to change shape, potentially to the extent that the time of peak demand shifts. This also means that there is likely to be an inconsistency between the EE intervention reduction profiles calculated by the tool (which are based on a 'bottom-up' analysis of heating demand) and the overall profiles which they are subtracted from.

This may be less of a concern over the relatively short period of time (5 years) that the CEM is currently used for, and given the relatively low levels of low-carbon technology (LCT) take-up at present. However when assessing EE interventions a longer time horizon may be necessary to capture the full benefits, and the accelerating take-up of LCTs will mean that the shape of the load profile may change significantly over this period.

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.

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

2.6.3 Load growth scenarios

At present, constraints are identified under the four DFES scenarios and the NGED ‘Best view’ scenario. These scenarios are then used within the FAT and CEM to determine optimal flexibility and reinforcement (although in practice most of this analysis relies on the ‘Best view’ scenario).

These scenarios 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.

As described in chapter 5, the least worst regrets analysis developed for this project can use a broader set of scenarios to account for these additional uncertainties. Further work could be undertaken to formalise how such scenarios could be constructed.

As the identification of constrained areas in the first place uses the original DFES scenarios, there is a risk that some areas that would be constrained if low carbon technologies cluster have been missed due to the limited range of scenarios used to identify them. However, in practice, omitting these scenarios is unlikely to matter for the assessment of EE interventions. This is since, as described above, EE interventions have relatively high up-front costs and are therefore less likely to provide value when it is very uncertain if they will be required.

3 What are the main drivers of value for EE interventions?

In this chapter, the suite of tools described above have been used to determine the sensitivity of the Ceiling Price for EE to factors such as reinforcement costs, intervention scale, property or retrofit types targeted, demand growth rates and limits on the availability of flexibility.

In line with past work, the Ceiling Price is relatively low – generally far under £100 per dwelling except in a very small proportion of CMZs. Reinforcement costs 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.

3.1 Drivers of EE effectiveness

This section summarises the results of a large number of sensitivity tests which have been carried out on the Gunnislake CMZ using the tools described in the previous section. Gunnislake is chosen as it has higher reinforcement costs relative to other CMZs but is not an outlier. Since we conclude below that reinforcement costs are both certain and a significant contributor to Ceiling Price, it is appropriate to model an area with relatively high reinforcement costs as it is more likely to represent an area that an EE intervention might take place in. The EE intervention that is modelled involves upgrading all thermally medium properties to thermally high (as described in section 2.1).

The results of the sensitivity tests are summarised in Table 1 below.

Table 1 Sensitivity tests for drivers of EE's effectiveness

DRIVER	SENSITIVITY TEST	IMPACT ON CEILING PRICE
Reinforcement costs	Increase reinforcement costs in the CEM	**Positive:** E.g. in Gunnislake (Best View), x2 reinforcement costs raises the Ceiling Price by x2.45. **Declining at very high reinforcement costs**: E.g. in this area x10 reinforcement costs raises the Ceiling Price by x7.5
The scale of the intervention	Scale the number of properties treated up or down and re-run through the EE assessment process	**Positive:** Increasing the EE intervention size can lead to higher EE Ceiling Price. E.g. in Gunnislake (Best View), x3.75 EE intervention size raises the Ceiling Price by x2.2, though under some scenarios there is reduced or no impact.
Type of property and retrofit	Analysis of distribution of costs per peak MW reduction for different measures	Some types of property and retrofit (e.g. suspended floor and cavity wall insulation) lead to a greater reduction in demand and therefore higher Ceiling price. There are also noticeable distributional differences of cost effectiveness for different types of retrofit (for example choosing to achieve a demand reduction with suspended rather than solid floor insulation results in lower costs relative to both MW saved and Ceiling Price).
The rate of demand growth	Adjusting demand growth rates in the FAT	**Negative**: E.g. in Gunnislake, increasing the demand growth from 1% per year to 0.4% per year leads to the Ceiling Price halving.
The availability of flexibility	Adjusting the CEM's flex availability parameter	**Positive to a point, then negative**. At very low flexibility availability, EE Ceiling Price is low. Ceiling Price increases to a maximum as flex availability is increased, then falls again. At the maximum point, Ceiling Price may be at least 2x what is with unlimited flex.

Source: Frontier Economics

3.1.1 Reinforcement costs

Reinforcement costs vary significantly across NGED's network and can have a big impact on the effectiveness of EE interventions. Increased reinforcement costs increase the value of EE interventions through two mechanisms:

- Directly, as the benefits of any deferral of reinforcement will be greater; and

- indirectly, since higher reinforcement costs make it economic to procure additional, and more expensive, flexibility. An EE intervention may be able to displace this more expensive flexibility.

To understand the effect of reinforcement costs, *all else held equal*, a single CMZ (Gunnislake) is taken as an example and its reinforcement costs varied to determine the impact on the Ceiling Price.

Sensitivity tests on the Gunnislake CMZ show increased reinforcement costs can materially increase NGED's Ceiling Price per dwelling. Figure 13 shows the Ceiling Price across the five demand scenarios for a variety of reinforcement costs: from £275k (one sixth of the actual cost), up to a multiple of 10 times (£17.3m). These reinforcement costs are within the bounds of those seen across NGEDs network, which range from £275k to £32m.[21] The line of best fit is also shown.

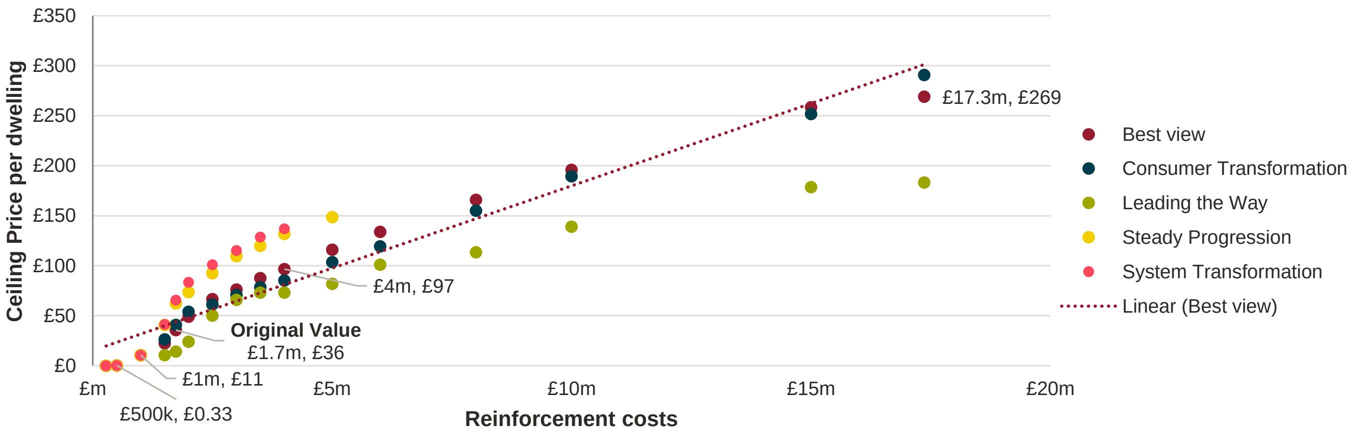
Where the modelled EE intervention is worth £36/dwelling under the original Best View scenario, the value varies from 0p/dwelling up to £269/dwelling under the sensitivities.

While the Ceiling Price increases with reinforcement cost, there are diminishing returns, and so increasing the cost of reinforcement ten-fold does not raise the value of EE ten-fold. This is for two reasons:

- First, if the intervention achieves additional deferral years, then increased reinforcement cost will be discounted further the lengthier the deferral is.

- Second, for very high reinforcement costs, it will be optimal to use high volumes of flexibility, which will be called in many hours of the year. As there are fixed costs associated with the availability of flexibility, the average cost per MWh of flexibility called will fall compared to the case when flexibility is only being used for the peak hours. Energy efficiency will therefore, on average, be displacing flexibility which is cheaper per MWh.

Figure 13 Sensitivity tests for increased reinforcement costs - Gunnislake



Source: Frontier Economics

Note: Reinforcement costs in Gunnislake are £1.70m, which translates to an NPV of reinforcing in year 0 of £1.73m. The costs on the x axis refer to the NPV costs, which are in all cases slightly higher than the upfront cost in 2022. A reinforcement cost of £0 translates to an NPV of £0.

21 It is also within the range of reinforcement costs per peak MW of demand.

3.1.2 The scale of the intervention

The total energy efficiency savings of an intervention will be affected by the scale of that intervention, as the more houses are within an intervention, the higher the overall reduction in demand and therefore potential for reduced flexibility or delayed reinforcement. However the Ceiling Price *per property* may also vary with intervention scale.

Within the model, there are two potential effects which may offset one another:

- EE may have diminishing marginal returns. A small intervention may displace flexibility in a large number of hours, however as the intervention increases in size, the demand on the network will move below headroom for more and more hours, and so the amount of flexibility that is displaced will reduce. This is similar to the effect described above for why reinforcement costs have a diminishing effect on the Ceiling Price. At the extreme, if an EE intervention is large enough to entirely avert the need for reinforcement or flexibility, there will be no value at all from adding additional houses, and so the Ceiling Price per dwelling will fall rapidly.

- However a larger intervention may enable a DNO to get closer to the optimal balance of reinforcement deferral and flexibility. Within the CEM, reinforcement can only be deferred by whole numbers of years – e.g. by 1, 2 or 3 years. In practice, the optimal mix of flexibility and deferral may involve a delay in between these periods. By extending the length of time for which reinforcement can be deferred, a larger EE intervention may help the DNO get closer to this optimal mix.[22]

This latter effect is to some extent an artifact of the way in which the CEM only allows reinforcement to take place at yearly intervals. If the CEM allowed reinforcement were to be delayed by an arbitrarily fine-grained amount, then this effect would not exist, as even the smallest EE interventions could lead to some deferral of reinforcement (even if only measured in days). However, in practice, DNOs are unlikely to reschedule planned works by small amounts of time as a result of lead times, uncertainties, and the way in which network planning is carried out to a regular cycle and not continuously. The effect we see in the model can therefore be said to proxy for the way in which reinforcement actually takes place.

There are two other potential effects which are *not* captured by the modelling here, but are noted in chapter 7:

- A small EE intervention may be able to focus on those types of properties with the greatest benefits to the network. Larger interventions may need to bring in types of properties with lower benefits, reducing the average Ceiling Price. To avoid this effect (which is described in the next section) being conflated with the scale of the intervention itself, the sensitivities described here hold the mix of retrofit types constant.

[22] For example, with a small EE scheme, if reinforcement is optimal after a year and a half then the DNO would need to reinforce after one year, half a year 'too soon'. A larger EE scheme might mean that reinforcement is optimal after four and a half years, requiring the DNO to reinforce after four years. While this is still half a year 'too soon', this matters less in the context of a larger scheme which buys more years of deferral and therefore has a larger total value.

- There may be fixed costs to rolling out an intervention (for example marketing) which mean that there is an advantage to larger interventions. These are not modelled.

To test the role of intervention scale on Ceiling Price, the Gunnislake area has again been used as an example. Figure 14 shows Ceiling Prices for the Gunnislake CMZ where the EE intervention has been either:

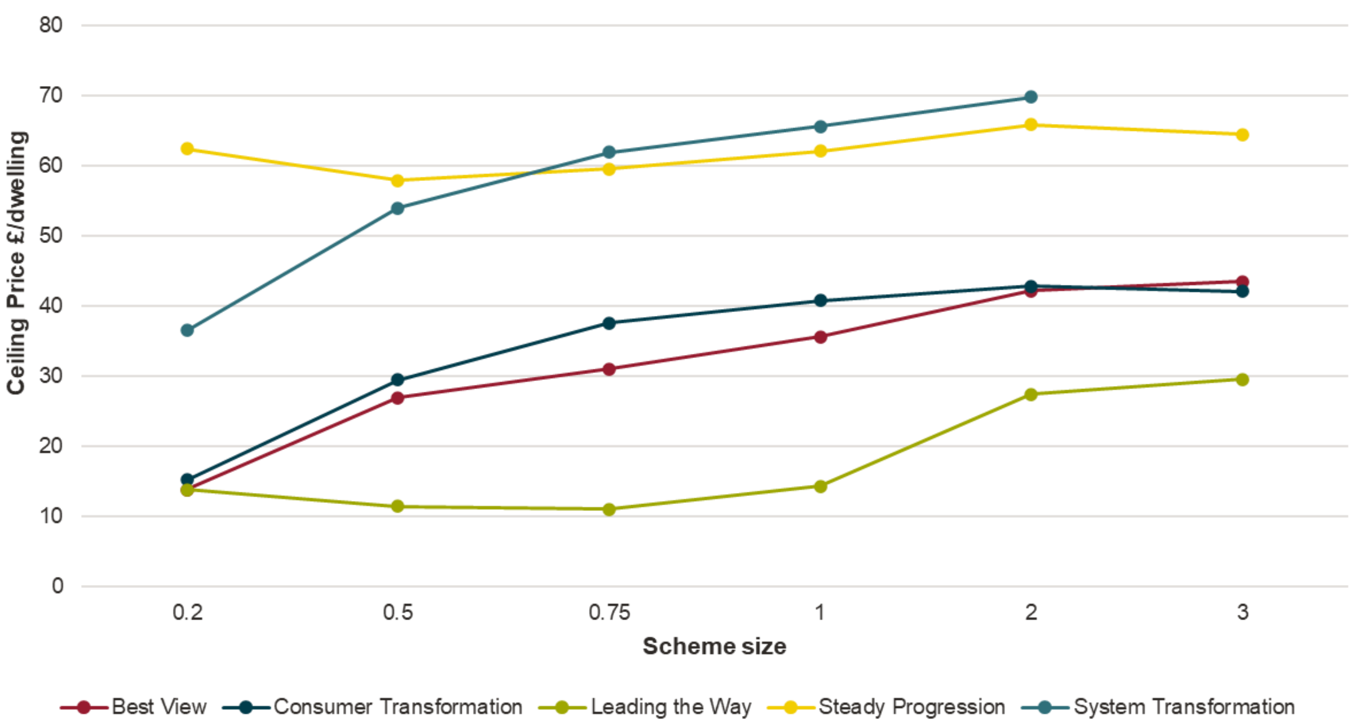
- Reduced in scale (e.g. a figure of 0.5 implies that half the number of houses are being targeted); or
- increased in scale (e.g. a figure of 2 implies that double the number of houses are being targeted).

The mixture of housing types and retrofits targeted is held constant. A value of 1 implies that all thermally medium houses are targeted, so values greater than this can be interpreted as considering what would happen if a higher proportion of houses in Gunnislake were thermally medium (we have capped it at 3 which is roughly equivalent to retrofitting every property in the area, if all of them were originally thermally medium).

These sensitivity tests show that the effect of scale of Ceiling Price is mixed. Under some scenarios and for some sizes of intervention, the Ceiling Price shows increasing returns to scale. However under other scenarios and intervention sizes (for example for any intervention size under Steady Progression) there is no clear link between intervention scale and Ceiling Price.

While the relationship between intervention scale and Ceiling Price is complex, it does appear that there are no obvious diminishing returns to scale, even for very large interventions.

Figure 14 Scale sensitivity tests – Gunnislake



Source: Frontier Economics

Note: The Ceiling Price for the 'system transformation' scenario has been removed for the 3 scale factor because deferrals extend beyond 10 years (where the CEM is less granular and the results less certain).

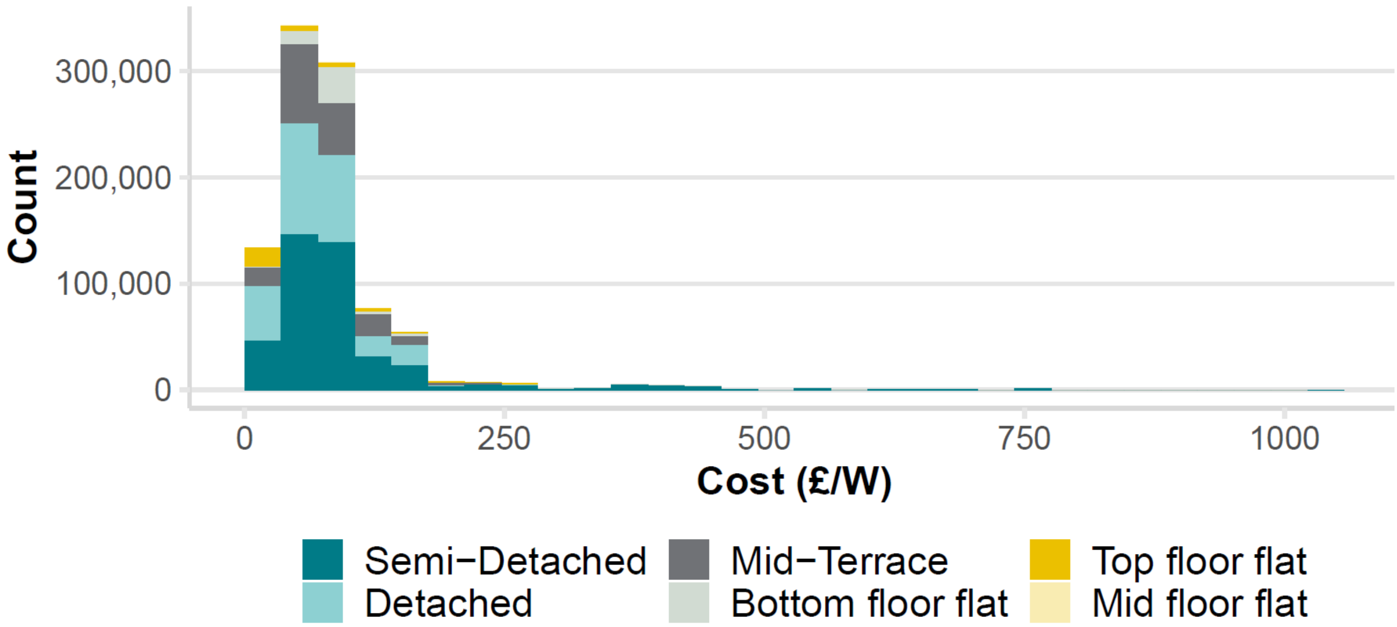
3.1.3 Type of property and retrofit

The energy efficiency savings for any given dwelling may be driven by both its built form (for example, whether the property is a flat or detached house) as well as the available retrofit options. Although the retrofits considered here all transform a 'medium' efficiency building into a 'high' efficiency one,[23] there is still a significant degree of variation in the resulting effect on peak demand.

In many cases, the interventions that have the greatest impact on peak demand (and thus Ceiling Price) will be more extensive retrofits with a higher cost. Focussing purely on the interventions that are associated with the highest Ceiling Price may therefore not be the most economic course of action. This is discussed further in the following chapter. In this section, we therefore focus on how the Ceiling Price could differ if the EE intervention is focussed on a subset of housing and retrofit types which offer especially high value-for-money.

Figure 15 shows a histogram of cost effectiveness (in terms of £ per peak MW saved) for all medium-efficiency properties across all CMZs. The bars are coloured based on the built form of houses that receive the EE upgrade. There is little apparent difference in distribution of the different built forms according to cost reduction per peak MW other than top floor flats (yellow).

Figure 15 Built form – all CMZs



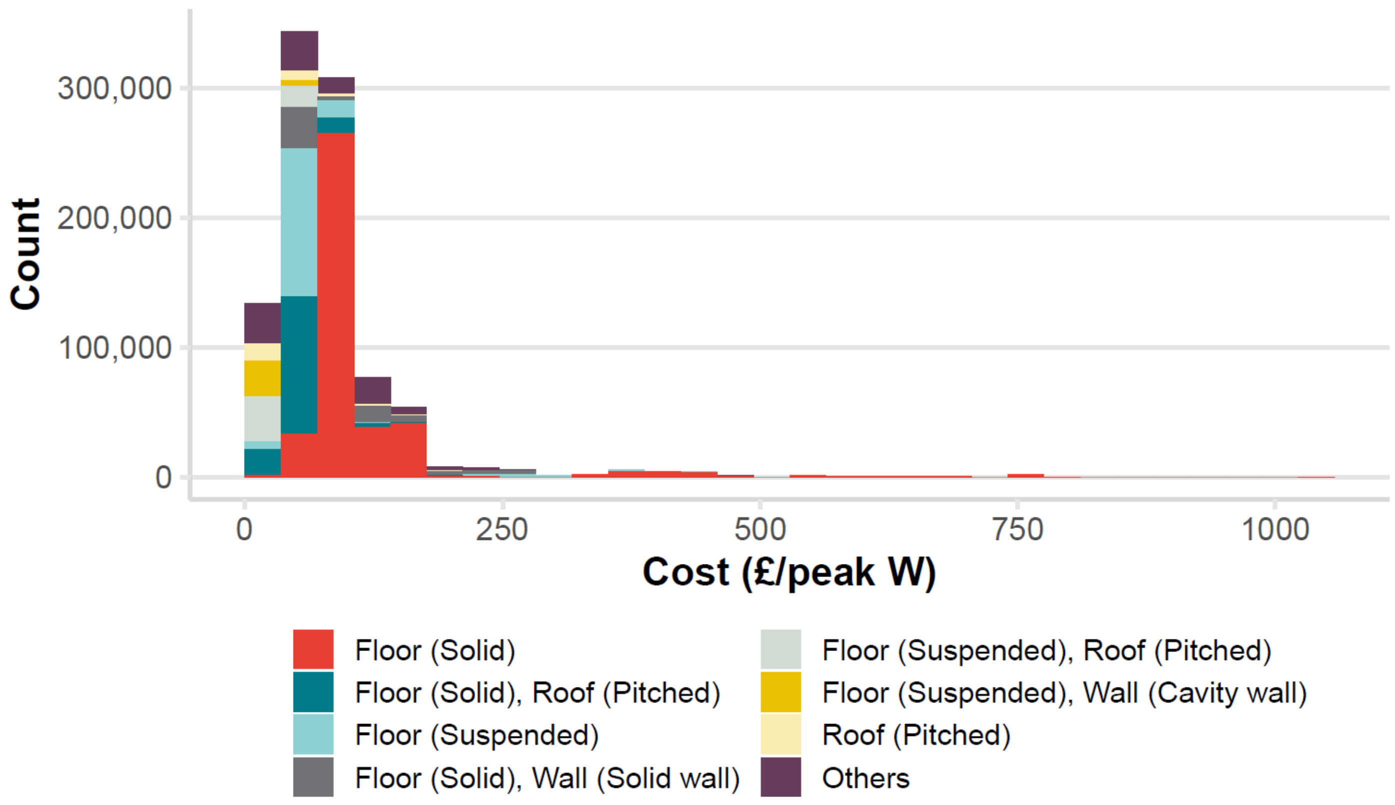
Source: Frontier Economics

23 As per our explanation in 2.1, it may be impractical to install a heat pump into a property with a low thermal efficiency, therefore we choose only medium thermal efficiency properties.

Figure 16 shows a similar histogram of cost effectiveness but identifying the form of EE upgrade. It can be seen that:

- Many of the retrofits consist of insulation of solid floors (red bars). However these are associated with a higher cost per peak MW saved than suspended floor insulation (light blue), or upgrades that also involve the walls and roof.
- The highest value-for-money retrofits (those on the left hand side of the graph) are:
  - upgrades that combine suspended floor insulation with cavity wall insulation (gold); and
  - upgrades that combine suspended floor insulation with pitched roof insulation (grey).[24]

Figure 16 Form of EE upgrade – all CMZs



Source: Frontier Economics

To measure the impact of the choice of retrofit on Ceiling Price and cost effectiveness we consider the two interventions which would both reduce peak demand in the Gunnislake CMZ by 1MW in different ways:

- If only carrying out solid floor insulation, this intervention would require 9,250 homes to be retrofitted at a cost of £5.3m; or

24 The high cost-effectiveness of this package explains the results seen above for top floor flats, which typically require these interventions.

- if only carrying out suspended floor insulation then 8,770 homes would need to be retrofitted, at a cost of £3.7m.

The Ceiling Price would be approximately 5.5% higher for the intervention involving suspended floor insulation (as the required number of houses is 5.5% less). However this difference in Ceiling Price is likely to make far less difference to the overall viability of the intervention than the difference in costs, which is about 30% lower for the suspended floor insulation retrofits.

This example therefore demonstrates that, while the choice of what type of property and retrofit to target can affect the Ceiling Price, the impact on intervention cost can be more significant, and it is important to consider both in combination. This is dealt with in more detail in chapter 7.

Box 1 EE potential in properties with direct electric heating

The majority of this study is focussed on properties with heat pumps since, as shown in Figure 8, these are projected to be the main source of electrically powered heating for domestic properties. Properties with direct electric resistive heating are not forecast to be highly prevalent, however retrofitting these properties may represent a potential higher value-for-money for DNOs.

To illustrate, consider an EE upgrade that leads to a 1kW decrease in heat demand. This would reduce an air-source heat pump's electrical demand by around 0.34kW. However if the property had electric resistive heating that was providing the same hourly profile of heat, its electrical demand would be reduced by about 1.1kW.[25] This means that a DNO's Ceiling Price would be approximately three times greater for energy interventions in households running non-storage electric resistive heating, all else held equal.

As described in section 3.2, electric resistive heating is currently more common in off-grid rural areas which may also have high reinforcement costs and may therefore be better candidates for DNO EE interventions. Further research would be needed to understand if these are also the types of properties which would tend to be using direct electric heating in future.[26] In addition, many houses that run electric resistive heating are likely to use storage heaters which run overnight, not during peak hours, and so there may be no benefit at all to the DNO from reduced consumption.

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25 Based on efficiency and coefficient of performance figures from the ESME data set, v4.4, available at: https://www.eti.co.uk/programmes/strategy/esme. We have used the 'Heat Pump (Air Source, space heat), kWh of electricity in winter' and 'Electric Resistive Heating - space heat, kWh of electricity in winter' values.

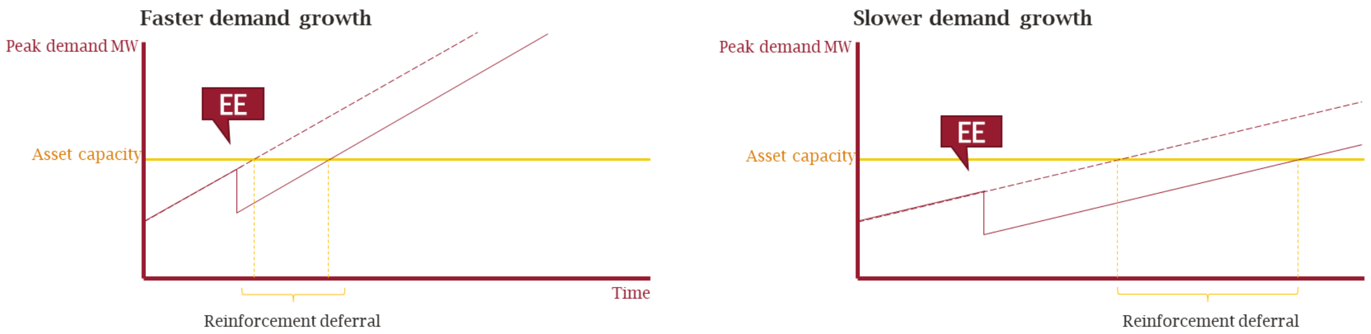
26 For example, it may be that these rural properties could upgrade to a heat pump, and that the remaining properties on direct electric are off-grid flats in urban areas where reinforcement costs are not as high. While a property changing heating system from electric resistive to a heat pump may in itself have a significant benefit for the DNO, this is outside the scope of the EE measures considered in this study.

3.1.4 The rate of demand growth

In a CMZ with low demand growth, EE may enable reinforcement deferral for a longer period, relative to a high demand growth scenario. This is because the additional headroom provided by EE will be depleted slower in slow demand growth scenarios, allowing the benefits of EE to be realised over a longer period.

This can be seen in Figure 17 below. The dotted red line shows the demand on the network without the EE intervention (but after any economic sources of flexibility are called), and the solid line shows the demand after the intervention. The yellow line indicates the point at which the network will reach its headroom and reinforcement is required. It can be seen that the for the same reduction in demand due to EE, the fast demand growth scenario (shown on the left) quickly depletes this headroom while the low demand growth scenario (on the right) does so more slowly, resulting in a longer deferral of reinforcement.

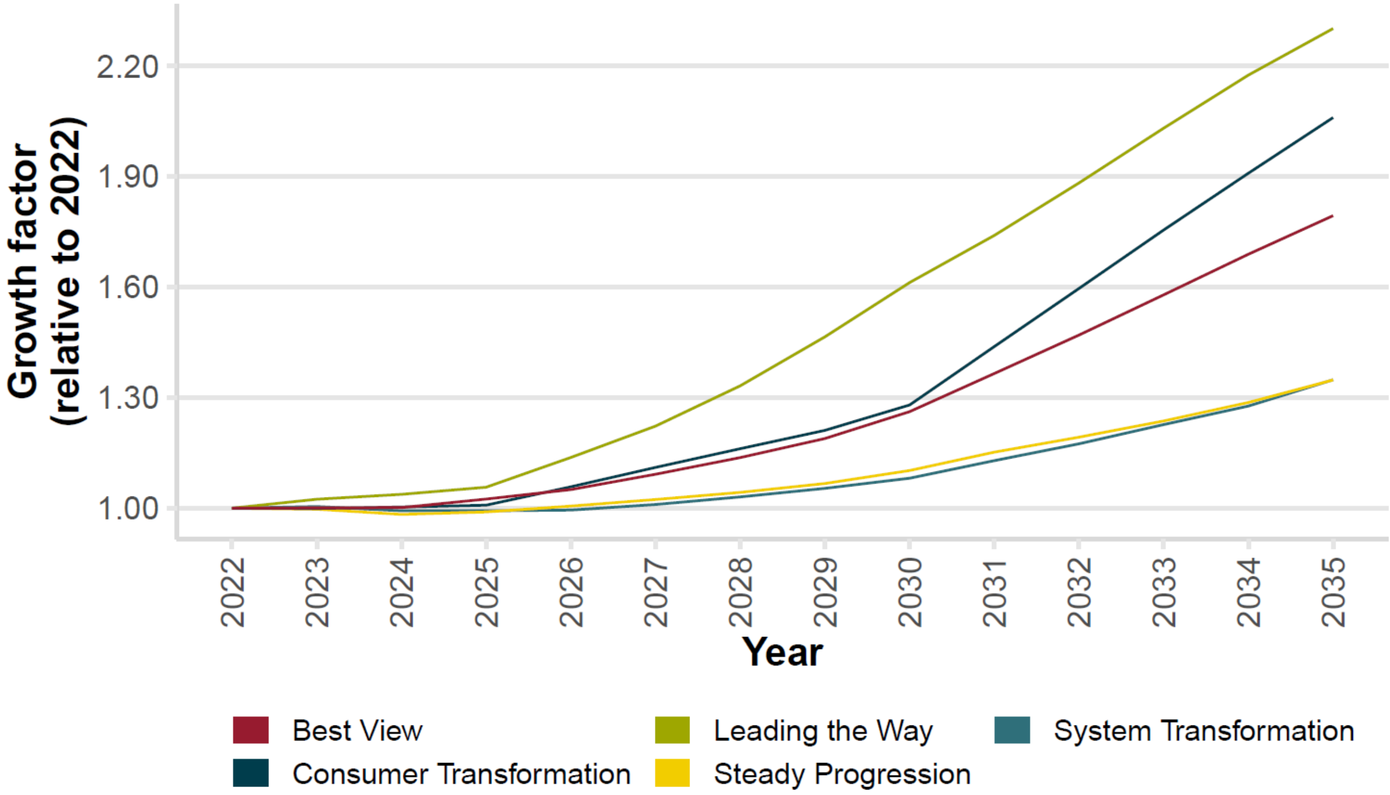
Figure 17 EE headroom depletion in low vs high demand growth scenarios



Source: Frontier Economics

The distribution of possible demand outcomes is represented in the model through the five different demand scenarios that NGED are using ('Best view', 'Consumer transformation', 'Leading the way', 'Steady progression' and 'System Transformation'). Here the average year on year rate of demand growth ranges from 2% to 7%, as seen in Figure 18 below.

Figure 18 NGED demand scenario growth rates

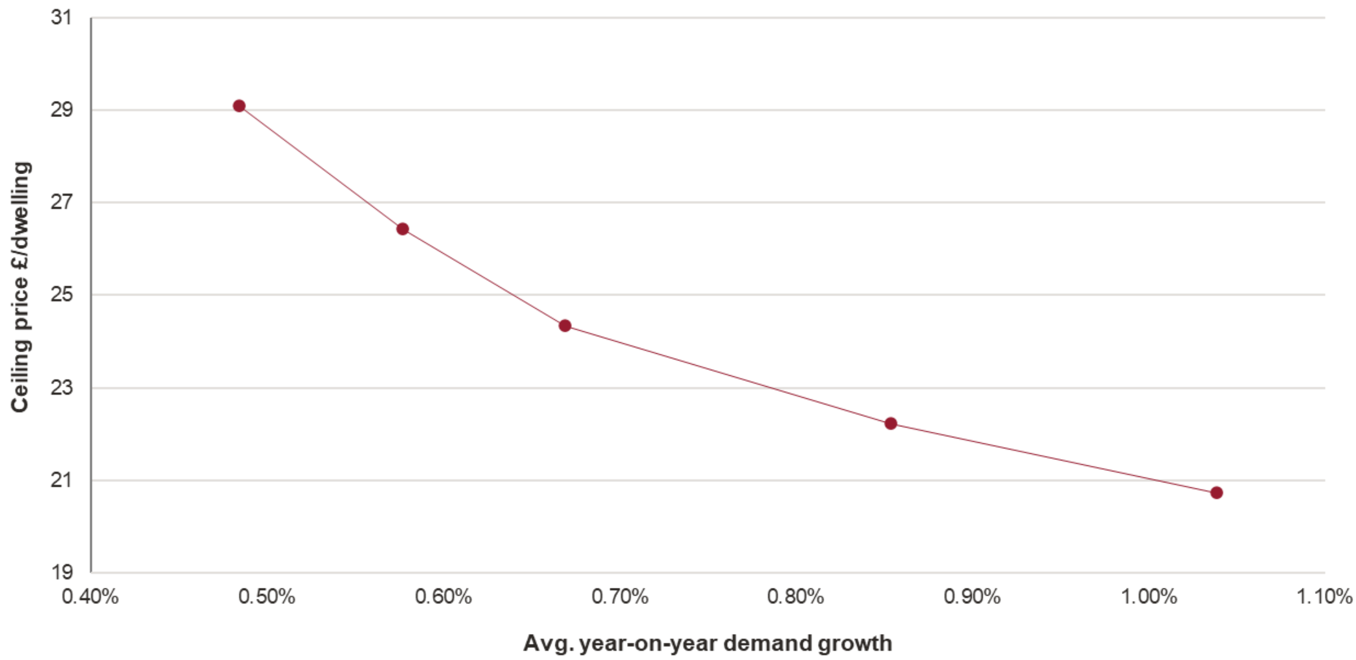


Source: Frontier Economics based on figures from NGED

Sensitivity tests confirm that, all else held equal, an increased year on year rate of demand will decrease the Ceiling Price. Figure 19 plots the Ceiling Price for the Gunnislake CMZ for rates of annual demand growth ranging from 0.4% to 1%. A doubling of the growth rate from 0.5% to 1% corresponds to a decrease in the Ceiling Price of approximately 30%.

Note that, for very low rates of demand growth, there may be no need for reinforcement or flexibility and so the Ceiling Price would be zero. The scenarios below have been set up with an initial trajectory of demand to 2024 that means some flexibility would be required.

Figure 19 Adjusted demand scenarios and Ceiling Price outcomes – Gunnislake CMZ



Source: Frontier Economics

3.1.5 The availability of flexibility

When NGED runs the CEM, it assumes that there is no technical limit on the volume of flexibility that can be procured (instead, the limit is set by what would be economic for a given price, which is held constant). However, in practice, there is not an infinite source of flexibility, and some CMZs may have a particularly constrained set of flexibility options.

It is difficult to say ex-ante what impact varying the availability of flexibility will have on the Ceiling Price, as flexibility is both a complement and a substitute for EE.

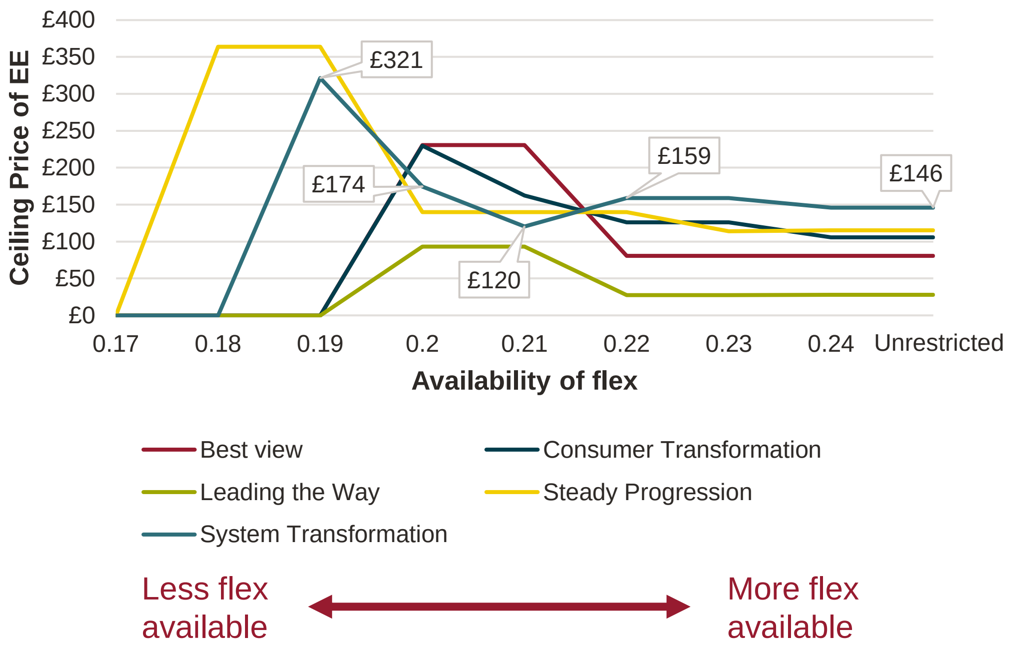
- **Complement (greater flexibility increases the Ceiling Price)**: EE produces a reduction in demand which is not perfectly targeted at the hours of the year when demand is highest. Flexibility can be targeted, and so could complement an EE intervention by being called on during the hours when EE alone is insufficient.
  - In the extreme, if there is so little flexibility that the network would need to be reinforced immediately even with the EE intervention, then the Ceiling Price would be zero.
- **Substitute (greater flexibility Decreases the Ceiling Price)**: On the other hand, flexibility and EE are alternative ways of reaching the same goal (deferring reinforcement). It might therefore be expected that increasing the availability of flexibility would reduce the Ceiling Price that a DNO is willing to pay for EE.

To test which effect dominates, constraints on flexibility availability were applied in the CEM. Morwenstow CMZ was chosen for this sensitivity test as it tended to require reinforcement in later years – there is therefore scope for reduced flexibility to move reinforcement forward.[27]

The results in Figure 20 below show both effects. Focusing on the 'System transformation' scenario as an example (teal line):

- If there is any less than 0.18MVA of flexibility available, the combination of flex and EE is insufficient to defer reinforcement, which must occur immediately. The Ceiling Price is therefore zero.
- Higher levels of flexibility increase the Ceiling Price (through the complement effect described above) until it reaches its maximum of £321 per property if there is 0.19MVA of flexibility available. At this point, flexibility alone cannot defer reinforcement, but the combination of flexibility and EE can.
- Beyond this point, the Ceiling Price generally decreases as more flexibility becomes available, settling at £146 for a flexibility availability of 0.24MVA and above.

Figure 20 Sensitivity tests for availability of flexibility – Morwenstow CMZ



Source: Frontier Economics

These results show that the Ceiling Price can be very sensitive to the availability of flexibility (in some cases, the Ceiling Price with restricted flexibility can be more than double what it would be if flexibility were infinite). However the 'sweet spot' where the Ceiling Price is at its highest is very narrow: It may be difficult to assess the exact amount of flexibility available in a CMZ with sufficient accuracy to target on this basis.

27 Gunnislake requires reinforcement much earlier, even with unlimited availability of flexibility.

3.2 Features of CMZs with high reinforcement costs

The sensitivity analysis above indicates that reinforcement costs are likely to be the main driver of differences in average Ceiling Price by CMZ. As shown in Figure 13, differences in reinforcement cost that are representative of the variation in costs across NGED's network can move the Ceiling Price from zero to hundreds of pounds per property. This variation is far greater than any of the other sensitivities that were explored. In addition, the other factors are either likely to be within the gift of the DNO to determine for a given intervention (e.g. the scale of the intervention and types of properties targeted), or else subject to substantial uncertainties (demand growth and flexibility availability). Targeting EE interventions at areas with high reinforcement costs is therefore likely to be an effective way of ensuring a high Ceiling Price.

All else equal, a network covering more properties will tend to have a greater peak demand. This will require network assets to be capable of handling this higher peak demand, which is likely to increase the costs of reinforcement. However the absolute rate of demand growth will also tend to be higher in such an area, and so a larger EE intervention will be needed to defer reinforcement for the same length of time. It is therefore likely to be the *relative* cost of reinforcement (compared to overall peak demand) that is important for Ceiling Price, rather than the *absolute* level of cost.

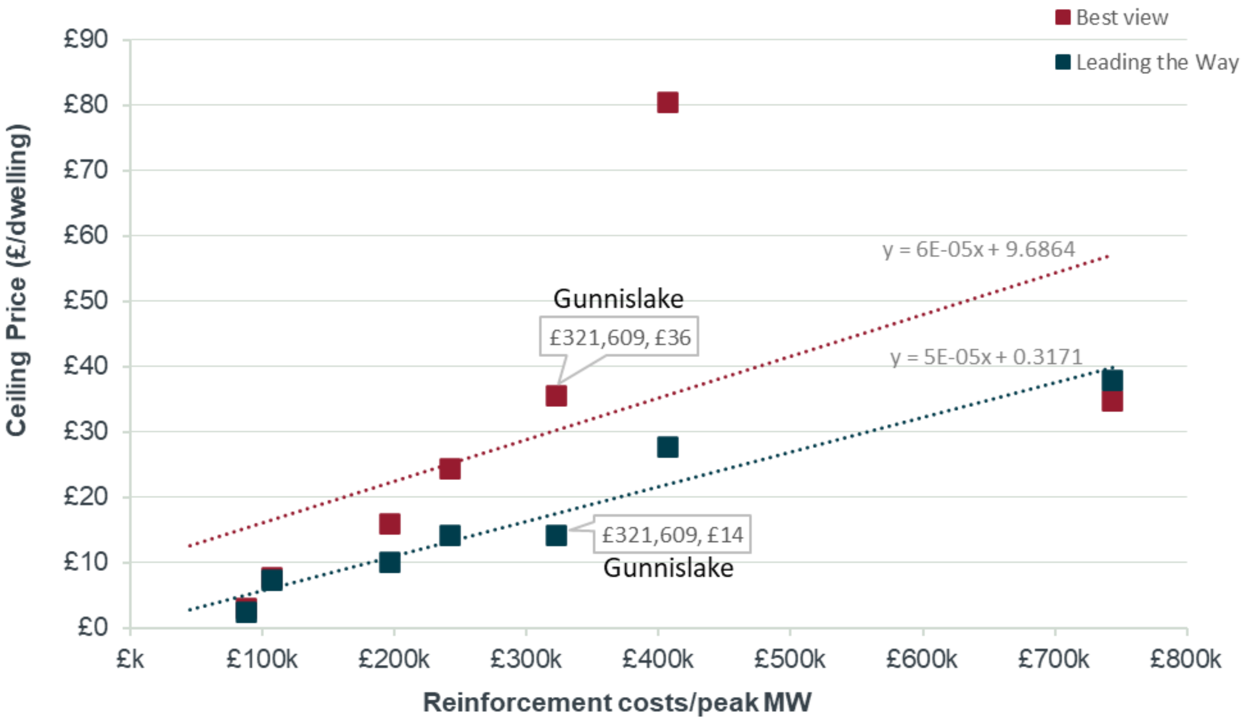
To test the predictive power of reinforcement costs for the effectiveness of EE interventions, seven CMZs[28] with a range of high and low reinforcement costs were passed through the EE assessment process. The results can be seen in Figure 21 below for the 'Best view' and 'Leading the way' demand scenarios. Reinforcement costs are shown in terms of cost per peak MW of demand, to normalise for the effect of different sized areas. This shows that there is a strong positive relationship.[29]

[28] In South West England: Chewton Mendip, Countess Wear, Gunnislake, Morwenstow, Roundswell, Stokenham, Truro Treyew, Witheridge

In East Midlands: Chesterfield Main, Loughborough, Mackworth, Sharnbrook

[29] The line of best fit for the 'Best View' scenario is influenced by one particular outlier. However the analysis for Gunnislake shown above indicates that such high Ceiling Prices (nearly £100 in this case) are feasible. Since we have no reason to believe that the outlying area (Truro Treyew) is otherwise unrepresentative, it has been kept in the analysis. Were it to be removed, value to the DNO estimated in Chapter 6 would be somewhat lower.

Figure 21 Comparison of EE benefits and reinforcement cost



Source: *Frontier Economics*

Note: *The two points in the bottom-left of this graph overlap for Best View and Leading the Way.*

GIS data has been used to identify the characteristics of the areas with highest reinforcement costs (which, as shown above, also have higher Ceiling Prices, and are therefore likely to be better candidates for EE interventions). This analysis has shown that areas with higher reinforcement costs tend to be rural areas. NGED has indicated that such areas are often associated with higher reinforcement costs, due to features such as long cable distances and single transformer feeders. Examining the local characteristics of the sample of areas considered above, they also have:

- **A higher share of off-grid houses using electric heating**. As described in the previous section, facilitating the retrofit of these houses may offer especially high value for the DNO, depending on the prevalence of non-storage electric heating.
- **Lower average incomes**. If the EE intervention involves any element of subsidy by the DNO, then this will involve some redistribution of income from consumers as a whole (as DUoS charges are set across a wide area) to the recipients of the funding (all of whom will be in the targeted CMZs). This result shows that focussing on CMZs with the highest reinforcement costs may reduce the risk that this redistributes money from poorer to wealthier households. However this analysis does not indicate whether the houses that would be targeted for interventions *within* these CMZs are likely to have higher or lower incomes than the average.
- **More thermally ‘poor’ houses (and fewer thermally ‘medium’ houses)**. If (as assumed in this work) EE interventions need to be targeted at thermally medium houses which could have a heat pump installed, this would reduce the potential scale of the interventions. As the rural areas with high

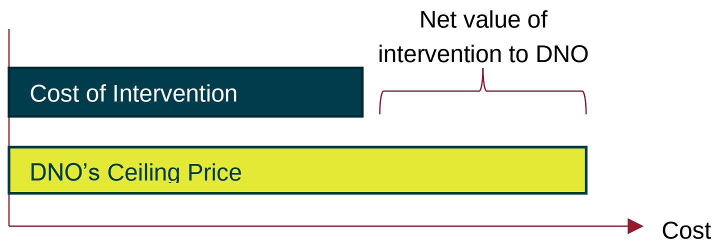
reinforcement costs tend to have fewer thermally ‘medium’ homes, this effect is stronger for the very areas where EE interventions may otherwise have the highest value.

- **A lower proportion of social housing**. Social housing could offer value to EE interventions since it potentially aligns with a DNO’s vulnerability obligations, and may allow for effective implementation as social landlords can be engaged to upgrade significant batches of houses at a time. However this result shows that social housing is more associated with urban areas which (currently) have lower reinforcement costs and therefore lower ceiling price.

4 The value of EE interventions to the wider electricity value chain

As described in the preceding chapter, EE interventions have the potential to reduce flexibility and reinforcement costs for DNOs. These avoided costs determine the DNO's Ceiling Price for an intervention – i.e. the value of the benefits the DNO receives. Figure 22 below illustrates that if the DNO's Ceiling Price exceeds the consumer's cost of installation (the cost of the intervention), then the DNO could pay the consumer's full cost and still obtain an overall reduction in its own costs. The larger this difference, the more the DNO could provide without spending more than the network costs it is saving. We refer to this difference between the cost of intervention and the DNO's Ceiling Price as the 'net value' of the intervention to the DNO.

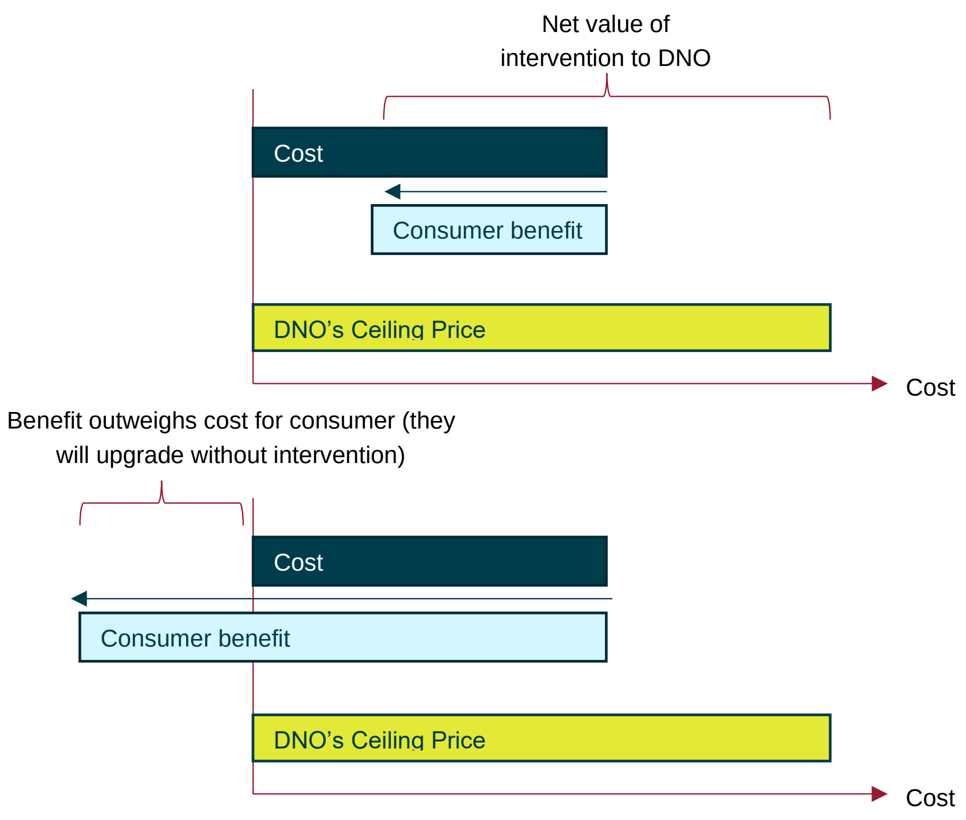
Figure 22 Net value of EE intervention to the DNO



Source: Frontier Economics

The cost of the intervention itself and the savings to the network are not the only relevant factors. The consumer may obtain additional benefits from EE measures (such as reduced electricity bills) which reduce the net cost to the consumer of installing the measures. By decreasing the gap which the DNO needs to cover, this could increase the net value available to the DNO (as in the top half of Figure 23 below). However if the consumer receives an overall benefit from EE measures *without* taking into account additional funding from the DNO (as in the lower half of Figure 23) then they may carry out the retrofits by themselves. In this case, DNO funding is not required (and, if it was provided, would effectively be wasted – we discuss this issue further in chapter 5).

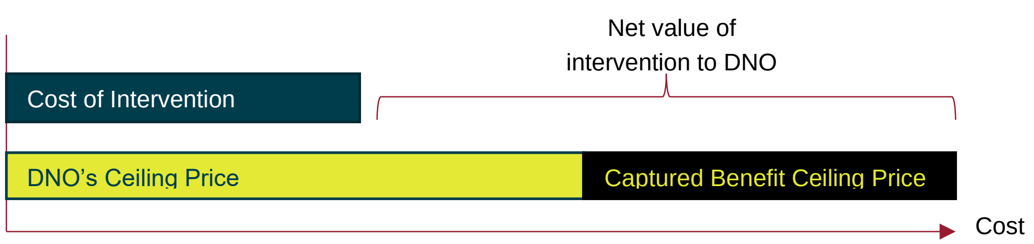
Figure 23 Net value to the DNO after consumer benefits



Source: Frontier Economics

EE interventions may also lead to benefits to other parties (for example, the TSO). If the consumer would not receive these benefits on their own but the DNO *is* able to receive a payment for these benefits, it could 'stack' them with its own, increasing its Ceiling Price. This is illustrated in Figure 24.

Figure 24 Other parties' EE benefit



Source: Frontier Economics

This demonstrates why it is necessary to consider the full set of costs and benefits which may impact both consumers and DNOs in order to determine the overall value of EE interventions. To do this in a systematic way, the whole system impact framework developed for BEIS[30] has been applied. This categorises the costs (or cost savings) of a technology into:

- The costs of the intervention itself;
- the impacts on the wider power system; and
- a broader set of impacts which go beyond the power system.

In the sections below, each type of impact is quantified for an example EE intervention, and an assessment is then made of whether the impact is faced by consumers or DNO. Section 4.4 calculates the net value to the DNO and therefore summarises the implication of these findings on the viability of EE interventions for DNOs.

4.1 Intervention costs

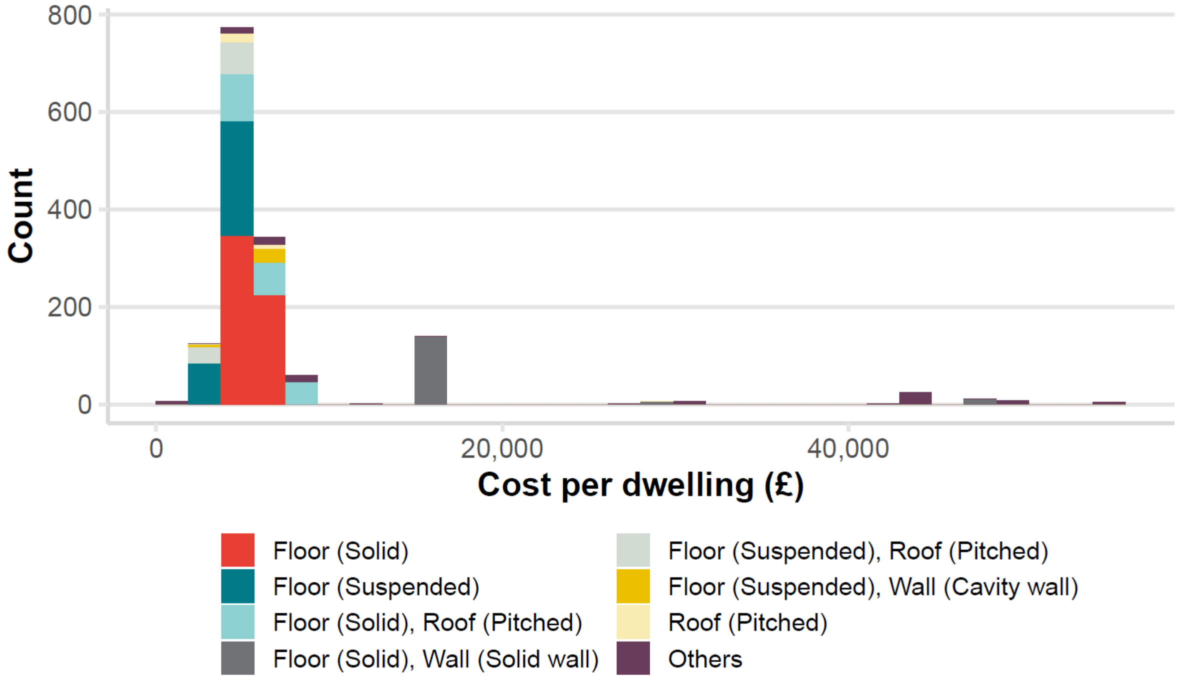
To illustrate the various benefits of an EE intervention the Gunnislake CMZ will continue to be used as an example. In chapter 3, it was established that Gunnislake had a Ceiling Price of £36 per property under the Best View scenario (based on an EE intervention targeting all medium-efficiency homes).

Based on the figures calculated by Defender workstream 1, the total cost of retrofitting all these homes would be £11.3 million and it would cover 1,512 households, equating to an average cost per household of £7,483. Note that there is significant variation within this average, as shown in Figure 25 below.

This intervention is estimated to result in approximately 234 kW in peak load reduction and is achieved through a range of upgrades. Figure 25 arranges the different types of upgrade in order of cost. The cost per dwelling varies widely, from around £2,000 to £50,000. This suggests that a smaller intervention can be more cost-effective by targeting those properties with lower costs.

30 Frontier Economics for DECC (2016) "*Whole power system impacts of electricity generation technologies*". This framework forms the basis of the 'enhanced levelized costs' used in BEIS's regular generation cost reports.

Figure 25 Spread of costs per household in Gunnislake



Source: Frontier Economics

4.2 Power system costs

This section identifies the savings across the broader power system resulting from the EE intervention described above. These savings will persist as long as the retrofit measures, which are assumed to remain equally effective over time, are in place. For the purpose of these calculations, a lifetime of 50 years has been assumed (by this point, the use of discounting means that the benefits are minimal).

Drawing on the BEIS enhanced levelized cost framework, the benefits described below are:

- **Displaced generation costs** – reduced costs due to the need to produce fewer MWh of electricity.
  - Carbon emissions, a component of displaced generation costs, are also separately quantified.
- **Capacity adequacy costs** – reduced costs due to the need to have less MW of generation capacity to cover peak demand.
- **Balancing costs** – reduced (or increased) costs due to the need to ensure electricity supply and demand are always in line with one another.
- **Network costs** – reduced costs due to lower loads on the transmission and distribution networks.

4.2.1 Displaced generation costs

The reduction in demand from EE interventions leads to a reduction in the variable costs of producing power. For example, if gas generation can be reduced, this will result in savings through:

- combustion of a lower volume of gas;

- production of a lower volume of CO_2 (which will in turn require the purchase of fewer UK emission allowances); and
- a reduction in variable O&M costs such as maintenance.

These cost savings are, broadly,[31] passed through to consumers, as bills will cover the wholesale costs of energy.

To estimate the total savings to consumers, BEIS's standard electricity retail price forecasts have been used to value the energy savings from a typical intervention (a thermally medium property, as identified in section 2.1). For the Gunnislake CMZ, this would result in savings of 710,129 kWh per year. These savings have been valued using retail price forecasts from BEIS' Domestic central price scenario.[32]

If consumers fully accounted for these savings in a way similar to a Government cost-benefit analysis (which applies a discount rate of 3.5% until year 30 and 3% from then onwards)[33] then they would result in a discounted total benefit of £3.5m, or £2,309 per dwelling.

However consumers may in practice discount distant benefits to a much greater extent. If a discount rate of 50%[34] is applied then this leads to a much lower discounted total benefit of £454,175 (i.e. £300 per dwelling).

4.2.2 Carbon costs

The reduction in demand caused by EE interventions will also result in a reduction in carbon emissions. Carbon costs are already factored in to wholesale power prices (and therefore consumer bills). **These costs therefore do not reflect an additional benefit, and including them in addition to the effect on consumer bills described above would lead to double-counting**.

Nevertheless, it may be insightful to split out the benefit accruing as a result of carbon emission reductions (for example, this is a non-financial benefit which can be considered for Strategic Innovation Fund projects).[35] The model developed for this work therefore allows the carbon reductions of an EE intervention to be assessed in line with the Government's Green Book guidance (one of the approved methodologies noted in the SIF Governance Document).

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31 Consumer bills are not currently fully cost-reflective. For example, most consumers currently pay a flat pounds-per-kWh fee for energy, which will not reflect the different costs of energy throughout the day and the year. Bills will become more cost-reflective if time-of-use tariffs become more common following the introduction of mandatory half-hourly settlement.

32 HM Treasury (2022) "Green Book supplementary guidance: Data table 4". BEIS's projections account for the current high levels of bills, but assume that unit rates will fall back towards historic levels.

33 HM Treasury (2022) "The Green Book".

34 Choice experiments conducted in the study by Element Energy (2008) found that consumers are willing to pay £2.91 in up-front costs to reduce their annual fuel bills by £1. Given that the expected lifetime of a boiler is 15 years, we have calculated that the discount rate for a typical consumer is about 50%.

35 Ofgem (2021) "*SIF Governance Document*", para 4.23

Based on this methodology, the intervention described above for the Gunnislake CMZ would save approximately 1.2 tonnes of carbon per dwelling over the 50 year period. Due to projected carbon intensity[36] of the grid falling over time, most of these emissions occur in the first 10 years. Using the social discount rate from the Green Book[37], and costs of carbon from CEM[38] (which itself uses figures from BEIS) this would lead to a total benefit of £110,387 (i.e. £73 per dwelling).

4.2.3 Capacity adequacy costs

Another cost reduction due to the EE intervention relates to the fixed costs of building and maintaining generation capacity. All else equal, a reduction in peak demand will mean a lower generation capacity will be required, which implies lower costs of building and maintaining power stations. **As with displaced generation and carbon costs, these savings will be broadly passed through to consumers in their bills**. This is because suppliers' bills will generally include an element designed to pass through the cost of funding Capacity Market payments.

To give a broad sense of the magnitude of these costs, the T-4 capacity market auction for delivery in 2025-26 cleared at £30.59/kw/yr.[39] The EE interventions in Gunnislake CMZ described above would save 234kw in peak demand, which would therefore be valued at £7,143 per year. If such benefits were to be realised over a 50 year life of EE measures using the social discount rate then the resulting discounted value of the cost saving would be £174,972 (i.e. £116 per dwelling). However, as noted above for displaced generation costs, consumers may apply a higher effective discount rate when considering whether or not to pay for EE measures.

4.2.4 Balancing costs

Some technologies affect the costs of balancing the power system. For example, intermittent generators like wind can add to the unpredictability of supply, requiring additional balancing costs. Flexible technologies like demand-side response can counteract this, reducing the costs of balancing the system.

Thermal efficiency measures will tend to reduce demand in a predictable way, and cannot be dispatched to balance the system. **EE interventions are therefore, by themselves, unlikely to affect balancing costs in a material way.**

It is possible that improved thermal efficiency could enable more extensive demand-side response, which could then be used to reduce balancing costs (as well as the other categories of costs described in this section). This is since a heat pump in a better insulated building can be turned off for a longer period without the temperature becoming too low, with the building fabric itself acting as a form of thermal storage. This is potentially an area for future research.

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36 BEIS (2022) "Tables supports the Treasury Green Book supplementary appraisal guidance on valuing energy use and greenhouse gas (GHG) emissions". Table 1 is used for the Grid intensity.

37 HM Treasury (2022) "The Green Book".

38 CEM model 'Fixed Inputs' tab.

39 https://www.emrdeliverybody.com/CM/T42022.aspx

4.2.5 Network costs

The impact of EE measures on reducing distribution network costs is the main focus of this project, and chapter 3 describes the direct benefits to a DNO. These benefits are not, currently, available to consumers. This is due to the following two factors:

- First, DUoS charges are set for large regions, and are therefore not fine-grained enough to reflect the much higher costs of capacity on part of the network which are constrained.
- Second, even if DUoS charges could be made fully cost-reflective, this would reflect the *long-run* costs of network capacity in an area. In the short-run, there may be binding network constraints which EE interventions could alleviate. At present there is no mechanism for DNOs to compensate consumers for this, although such interventions are the topic of this report.

An analogous benefit may also exist on the transmission network: If a consumer in a region with an import-constrained grid supply point (GSP) reduced their demand as a result of energy efficiency measures, then this would reduce the costs associated with either reinforcing the transmission network, or procuring flexibility to overcome the constraint.

TNUoS charges for domestic consumers are set for each of 14 demand zones. Therefore, while TNUoS charges will not reflect the situation at the specific GSP a given consumer is connected to, they will reflect overall constraints on that part of the transmission network. For example, TNUoS charges in the South-East are over double what they are in Northern Scotland.[40] An element of the long-run costs of the transmission network is therefore already reflected in consumer bills.

However, these charges do not reflect the short-run costs of constraints. Currently, if a transmission link is constrained, National Grid ESO procures flexibility through the balancing mechanism (BM). For example, if there is more energy flowing from the North to the South than the network can handle, then ESO may need to:

- Pay generators in the North to curtail their output; and
- pay generators in the South to increase their output.

By decreasing demand, EE measures could act as a substitute for turning up generation in import-constrained zones. These savings might be material. To give an upper bound, the costs of turning up generation in 2021 were approximately £200/MWh.[41] This is therefore the amount that an EE intervention might save if it was in a zone where constraint management was required during all hours of the year.[42]

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40 nationalgridESO (2022) "Final TNUoS Tariffs for 2022/23".

41 Based on figures from LCP for Drax (2022) "Renewable curtailment and the role of long duration storage*"*. This indicates that, in 2021, the total costs of BM offers relating to system operator actions was £429m, accounting for roughly 2TWh of energy.

42 *Ibid* figure 4 indicates that there is at least a small amount of generation curtailment in most hours of the year.

Under such a constraint, the intervention for Gunnislake CMZ described above might therefore save £142,026 of transmission constraint costs for each year in which the constraint exists. Discounted over 50 years at the social discount rate, this is total benefit of £3.5 million (i.e. £2,301 per dwelling).

This estimation is likely an upper bound. First, most areas will not be subject to import constraints every hour. In practice there is also some double-counting between these benefits and the displaced generation benefits described above. The displaced generation benefits come from being able to turn down the marginal (i.e. most expensive to run) generator on the national network. If the EE intervention is in an area of the transmission network where there is an import constraint, then it may instead displace more expensive local generation which would otherwise have to have been dispatched to relieve the constraint. Nevertheless, this figure does indicate the potential for material cost savings.

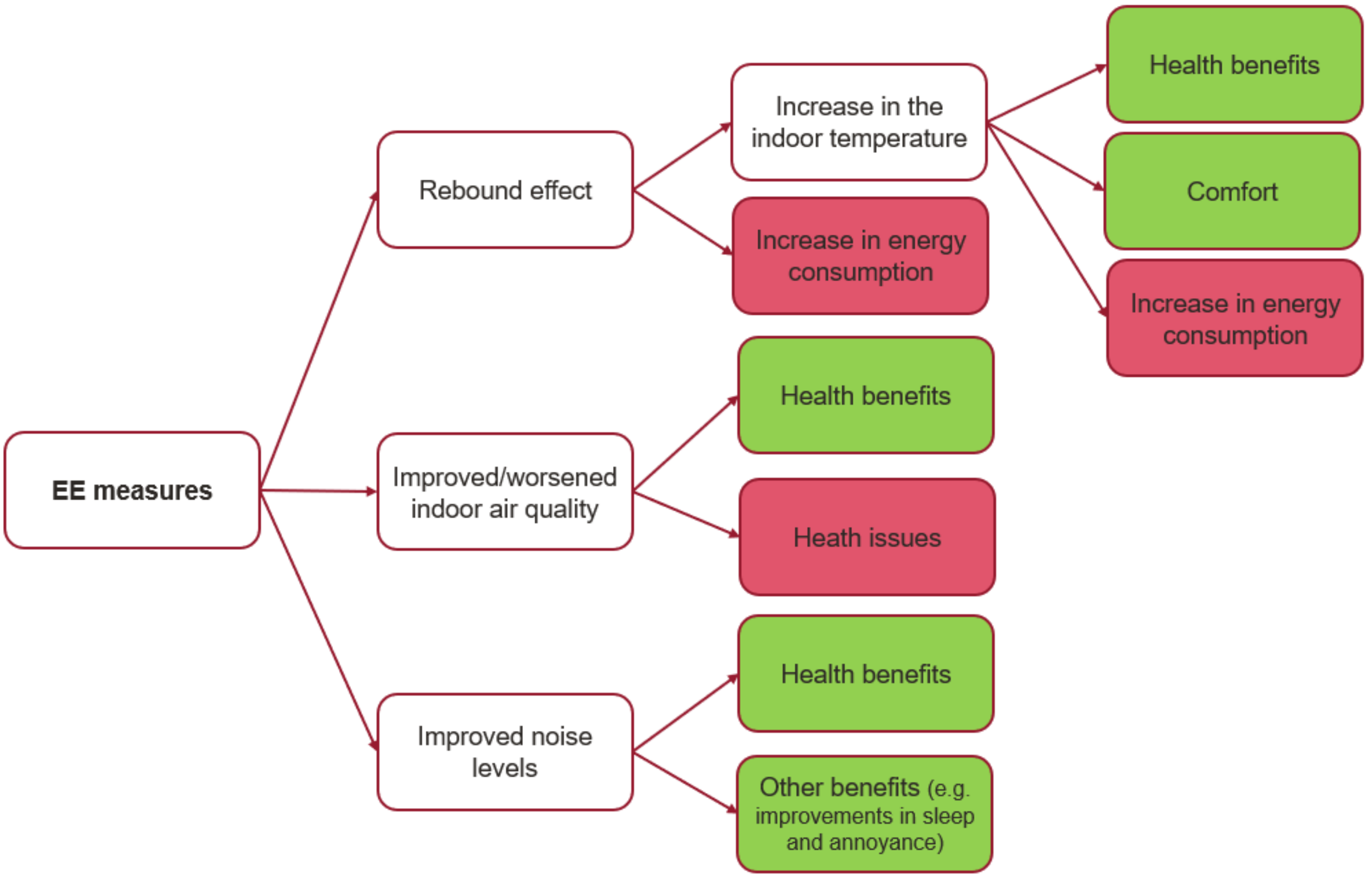
However, under the current market, these savings are available to neither consumers nor DNOs. The bids and offers in the BM are in relation to a baseline amount of generation, declared at Final Physical Notification. For example, a site offering demand-side response might declare that it intends to consume 1MW over a half-hour, but that this could be reduced if it is paid £100/MWh. But with energy efficiency, the reduction in demand is already committed to once the investment is made: There is no adjustment in demand which can be offered to the market.

Allowing EE interventions in constrained areas of the transmission network to receive the benefits of these actions would require a substantial redesign of the way the electricity market works.

4.3 Benefits beyond the power system

This section identifies benefits from EE interventions that go beyond the power system. Figure 26 illustrates these impacts, all of which relate to changes in levels of comfort or health condition for occupants. Each of these impacts is described below, and where possible broadly quantified.

Figure 26 Benefits beyond the power system



Source: Frontier Economics

Overall, the benefits beyond the power system may be material (several hundred pounds per property, hence higher than the DNO benefits quantified by the Ceiling Price). The implications of this are as follows:

- If consumers recognise these benefits themselves, they may reduce the gap between the cost of insulation and the benefits to householders. This means that DNOs may need to contribute less in order to incentivise a given household to install insulation.
- However the value placed on these benefits by a consumer is highly uncertain and subjective – it will not accord with the simple calculations shown here. Given the value of these benefits is potentially much higher than a DNO's Ceiling Price, this uncertainty increases the risk described in chapter 5 that a DNO pays for retrofits that would have been undertaken regardless (or at least for a lower payment).
- If consumers do under-value these benefits, it may be that DNOs could encourage installation of some EE measures through helping to inform consumers of them.
- Finally, the nature of these benefits, which all relate to consumer wellbeing, may themselves provide a further rationale for DNOs to encourage uptake of EE, especially among vulnerable consumers.

4.3.1 Rebound effect (take-back effect)

The demand profiles used for this work assume that EE measures allow the same level of heating to be produced for a lower input of electrical energy. However, studies show energy consumption often does not fall as much as expected following EE interventions – a 'rebound effect' occurs. This relates to '*…the fact that improvements in efficiency often lead to cost reductions that provide the possibility to buy more of the improved product; or other products or services*'.[43]

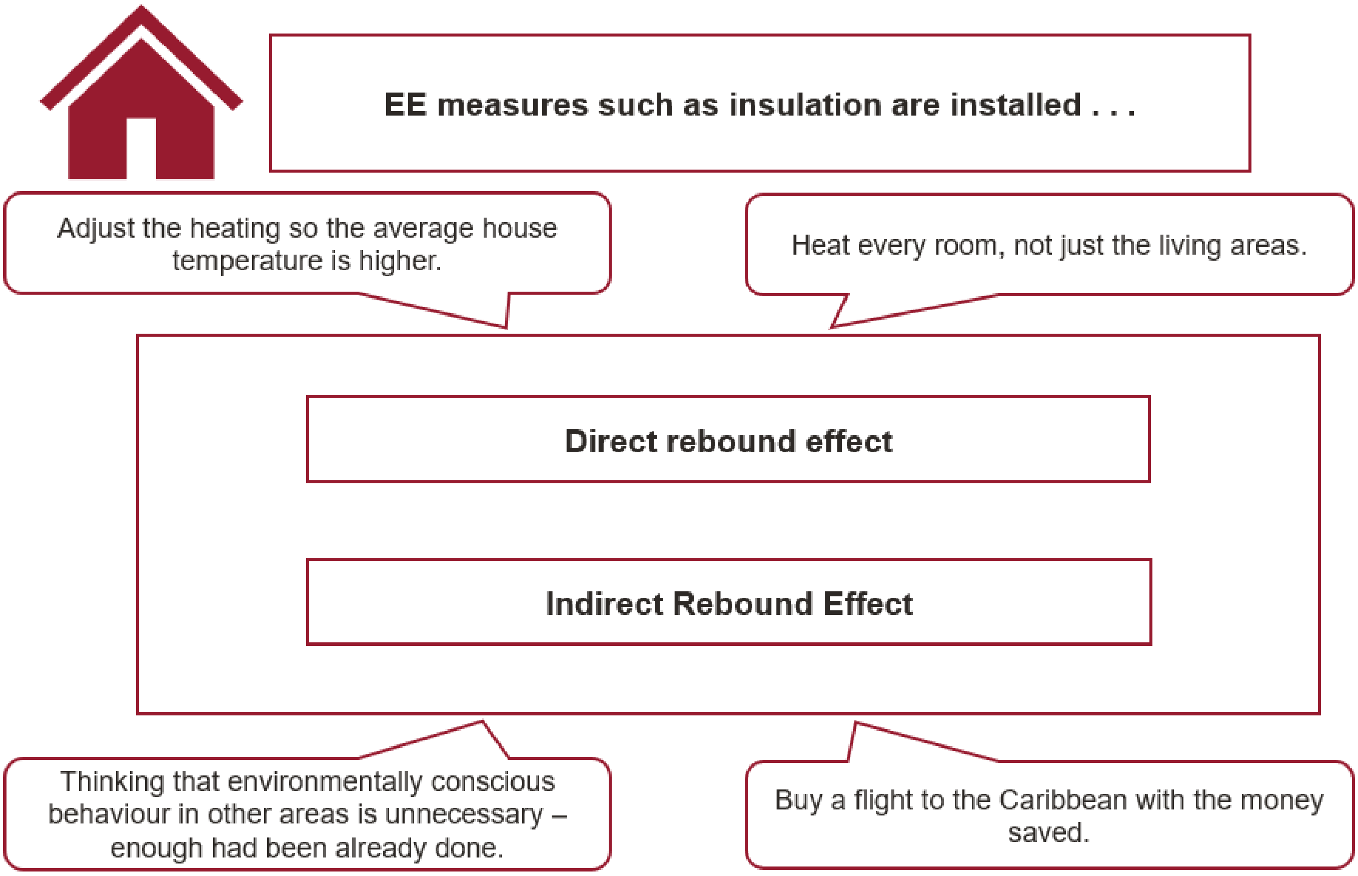
There are two different types of rebound effects, as illustrated in Figure 27:

Direct rebound effects occur when EE results in higher demand for heating itself. For instance, after insulating a house, the occupants adjust the heating so that the average temperature in the house is higher than before the retrofit. This could be both due to an 'income effect' (the reduction in bills means that the household has more disposable income, some of which can be spent on heating) or a 'substitution effect' (as the same amount of heating can be bought for less, it is worth 'buying' more heating).

Indirect rebound effects occur when efficiency gains in one area lead to higher resource consumption in *other* areas. This is another example of an income effect: For example, a lower heating bill following insulation may create financial leeway for other activities such as more holidays.

43 Thiesen, J. *et al.* (2006) "Rebound effects of price differences" *The International Journal of Life Cycle Assessment*, 13(2), pp. 104–114.

Figure 27 Examples of direct and indirect rebound effects



Source: Frontier Economics

This section does not attempt to quantify indirect rebound effects: The lower heating bills themselves are taken into account rather than the additional consumption these may allow. However the direct rebound effect may be important, as it will lead to a benefit for consumers, but at the same time a reduction in energy savings (which will lead to lower bill savings, as well as a reduction in the benefits for DNOs).

A UK Energy Research Centre study estimated the long-run direct rebound effect for space heating in OECD countries between 10% and 30% with 'medium' degree of confidence.[44] Furthermore, the magnitude of the direct rebound effect should decline rapidly once the indoor temperature approaches the maximum level of thermal comfort. A UK study shows that once the average indoor temperature had risen above 19°C the rebound effect settles at around 20%.[45] However the direct rebound effect tends to be higher among low

44 UK ERC (2007) "The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency".

45 Milne, G. and Boardman, B. (2000) "Making cold homes warmer: The effect of energy efficiency improvements in low-income homes a report to the Energy Action Grants Agency Charitable Trust" *Energy Policy*, 28(6-7), pp. 411–424.

income groups since these are further from reaching satiation in their energy consumption.[46] Some research also indicates that the rebound effect could be greater still.[47]

Any increase in indoor temperatures from the rebound effect may result in health and comfort benefits for consumers.

Health Benefits

An increase in indoor temperature plays an important role in reducing indoor dampness and associated mould. This leads to a positive health benefits such as a reduction in symptoms of respiratory and cardiovascular conditions, rheumatism, arthritis and allergies.[48,49]

Modelling of the impact of solid wall insulation in all properties in England carried out by Department of Energy and Climate Change (DECC) indicated a total improvement in the health of the individuals in the properties of £3.5bn-£6bn over the lifetime of the measure (these benefits are calculated by applying a value to each quality-adjusted year of life). Also, if all cavity walls reported in 2009 were filled this would provide further health benefits of £4bn-£6bn over the life time of the insulation.[50] The average per dwelling health benefits range between £916-£1,308 for solid wall insulation and £519-£779 for cavity wall insulation.[51]

In addition to improvements to consumers health, there may be further savings if the health service is required to spend less on treating conditions associated with under-heating. For instance, BRE estimate that approximately £857 million of NHS treatment bills can be attributed to 'defects in poor homes which expose residents to excess cold'.[52] EE measures could bring an additional benefit of £1,026 per dwelling to the NHS by mitigating the excess cold hazard in poor homes.

While the benefits associated with heating currently underheated properties are substantial, it is important to note that come from a large rebound effect (as insulation permits the temperature to be raised). There may therefore be relatively little (if any) impact on energy consumption and avoided network investment costs for such houses. Additionally, many under-heated properties may be low efficiency buildings for which a heat pump would not be viable in any event.

46 Milne, G. and Boardman, B. (2000) "Making cold homes warmer: The effect of energy efficiency improvements in low-income homes a report to the Energy Action Grants Agency Charitable Trust" *Energy Policy*, 28(6-7), pp. 411–424.

47 Peñasco and Anadón (2023), *Assessing the effectiveness of energy efficiency measures in the residential sector gas consumption through dynamic treatment effects: Evidence from England and Wales*, suggests that, four years after the installation of lofts and cavity walls, the energy savings were negligible.

48 Barton, A. *et al.* (2007) "The Watcombe Housing Study: The short term effect of improving housing conditions on the health of residents" *Journal of Epidemiology; Community Health*, 61(9), pp. 771–777.

49 WHO (2008) "Preliminary results of the WHO Frankfurt housing intervention project".

50 DECC (2012) "The Energy Efficiency Strategy: The Energy Efficiency Opportunity in the UK".

51 Second order effects such as the cost savings to health services could also be taken into account in further work. For instance, BRE estimate that approximately £857 million of NHS treatment bills can be attributed to "defects in poor homes which expose residents to excess cold". See: https://bregroup.com/press-releases/bre-report-finds-poor-housing-is-costing-nhs-1-4bn-a-year/

52 BRE (2021) "The cost of poor housing in England".

While most evidence relates to the impact of cold environments, it is important that EE measures do not cause overheating in the summer, which can damage health through worsening asthma and cardiovascular conditions[53] or dehydration.[54]

Comfort benefits

A key driver of the rebound effect is the greater comfort associated with warmer houses. However benefits resulting from increased comfort are difficult to quantify – they may considerably vary between different types of consumer as perceptions of comfort can vary depending on factors such as age and culture.[55] As a lower bound, it could be assumed that comfort benefits exceed the additional energy costs for heating (as otherwise it would not make sense for the consumer to increase their heating in such a way).

Greater comfort can also drive significant mental health improvements.[56]

4.3.2 Improved air quality

Air pollution is an important cause of morbidity and mortality. If EE measures are coupled with improved ventilation systems such as mechanical ventilation with heat recovery (MVHR), they may reduce indoor dampness and associated mould build-up. This can have a positive impact on the air quality, reducing respiratory and cardiovascular diseases, and allergies.

There is, however, a risk of worsening indoor air quality as a result of certain EE measures. For instance if measures such as insulation and double glazing improve airtightness and additional ventilation is not provided, this might worsen the indoor air circulation and therefore air quality. This is particularly true if other sources of indoor air pollution such as gas hobs are in use. Special care is needed to ensure that suitable construction materials, ventilation and air management is in place to avoid unintentional accumulation of air pollution indoors.[57]

Given the ambiguous impact of the individual EE measures and their combination on the indoor air quality we do not attempt to quantify the potential health benefits.

4.3.3 Improved noise levels

A WHO report in 2011 identified environmental noise as the second largest environmental health risk in Western Europe.[58] DEFRA's Noise Marginal Values model suggests that noise reduction can carry health,

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53 Sharpe, R.A. *et al.* (2019) "Household energy efficiency and health: Area-level analysis of hospital admissions in England" *Environment International*, 133, p. 105164.

54 Naughton, M. (2002) "Heat-related mortality during a 1999 Heat wave in Chicago" *American Journal of Preventive Medicine*, 22(4), pp. 221–227.

55 Winther, T. and Wilhite, H. (2014) "An analysis of the household energy rebound effect from a practice perspective: Spatial and temporal dimensions" *Energy Efficiency*, 8(3), pp. 595–607.

56 Liddell, C. and Morris, C. (2010) "Fuel poverty and human health: A review of recent evidence" *Energy Policy*, 38(6), pp. 2987–2997.

57 DEFRA (2020) "Impacts of Net Zero pathways on future air quality in the UK".

58 WHO (2011) "Burden of disease from environmental noise".

sleep and amenity (annoyance) benefits.[59] Any noise exceeding 70 decibels (dB), equivalent to city traffic, is generally considered disturbing and over a prolonged period of time may start damage you hearing.[60]

EE measures, particularly double glazing, in residential buildings can reduce indoor noise levels. The CCC assumes that moving from single to double glazing might result in 10dB decrease in indoor noise levels; and upgrading old double glazing brings indoor noise level reductions of 5dB.[61] Based on DEFRA appraisal values[62] and assuming a noisy area with 70dB of noise levels, replacing single with double glazing might result roughly in a total benefit of £1,015 per dwelling in residential areas, while replacing old double glazing with new might bring a per dwelling benefit of £585.[63] In both cases, this is likely to be an upper estimate of the benefits, which would be less in quieter areas. It is less clear whether other forms of insulation on their own have a significant impact on noise levels.

4.4 Implications for the value to DNOs

This section brings together the different components of the DNO's net value to illustrate whether the Ceiling Price might be sufficient to incentivise a household to install insulation.

To illustrate the overall value of EE intervention the Gunnislake CMZ will continue to be used as an example. Overall value figures accounting for monetary/non-monetary benefits are calculated for two scenarios:

- An EE intervention targeting all medium-performance properties (i.e. the broad mix of various EE measures considered in chapter 3); and
- an intervention that only targets the most cost-effective EE measure (i.e. only cavity wall and suspended floor insulation) identified in section 3.1.3.

Table 2, below, shows the summary of the DNO net value. This does not account for non-monetary benefits to consumers (including the impact of the rebound effect) or reductions in transmission constraint costs.[64] Bill reductions have been discounted at the Green Book rate of 3.5%. As noted above, many consumers are likely to discount future benefits at a much higher rate, and so this is a best-case scenario in terms of the value of EE.

59 DEFRA (2014) "Transport Noise Marginal Values Mode".

60 WHO (1999) "Guidelines for Community Noise".

61 CCC (2013) "Review of the impacts of carbon budget measures on human health and the environment".

62 Based on the road traffic noise (excluding rail and aircraft noise).

63 DEFRA (2013) "Noise pollution: economic analysis".

64 As described in section 4.2.5 the current market structure would not permit EE interventions to receive these benefits.

Table 2 DNO net value (without considering non-monetary benefits to consumers)

DRIVER	ALL MEDIUM-PERFORMANCE PROPERTIES	ONLY CAVITY WALL AND SUSPENDED FLOOR INSULATON
Intervention cost	£7,483	£4,858
Discounted reduction in bills	£2,309	£3,389
Net cost to consumer	£5,174	£1,469
DNO Ceiling Price	£36	£52
Net value to DNO	**-£5,138**	**-£1,417**

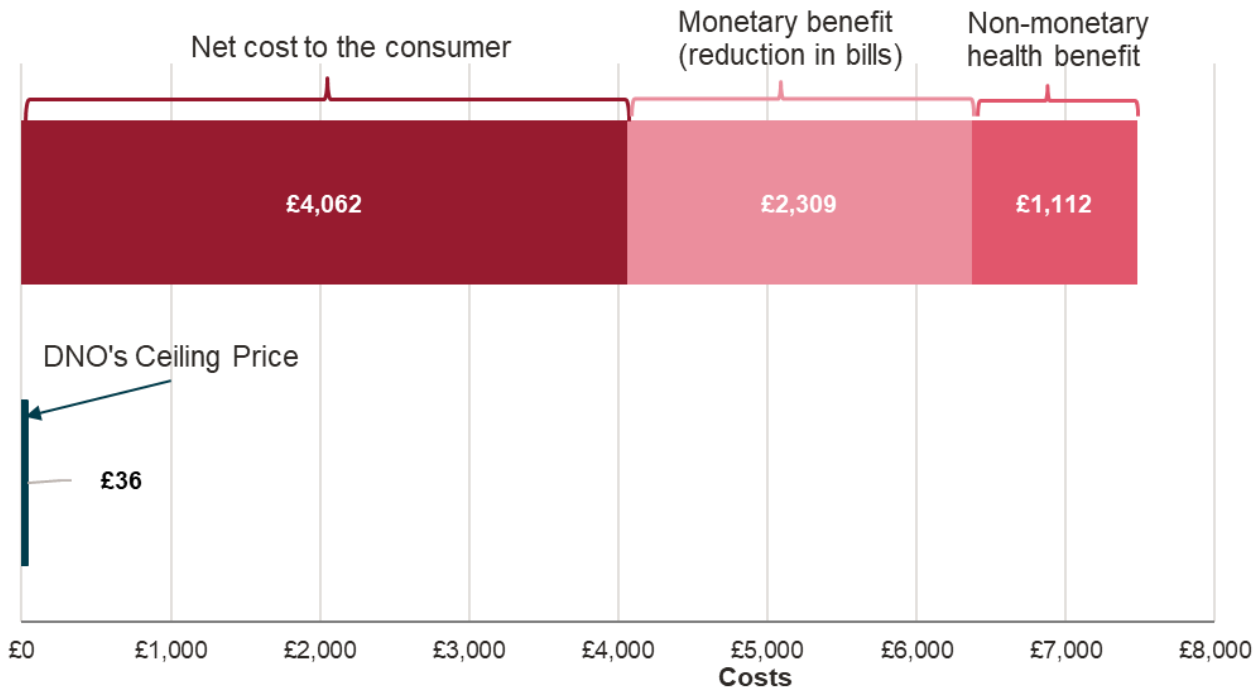
Source: Frontier Economics
Note: Units are in £ / Dwelling

For the broad intervention covering all medium-performance properties, the DNO Ceiling Price (£36) is far below the net cost to the consumer of £5,174. The Ceiling Price would need to be around 140 times higher to incentivise the consumer to install an EE measure. Such an increase in Ceiling Price would be unrealistic even in areas with extremely high reinforcement costs.

Even if the consumer valued the non-monetary health benefits at £1,112[65] (the midpoint of DECC's health benefit estimate resulting from solid wall insulation, see section 4.3) this would still leave an extremely large gap between the Ceiling Price and net cost to the consumer, as illustrated in Figure 28. Fundamentally, the value to the DNO is simply too low compared to the other costs and benefits involved to make much difference.

65 And assuming that there was no rebound effect.

Figure 28 DNO net value (including illustrative value of non-monetary benefits) – Gunnislake CMZ



Source: Frontier Economics

The more targeted measures fare better, however there is still a gap of £1,417 between the DNO Ceiling Price and the net cost to consumers. The Ceiling Price would still need to increase by nearly thirty times without the non-monetary benefits, and by 7x if the illustrative value of the non-monetary benefits were included (see Figure 29). Given the spread of reinforcement costs shown in Figure 21, it seems very unlikely that there would be areas where the value of EE is this high.

Figure 29 DNO net value (including illustrative non-monetary benefits to consumers) – Gunnislake CMZ, intervention targeted at more cost-effective retrofits

Source: Frontier Economics

These results show that the value to the DNO of the types of EE interventions considered above will not be sufficient to incentivise the take-up of EE when it would not otherwise be installed. However, it may be possible for a DNO to obtain greater value for money by focussing on retrofits that would have been installed by consumers *at some point*, but too late to make a difference to the network.

This is since, from the DNO's perspective, an EE retrofit that the consumer would install after the network has already been reinforced has just as little benefit as one that would never have been installed. For example, in Gunnislake under 'best view' and without any EE interventions, reinforcement would be required in 2023. Any EE retrofits made by consumers in 2024 would therefore have no impact on DNO costs (since by that point the 'fit and forget' reinforcement would already have been carried out). But if the DNO was able to move such measures two years forward to 2022, they would be able to displace flexibility (and potentially defer reinforcement).

Bringing forward EE measures in this way will be associated with a much lower cost for consumers (the same amount of money is being spent, just earlier). In Table 3 below, this has been quantified by using the Green Book social discount rate of 3.5%. Note that this may significantly underestimate the perceived cost to consumers, who may in practice attach a higher value to deferring spending.

Table 3 DNO net value of bringing EE measure forward by two years (without considering non-monetary benefits to consumers)

DRIVER	ALL MEDIUM-PERFORMANCE PROPERTIES	ONLY CAVITY WALL AND SUSPENDED FLOOR INSULATION
Intervention cost	£497	£323
Discounted reduction in bills	£198	£291
Net cost to consumer	£299	£32
DNO Ceiling Price	£36	£52
Net value to DNO	**-£263**	**£20**

Source: Frontier Economics
Note: Units are in £ / Dwelling

As can be seen from the table above, the wider intervention still has no net value to the DNO. However the more targeted intervention does now have a small value of £20.

This illustrates how a DNO might be able to bring forward some types of EE measures in a way which is cost-effective. However the result is extremely sensitive to the assumptions that have been made:

- It is assumed that consumers will make a decision whether or not to take up the intervention based on a simple calculation of costs and benefits and a low discount rate. In practice, consumer decision-making will be far more complex than this, and consumers may place a higher value on delaying the cost of the retrofit than the social discount rate of 3.5% suggests. The costs and benefits of the intervention will also be far more uncertain than this. The following chapter explains some of the uncertainties that may exist.
- The result above does not include the non-monetary benefits of EE. The level of these benefits, and the extent to which consumers value them, adds another layer of uncertainty. For example, it is possible that some consumers would have installed the EE retrofits anyway, even without receiving a payment from the DNO. Such a payment would therefore be wasted.
- The assumption that households would carry out the retrofit in two years without the DNO's intervention is a best-case from the DNO's point of view. If households would not have carried out the retrofit until later than this, then the costs of bringing it forward would be higher.

Chapter 7 describes the implications of these findings for the implementation of an EE intervention.

5 Accounting for delays and uncertainties

Chapters 2 and 3 above described a process where a DNO's ceiling price for a particular EE intervention can be calculated. Using these techniques, a DNO could simply fund any interventions which cost less than the calculated Ceiling Price. As noted in chapter 4, the Ceiling Price is extremely low compared to the cost of the retrofits themselves, however the DNO might be able to make a difference in cases where the consumer would have installed the retrofits (but later) and if the retrofits in question are particularly high-value ones.

In practice this calculation is an oversimplification, as it treats EE interventions as a 'now or never' decision, when in some cases, it may be optimal to defer an intervention. This is since:

- The avoided costs of flexibility (the benefits of an EE intervention) will tend to rise over time as demand on a network increases and the volume of flexibility that needs to be procured increases. Due to the time value of money, it may therefore be preferable to delay investment in EE until the flexibility costs have risen higher.

- There are also uncertainties in the value of EE. For example, if demand growth is lower or higher than expected then an EE intervention may no longer be required and any money spent on it will have effectively been wasted. There may therefore be benefits to deferring the installation of EE until the benefits are more certain.

Both of these effects may reduce the Ceiling Price even further for an intervention *now* as they make it more attractive to carry out the intervention later.

This chapter sets out a simple framework which takes these issues into account. It estimates an adjusted Ceiling Price that DNOs can use to determine whether a given EE intervention is likely to represent value for money. Specifically, it:

- first calculates a Ceiling Price which accounts for the option to defer an investment in EE (the first effect above);
- describes the types of uncertainty which exist, how they can be represented and any actions which might minimise them;
- describes the types of analysis which can help make an optimal choice despite this uncertainty; and
- identifies how one such analysis ('least-worst regrets') can be used in practice to derive a Ceiling Price which incorporates both of the effects described above.

The results of this analysis are then used in chapter 6 to determine the distribution of benefits of EE interventions across NGED's network.

5.1 Calculating a Ceiling Price for EE that allows for deferral

As described above, the Ceiling Prices we have calculated so far implicitly assume that a DNO is making a 'now or never' choice. This section first unpacks the definition of the Ceiling Price to illustrate the assumption that is being made. A Ceiling Price that allows for deferral (while still assuming that the future value of EE is known with certainty) is then calculated.

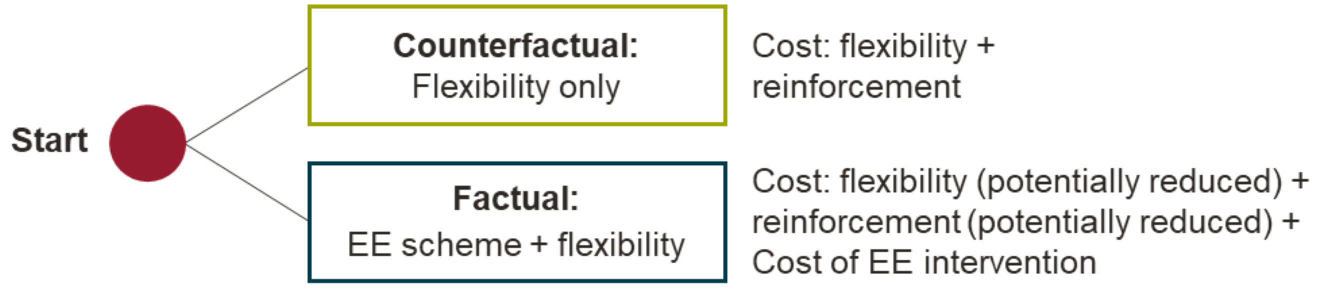
5.1.1 Ceiling value with no deferral

Using the approach taken in chapter 3, a DNO faces a single choice: It can implement an energy efficiency intervention *now*, or it can choose a counterfactual where it *never* implements the intervention.

Whichever choice is made, the DNO is assumed to undertake other actions as required to ensure the network does not exceed its headroom. This will involve the purchase of flexibility when necessary until the point at which it is more cost-effective to reinforce the network.

The DNO's decision is illustrated in Figure 30 below. Note that this only illustrates the decision whether or not to invest in EE – the decisions regarding how much flexibility and reinforcement to carry out are not explicitly shown.

Figure 30 Sample decision tree for whether to invest in EE



Source: Frontier Economics

If the cost of the EE intervention to the DNO was zero, then it would always be optimal to invest in it (as it will reduce at least some flexibility or reinforcement costs). However, if the cost of the EE intervention is too high (e.g. it is necessary to give a large grant to homeowners), then it would be preferable to not carry it out and to rely solely on flexibility and reinforcement. The Ceiling Price for the intervention is therefore the highest EE intervention cost for which the DNO still experiences an overall reduction in costs. This is equal to the total savings (reduced flexibility and reinforcement costs), which must be discounted to take account of the time value of money.

For example, in the CMZ Gunnislake, for a hypothetical intervention affecting 1,512 dwellings, these are the relevant figures:

- **Counterfactual:** In the Best View scenario, flexibility costs £31k in 2022, and it is optimal to reinforce in 2023, at a cost of £1,680k. The total cost of this strategy in NPV terms is therefore £1,711k.
- **Factual:** With the intervention, reinforcement can be deferred to 2026, saving £165k in NPV terms. Flexibility costs in a given year are reduced by 35% – 50%, and so flexibility in 2022 costs £14k less -

however, flexibility now has to be contracted for an additional 3 years (2023 – 2025), costing an additional £130k. The total cost of this strategy is therefore £1,657k[66], plus the costs of the EE intervention itself.

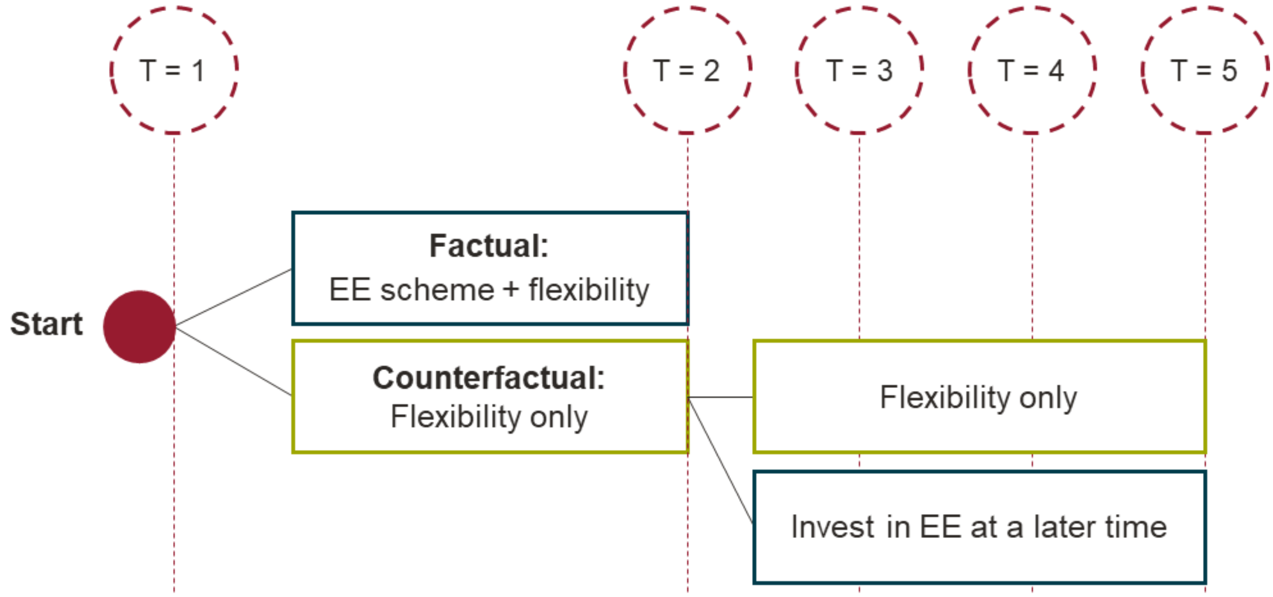
- **Value**: The EE intervention has an NPV of £54k (the difference between the factual and counterfactual). Dividing by the 1,512 dwellings gives a Ceiling Price of about £36 per home.

5.1.2 Ceiling Price with the option of deferral

In a real-world scenario, it may be optimal to defer EE rather than implementing it right away. This may be the case if the cost savings from reduced flexibility payments are initially quite low, which would be the case if demand only exceeds capacity for a small number of hours per year. Given the DNO's discount rate (which implies a greater cost for spending that occurs sooner), it could be more cost-effective to defer the EE intervention, relying on flexibility until demand (and therefore flexibility costs) rise and the costs of further deferral become too high.

The decision tree will now look like Figure 31 (again, for simplicity, this only shows the decisions relating to EE, and not reinforcement or flexibility). The investment in EE can happen in the first period, but it can also be deferred to any later period, or never undertaken at all ("Flexibility only" in the figure).

Figure 31 Sample decision tree



Source: Frontier Economics

It is optimal for a DNO to undertake an EE intervention now if the costs of doing so are lower than the present value of the costs of doing so at any point in the future. If the cost of the EE intervention were zero, then it would definitely be optimal to undertake it right away. However, if the cost of the EE intervention rises, then deferral is likely to look more attractive (since, due to the time value of money, it is better to wait to incur the

66 Note that these figures do not tally up exactly, due to rounding, as well as the NPV being calculated in the CEM which takes into account factors such as capitalisation rates and depreciation.

costs of an EE intervention until the avoided flexibility costs are higher. The Ceiling Price for undertaking EE *now* can therefore be calculated as the highest cost for which it is optimal to undertake the intervention now rather than later.

To provide an example, consider implementing the EE intervention in Gunnislake above, if this could be done at the Ceiling Price that was calculated in chapter 3 (i.e. at a cost of £36 per dwelling for around 1,500 dwellings), with certainty that the Best View scenario will come to pass. By examining the costs and benefits, it is possible to examine whether this is a low enough price to make it optimal to invest now rather than later.

Note that – as described in the preceding chapter – an intervention costing £36 per dwelling is extremely unlikely to make a difference to whether or not most properties install EE interventions. However this figure is used here as an illustration of how the possibility of deferral may affect the Ceiling Price.

As described above, the total reinforcement and flexibility costs of implementing the EE intervention today (the factual), in present value terms, are £1,096/dwelling (£1,657k). Adding the £36/dwelling for the EE intervention itself, this comes to a total of £1,132/dwelling. However, if the intervention is deferred by a year, the costs change as follows:

- A **saving** on the cost of EE – at a discount rate of 3.5%, the net present value of the cost of the intervention itself falls by £1.20/dwelling.
- A **cost** from flexibility – deferring EE means missing out on flexibility savings. This cost tends to be lower in earlier years (as demand and therefore the need for flexibility will generally grow over time). In Gunnislake, the additional flexibility cost (without EE) is £10.29/dwelling.

In this particular case, the costs of deferral exceed the savings. Therefore, if the EE intervention could be carried out for £36/dwelling, it is better to do this now rather than deferring it.

In general, this type of analysis can be used to calculate a cap on the Ceiling Price, above which it would be optimal to carry out the EE intervention later rather than now. For Gunnislake, we have calculated this cap is £305/dwelling: If the EE intervention cost more than this, then it would be better to defer it rather than carry it out now. However £305 is far above the £36 Ceiling Price, so such an expensive intervention would *never* be cost-effective.

Intuitively, the analysis in chapter 3 demonstrated that the value of EE interventions to the DNO are relatively low. Given this low value, the time value of money effect is relatively unimportant.

5.2 The impact of uncertainties

The analysis until now has assumed that there is no uncertainty. However, in practice, factors such as demand growth are uncertain. There is therefore a possibility that, even if a DNO spends no more than the calculated Ceiling Price for a particular intervention, circumstances change such that its overall costs are more (or less) than if it had not carried out the intervention at all, or had deferred it until later.

This section first describes the different sources of uncertainty, drawing on the analysis in chapter 3 to illustrate their impact on the effectiveness of EE interventions. Ways in which these uncertainties could be reduced are noted. It then illustrates the impact of these uncertainties on the decisions that a DNO must make. The following section describes the calculations that can be used to determine the best course of action, given this uncertainty.

5.2.1 Sources of uncertainty

Chapter 3 set out the key drivers of the value of an EE intervention. Some of these are relatively certain (e.g. the cost of reinforcement), or can be determined by the DNO (e.g. the scale of the intervention). However there are many significant uncertainties, which are summarised below.

Type of property and intervention

The broad types of property in an area are known, and a DNO could restrict an EE intervention to certain types of property and intervention. However the effectiveness of a given intervention on peak demand will depend on factors specific to a given property such as:

- the type of heating system (the intervention will only have an impact on peak demand if the household is using an electrically powered heating system);
- the nature of the property (e.g. the presence of certain types of construction which may increase heating requirements and may not be obvious);
- the behaviour of the occupier (e.g. the 'rebound effect' described in chapter 4, as well as how often and when the property is heated);
- how the retrofit is installed (a 'performance gap' is commonly observed where the additional insulation has less impact than predicted); and
- whether the property would have been retrofitted in the absence of DNO intervention (in which case the money is effectively wasted).

For a given property these uncertainties are likely to be very material. However, providing the EE intervention consists of a relatively large number of properties, experience implementing these types of interventions may enable DNOs to make a better assessment of the average impact of an intervention.

The rate of demand growth

When considering demand growth, there is a 'sweet spot' for which the value of EE is maximised. If the rate of demand growth is 'too slow', then there may never be a requirement for significant amounts of flexibility or reinforcement, and so EE will be of little value. However if the rate of demand growth is 'too fast', then reinforcement will be needed soon regardless of any EE intervention, which will again reduce its value.

The DFES scenarios used by NGED and other DNOs provide some indication of the uncertainty in demand caused by different trajectories for the take-up of technologies such as heat pumps and electric vehicles. However these are based on ESO's national FES scenarios and are likely to understate the level of uncertainty in a local area, which will be affected by local take-up of these technologies as well as events such as the construction of new housing estates or business parks.

This uncertainty will be greater the further out forecasts are made. It will always exist, although it will be especially significant while it is unclear what mixture of heating technologies (e.g. heat pumps or hydrogen boilers) will be adopted in a particular area. More sophisticated forecasting may reduce, but will not eliminate, these uncertainties.

Availability of flexibility

As with demand growth, there is a 'sweet spot' of the impact of flexibility availability on the value of EE interventions. If flexibility is widely available and cheap, then it may displace the need for EE. However if flexibility is very limited or expensive, it may mean that reinforcement is required too soon for EE to have a high value.

There may be more that can be done to reduce this uncertainty. For example, DNOs could experiment with over-procuring flexibility to determine how much supply exists, and using modelling to forecast available flexibility based on the types of local businesses in the area. However there will still be a large element of uncertainty, as the availability of flexibility may often be dependent on the decisions of a relatively small number of firms in the local area which have the capability to provide significant amounts of flexibility.

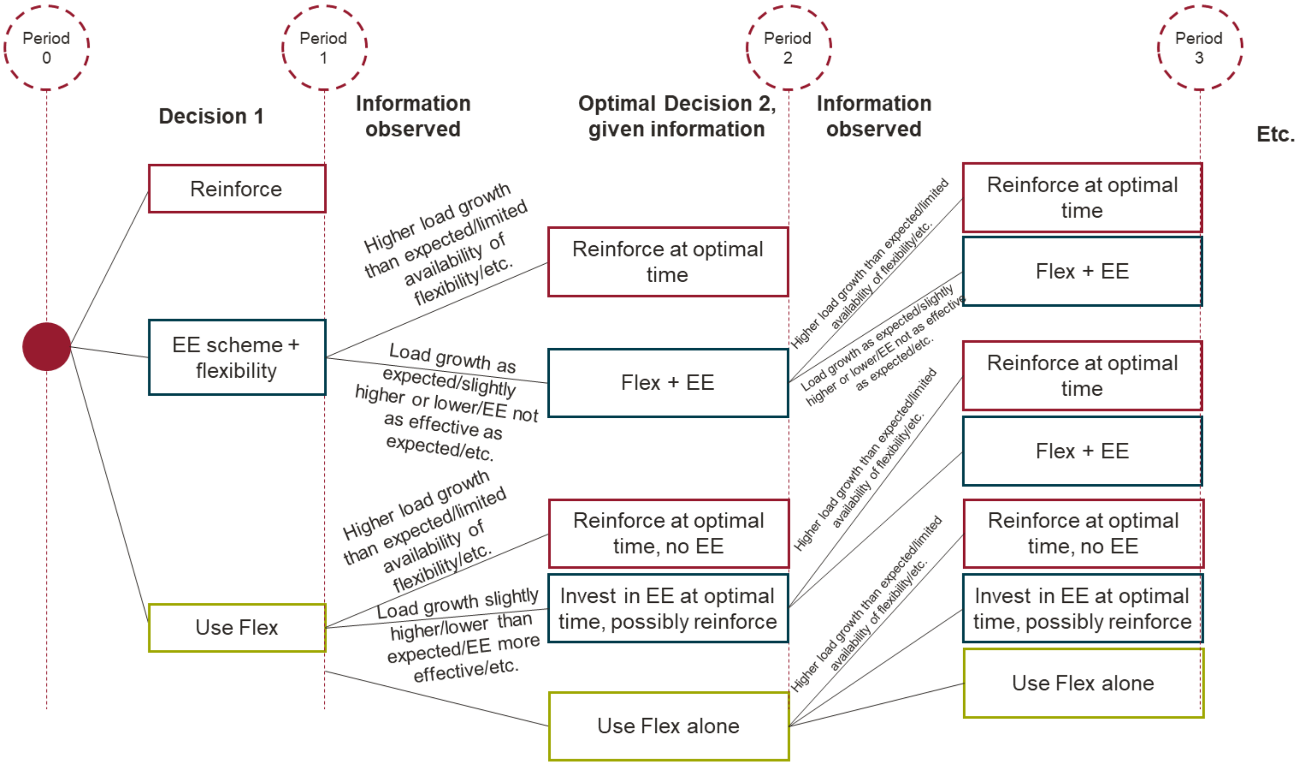
5.2.2 Accounting for uncertainty

These types of uncertainties can be modelled in a more complex decision tree:

- First, the choices available to the DNO at the present time are listed – for example whether to invest in energy efficiency, reinforce, or do neither.
- Next, for each DNO choice, a set of scenarios are provided that show how the uncertain factors could evolve over a short timeframe (such as a year). Each scenario is associated with a probability.
- The DNO can then make another choice, given the light of this new information.
- The following period, additional scenarios may be possible, and the DNO can then make a further set of choices.

This is illustrated in Figure 32. However such a decision tree quickly becomes unmanageable, as it must keep track of every combination of uncertainties, at every point in time. While a complex decision tree could be modelled in software, this would be a 'black box', and the aim of this project is to produce a pragmatic way of choosing how much to invest in EE which can be easily understood and utilised.

Figure 32 Sample comprehensive decision tree



Source: Frontier Economics

The decision tree can be simplified in two ways: reducing the number of time periods can be reduced, and reducing the number of scenarios that are considered.

The time periods have been reduced by modelling only two DNO decisions: One taken now under uncertainty, and one taken in the future, once the uncertainty has been fully resolved. The results of this type of model will be sensitive to when the uncertainty is assumed to be resolved and the DNO can make its second decision:

- If this is very early (e.g. after just a year) then the model will favour flexibility over reinforcement and energy efficiency. This is since only a year's worth of flexibility needs to be procured in order to make a decision with perfect information. However, in reality, it is doubtful that the DNO will be in a much better position to make a decision by then. The model is therefore likely to over-state the value of flexibility.
- If this is very late, then the DNO is assumed to be locked in to a strategy well beyond the point when it may become obvious that an alternative is required. Such a model would likely under-state the value of flexibility.

For the modelling below, it is assumed that new information is available and the DNO's second decision takes place after four years (2026). This aligns with the typical maximum duration of a flexibility contract, which we understand can be anywhere between 1 and 4 years.[67] Thereafter, investment decisions can be taken in any

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67 This four-year window was also used in the real options model constructed for SSEN. See Frontier Economics (2020) "*Evaluating Flexibility as alternative to Traditional Network Reinforcement*".

year – so for example, when contracting flexibility in year 0, this decision ‘sticks’ until year 4, and then EE and/or reinforcement can be implemented in any future year after this.

The other simplification is to reduce the number of scenarios that are considered. The most appropriate scenarios will depend on the process used to determine the DNO’s decision, and this is discussed in section 5.3.2.

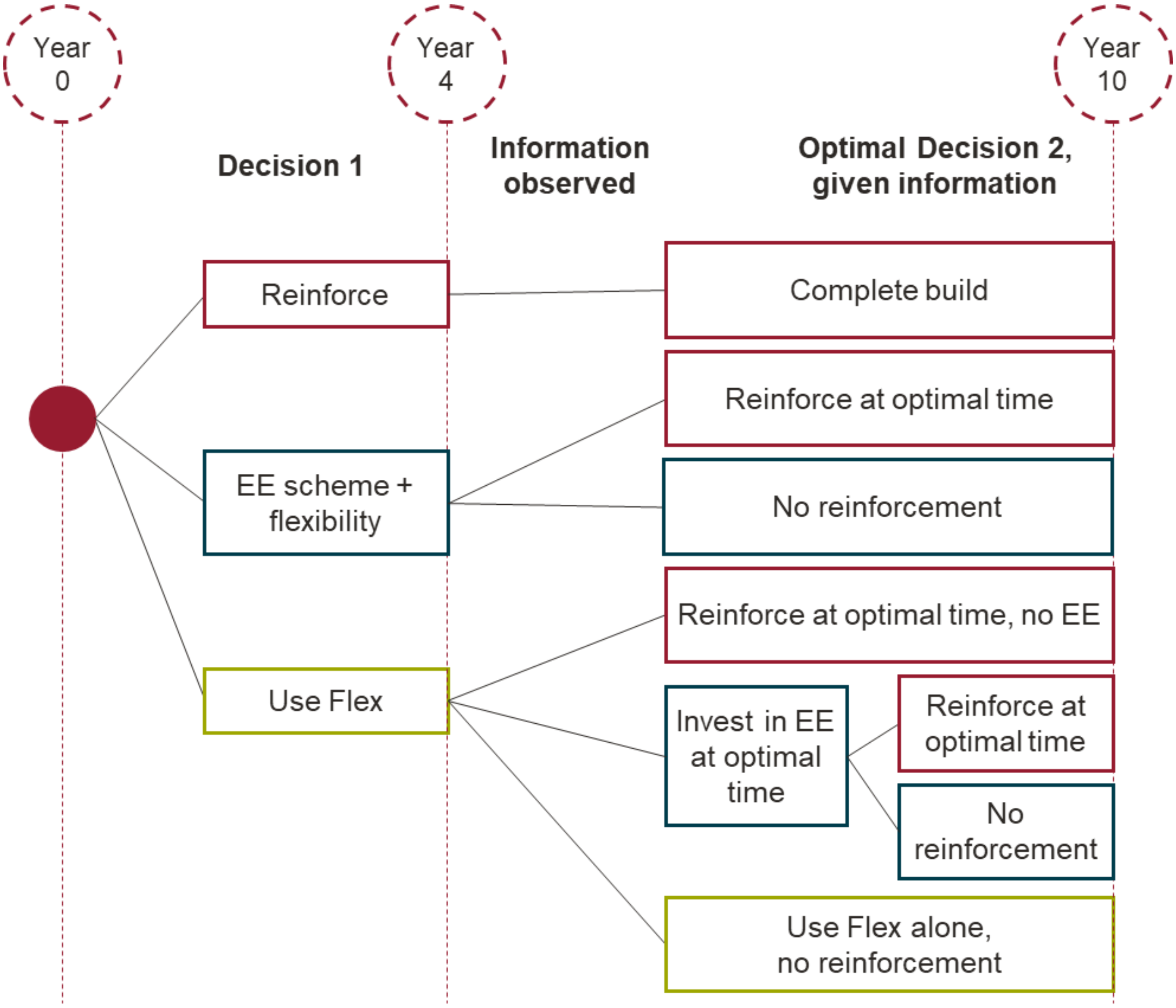
The resulting decision tree is shown in Figure 33. The DNO’s immediate decision (shown as occurring in 2022, and therefore in conditions of certainty) is to decide between three initial investments:

- **Reinforce the network**. It is assumed that this is a ‘fit and forget’ reinforcement which means that no further procurement of flexibility or EE will be needed in any scenario.
- **Procure energy efficiency**. To the extent to which this is insufficient to ensure that the network remains within its headroom, flexibility will also be procured.
- **Use flexibility only**.

After four years (shown as 2026), it is assumed to become apparent which scenario has taken place. The DNO can now make a further decision, this time under certainty, between:

- Reinforce the network (at the optimal time from 2026 onwards, using flexibility only until then).
- Procure energy efficiency (at the optimal time from 2026 onwards), and possibly reinforce later (at the optimal time from 2026 onwards).
- Use flexibility only, never reinforcing or procuring energy efficiency.

Figure 33 Simplified decision tree



Source: Frontier Economics

The following section describes how this decision tree can be 'solved' to determine the amount a DNO may wish to pay for energy efficiency now, given the uncertainties.

5.3 A framework to account for uncertainty in decision-making

The aim of this analysis is to calculate the Ceiling Price for a given EE intervention – i.e. the maximum amount the DNO would be willing to pay for it. As in section 5.1.2, this requires a model that can determine whether or not investing in EE now is optimal for a given intervention cost. The intervention cost can then be increased until it is no longer optimal to invest in it (i.e. the costs exceed the benefits).

This section first describes the analysis ('least-worst regrets') used to determine decision to take. It then sets out how scenarios can be chosen for use with this analysis. The following section applies this framework to determine a Ceiling Price for an EE intervention.

5.3.1 Determining the optimal decision under uncertainty

Once the problem has been set out in a decision tree, there are a number of different ways of 'solving' it to determine the optimal decision to be taken now.[68]

The most intuitive approach is to pick the action with the lowest expected cost. A process of backwards induction can be used to do this, where the model first finds the optimal decision in the last period, under each scenario. 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. The example below describes how this works for a simpler case.

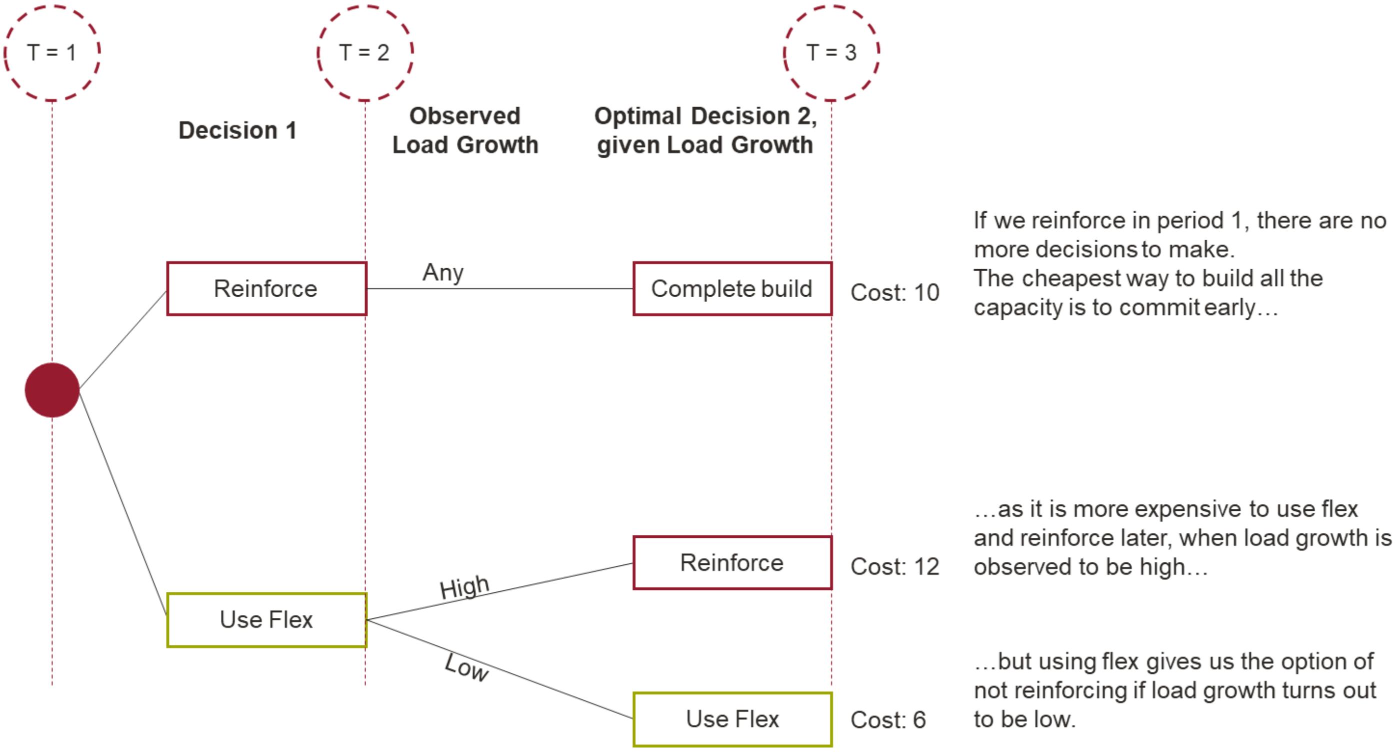
Simple Example with two scenarios and two strategies

In this example, the DNO faces two load growth scenarios ('high' and 'low') and can carry out two actions now – reinforcing the network, or using flexibility. Reinforcing now means no further decisions need to be made, at a cost of 10. When using flexibility initially, no reinforcement is necessary if load growth turns out to be low (at a total cost of 6), but if load growth is high and reinforcement is necessary, total costs to do so are higher (12) than if reinforcement had happened straight away.

The decision tree looks as follows:

68 National Grid ESO's "*Network Options Assessment Methodology Review"* describes a number of alternatives.

Figure 34 Example decision tree for LWR



Source: Frontier Economics

The least-worst approach then works as follows.

- First, the final costs of each combination of initial decision & scenario are calculated, assuming the DNO decides optimally once the true state of the world has been revealed. This is shown in the table on the left of Figure 35.
- Within each of the two scenarios, the approach assesses which initial decision would have been best (i.e. lowest-cost).
  - Under the 'low' scenario, this would be to choose flexibility, which in this example has a cost of 6.
  - Under the 'high' scenario this would be to immediately reinforce, which as a cost of 10.
- 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 calculated regret figures (cost of decision taken, minus minimum cost under the scenario) are shown in the right side of Figure 35.
  - By definition, the regret is zero for the two lowest-cost decisions noted above.
  - Under the 'low' scenario, reinforcement has a regret of 4. This represents the cost wasted in carrying out reinforcement which will not be required.

- Under the ‘high’ scenario, flexibility has a regret of 2. This represents the cost wasted in procuring flexibility, when reinforcement would ultimately be required.

- The ‘worst regret’ of a decision is calculated as the greatest regret across all scenarios for that decision. This is shown on the right-hand column of the table below.

- The approach then chooses the strategy which overall will cause the least worst regret across all possible scenarios. In this case, this is to carry out flexibility.

Figure 35 Least worst regrets – simplified example

Cost based on initial decision

Initial Decision	High	Low
Reinforce	10	10
Flex	12	6

Regret

Initial Decision	High	Low	Max
Reinforce	-	4	4
Flex	2	-	2

Within the high scenario, reinforcing is the least costly decision. Using flex initially costs 2 more, hence regret is “2”. Equivalently for “low”, reinforcing carries regret of 4.

Across all scenarios, using flex initially entails a maximum regret of 2, whereas reinforcing carries a maximum regret of 4. Using flexibility initially hence is the optimal decision.

Source: Frontier Economics

The advantage of this approach is that probabilities do not need to be assigned to each scenario. The next section applies this approach to the EE decision.

5.3.2 Designing scenarios

The choice under LWR is driven by the scenarios where particular choices are not well suited and are therefore associated with a high ‘regret’. High regret may occur for EE interventions if:

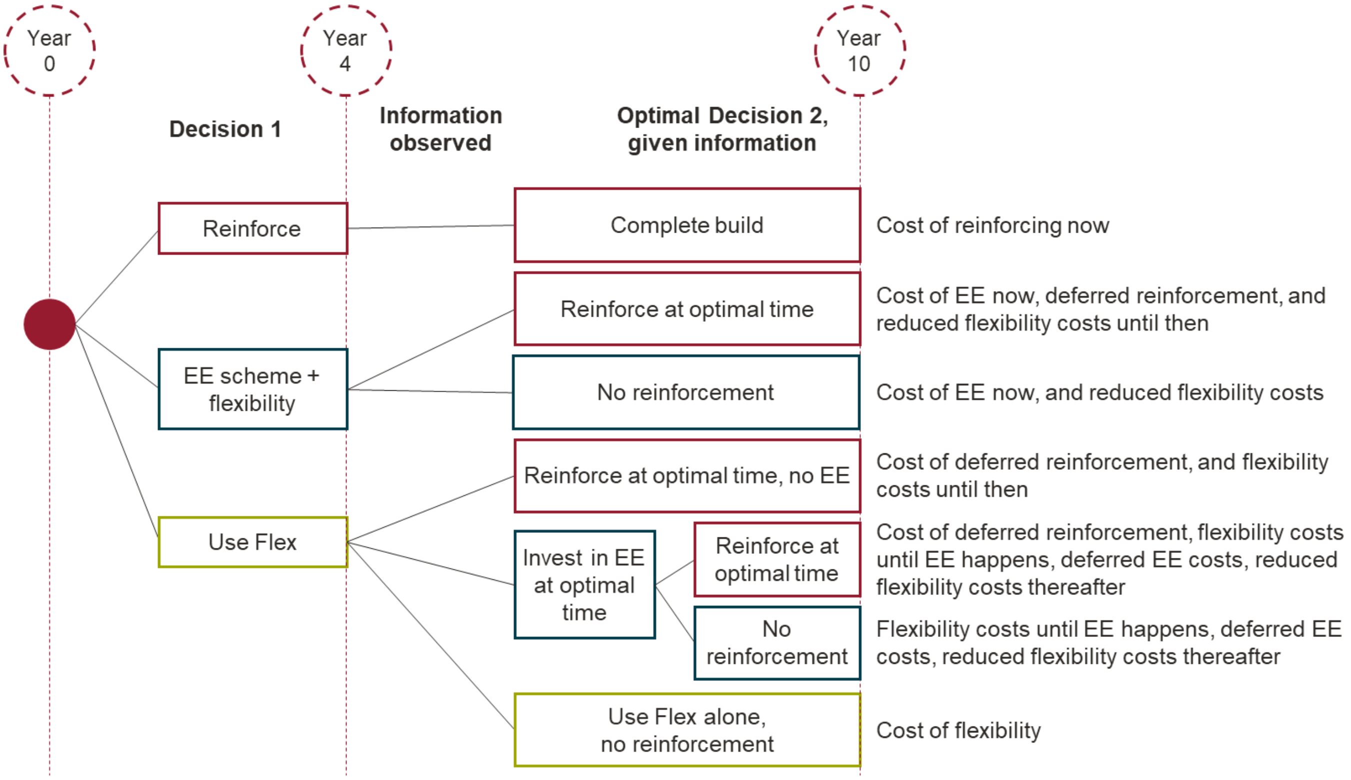
- once uncertainty resolves, it turns out reinforcing sooner would have been optimal, for example because growth is very high (or EE is not very effective), or
- once uncertainty resolves, it turns out that it would have been optimal to use flexibility alone, or do EE later, for example because load growth is very low (or EE is not very effective)

To capture these ‘high regret’ scenarios, the DFES scenarios used by NGED to account for uncertainty are used. While these scenarios have the advantage of already being in use, they not cover all uncertainties – growth might be even higher or lower, or EE might be less effective, etc. To capture this, a sensitivity is run further down in Gunnislake, using four additional growth paths, based on the DFES growth rates.

5.3.3 Decision tree

The resulting decision tree looks as follows.

Figure 36 Decision Tree underlying LWR approach



Source: Frontier Economics
Note: Year 0 = 2022, year 4 = 2026, year 10 = 2032

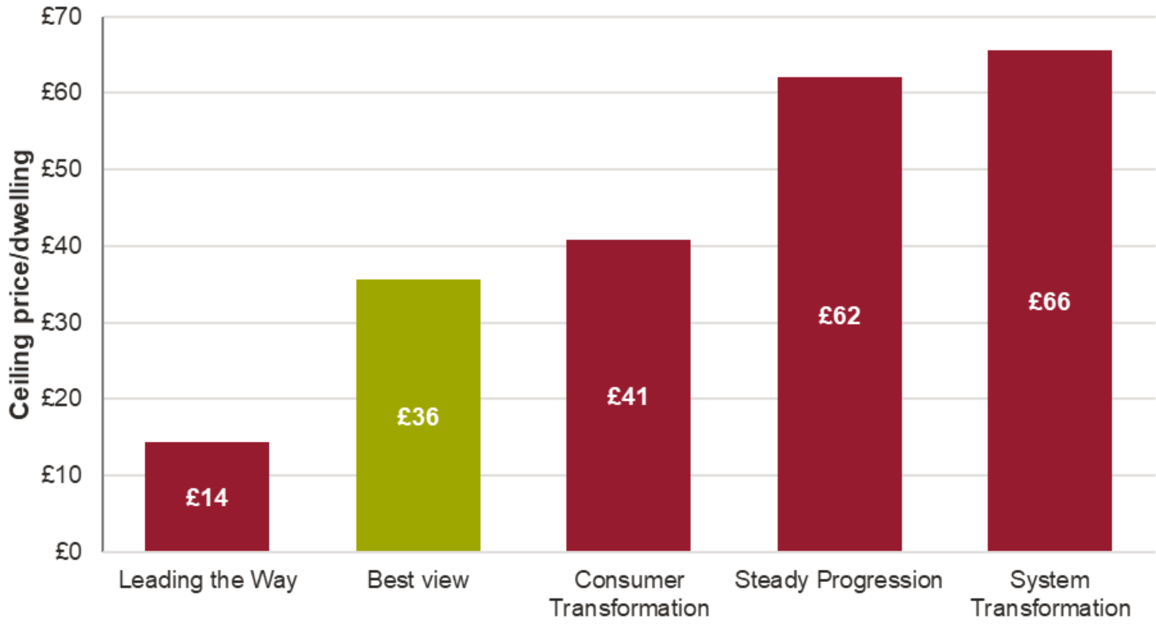
Note that the framework assumes that uncertainty will resolve during the first decision period (4 years), as discussed above.

5.3.4 Least worst regrets applied to one sample CMZ

The methodology is shown with the example of the CMZ Gunnislake, using the DFES scenarios. The initial decision is pursued for four years, and then the optimal decision is made.

Figure 37 illustrates the resulting value for a ‘now or never’ EE intervention under certainty for each scenario. This ranges from £66/dwelling under the slowest demand growth scenario, to £14/dwelling under the highest.

Figure 37 Value of EE per scenario



Source: Frontier Economics

The uncertainty model operates as follows. For each of the three strategies (flexibility only, EE first, or reinforce first), the model determines the total costs under each future scenario.[69] This involves using the CEM to identify the optimal year to reinforce and the optimal amount of flexibility to procure.

This is first carried out assuming that the EE intervention is costless. The model calculates the regret associated with each combination of strategy and scenario, and therefore identifies the least-worst regret strategy. In Gunnislake, this looks as follows:

69 To simplify the calculations, three scenarios have been used: Best View, along with Steady Progression and Leading the Way, the latter two of which represent the slowest and fastest demand growth rates.

Table 4 Costs, and optimal decision with £0 cost of EE

	Steady Progression*	Best View	Leading The Way	Highest Regret
Flexibility only first	Cost = £1,693k Regret = £78k	Cost = £1,745k Regret = £88k	Cost = £1,815k Regret = £111k	£111k
EE first	Cost = £1,615k Regret = £0 *(best strategy for this scenario)*	Cost = £1,657k Regret = £0 *(best strategy for this scenario)*	Cost = £1,704k Regret = £0 *(best strategy for this scenario)*	£0k
Reinforce first	Cost = £1,736k Regret = £121k	Cost = £1,736k Regret = £79k	Cost = £1,736k Regret = £32k	£121k

Source: Frontier Economics

This shows that when the EE intervention is free, EE is the optimal (i.e. lowest-cost) decision under all scenarios. EE first is therefore also the optimal decision under LWR, as it has the lowest 'highest regret' (£0k).

The model then increases the cost of the EE intervention, which will also increase its associated regret. The model calculates **the largest EE intervention cost for which EE remains the optimal LWR choice**. In Gunnislake, this is £77k, or £51/dwelling. At this level of EE intervention cost, the matrix looks as follows:

Table 5 Optimal decision & cost with LWR cost of EE

	Steady Progression	Best View	Leading The Way	Highest Regret
Flexibility only first	Cost = £1,709k Regret = £17k	Cost = £1,745k Regret = £12k	Cost = £1,815k Regret = £79k	£79k
EE first	Cost = £1,692k Regret = £0 *(best strategy for this scenario)*	Cost = £1,733k Regret = £0 *(best strategy for this scenario)*	Cost = £1,781k Regret = £45k	£45k
Reinforce first	Cost = £1,737k Regret = £45k	Cost = £1,736k Regret = £3k	Cost = £1,736k Regret = 0 *(best strategy for this scenario)*	£45k

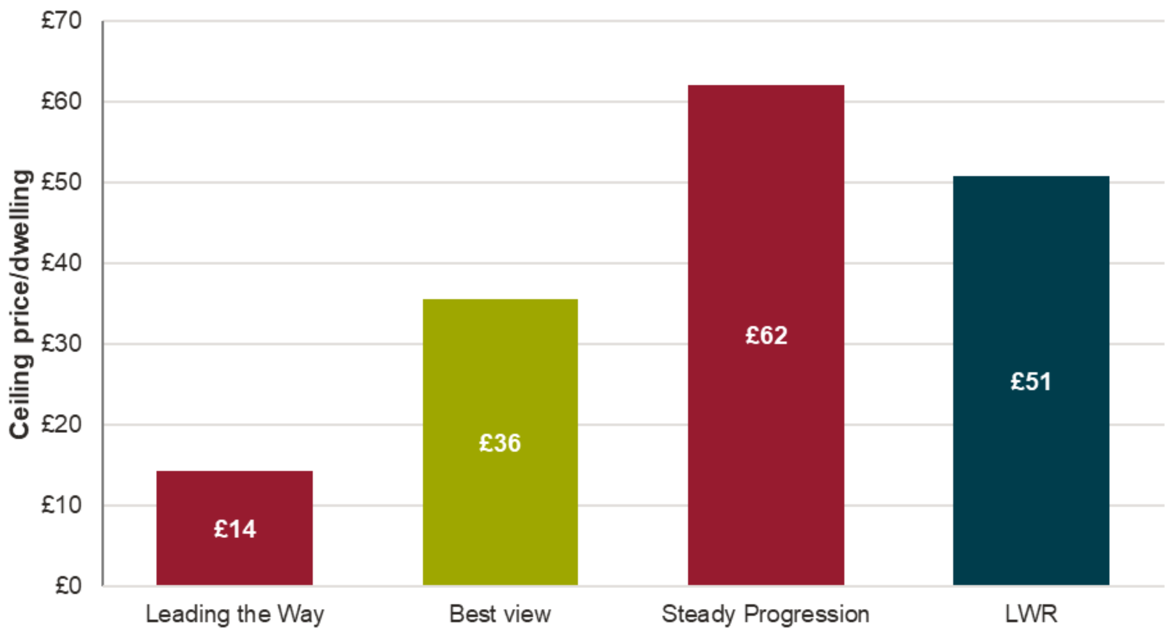
Source: Frontier Economics

Looking within scenarios (by column): EE first is the optimal decision under Steady Progression (the slowest-growth scenario) and Best View. Under the high-growth scenario, Leading The Way, it is optimal to reinforce straight away.

The worst regret associated with the EE first strategy is just under £45k (this is associated with picking this strategy under Leading the Way, when it would be optimal to reinforce first, as the fast growth in demand means that reinforcement will be required soon even if an investment is made in EE). This is just below the worst regret associated with Reinforce First (due to reinforcing first under Steady Progression, when it would be optimal to invest in EE). If the amount paid for the EE intervention was any higher than £51/dwelling, then the worst regret associated with EE first would be higher.

This 'LWR Ceiling Price', £51, is higher than the Ceiling Price under Best View (and between the Ceiling Prices under the other two scenarios), as illustrated below.

Figure 38 LWR compared to Ceiling Price (Best view) and other scenarios



Source: Frontier Economics

To determine how sensitive the analysis is to the scenarios used, a further analysis was carried out where additional demand growth rates scenarios were added which were 50% slower than Steady Progression, and 50% faster than Best View. The LWR Ceiling Price for EE fell from £51 to £40: With more uncertainties in demand, the option value provided by flexibility will be more valuable compared to investment in EE. However this shows that, even under a much wider range of uncertainty, the LWR Ceiling Price is not substantially lower.

5.3.5 Least worst regrets applied to a selection of CMZs

The methodology described above has been used to calculate LWR Ceiling Prices for a selection of CMZs which have a variety of Best View Ceiling Prices. Table 6 shows the Ceiling Prices and the percentage difference between them.

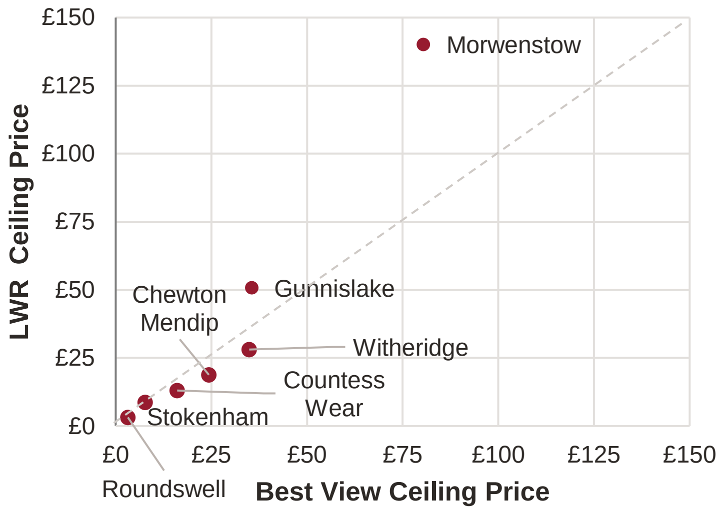
Table 6 LWR Ceiling Prices across CMZs

CMZ	A: Best View Ceiling Price (£/dwelling)	B: LWR Ceiling Price (£/dwelling)	Diff. between A and B (%)	Years to reinforcement (no EE)
Countess Wear	£16	£13	-18%	6
Chewton Mendip	£24	£19	-23%	6
Gunnislake	£36	£51	42%	1
Morwenstow	£80	£140	74%	3
Witheridge	£35	£28	-20%	8
Roundswell	£3	£3	0%	7
Stokenham	£8	£9	13%	5

Source: Frontier Economics

There is a clear correlation between the Best View and LWR Ceiling Prices, as shown below in Figure 39. This is since, as described in Chapter 3, reinforcement cost is the fundamental driver of the value of EE – and this holds true under the LWR methodology too. Indeed, there is no statistically significant difference (at the 10% value) between the two Ceiling Prices.

Figure 39 LWR and Best View Ceiling Price for a selection of CMZs



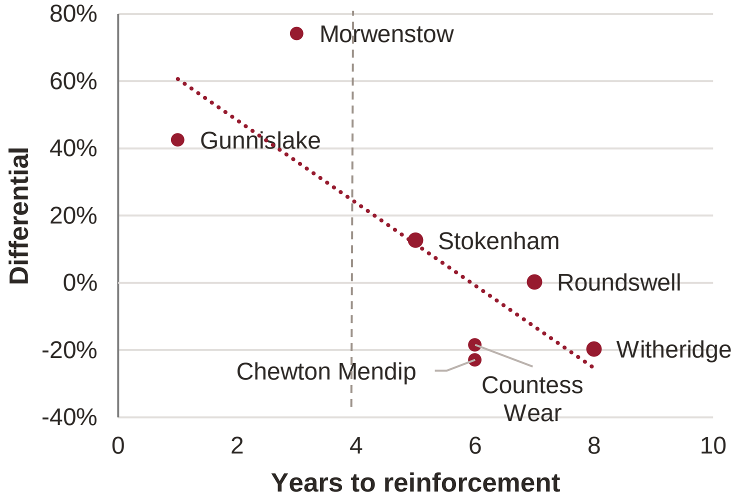
Source: Frontier Economics
Note: LWR run on 7 CMZs in the South West

However there is some noise around this relationship. For example, as described above, Gunnislake has a LWR Ceiling Price around 42% above the Best View Ceiling Price. On the other hand, Witheridge has a LWR Ceiling Price that is about 20% below the Best View Ceiling Price.

In general, The LWR Ceiling Price tends to be a lower share of the Ceiling Price when reinforcement (without EE) is optimal further in the future. This is as, when reinforcement is not required for some time, flexibility alone can 'buy' a longer delay, and therefore has a higher option value. However, as the need for reinforcement approaches, the option value of flexibility becomes of less value. EE (which, due to its up-front costs has less option value in the first place) therefore becomes a relatively more attractive option. This is the situation that applies in Gunnislake: because reinforcement is due soon, flexibility does not hold much option value, and so the LWR Ceiling Price exceeds that calculated under LWR.

The relationship between years to reinforcement and the gap between the two Ceiling Prices is shown in Figure 40.

Figure 40 LWR Ceiling Price relative to years to reinforcement (Best View, flexibility only)



Source: Frontier Economics

Note: Years to reinforcement refers to optimal time to reinforce according to the CEM, with no EE intervention,

6 Value present on NGEDs network

The analysis in the previous chapters has shown how to calculate a Ceiling Price which represents the maximum amount which a DNO may be willing to pay for an EE intervention. It has also shown how this Ceiling Price may be affected by uncertainties, and how to use Ceiling Price together with costs/benefits realised by individual consumers to determine if there is a net value in an EE intervention.

This chapter brings those together to provide a high-level estimate of the proportion of NGED's CMZs where there may be value from EE interventions.

6.1 Methodology

It would be impractical to run all of NGED's CMZs through both the CEM and FAT tools to produce a Ceiling Price for each. Ceiling Prices have therefore been estimated using the linear relationship between the Ceiling Price and reinforcement costs under the 'Best view' scenario from a selection of 8 South Western CMZs (see Figure 21).

Those Ceiling Prices do not directly take into account the impacts of delays and uncertainties described in chapter 5. However, as described in the preceding chapter, the Ceiling Price calculated using the LWR methodology is on average very similar to that calculated simply assuming 'Best View'.

The resulting Ceiling Price figures for each CMZ can then be compared to the net costs to the consumer (without non-monetary benefits) quantified in chapter 4 to illustrate whether the amount of money that the DNO could make available might be enough to allow the EE intervention to take place.

As noted in chapter 4, the broader EE intervention upgrading all 'medium' efficiency houses to 'high' is unlikely to provide sufficient value to the DNO in any CMZ. The EE intervention assessed here therefore consists only of the most cost-efficient measures (i.e. suspended floor and cavity wall insulation) identified in chapter 3.

Lastly as noted in chapter 4, the WS1 profiles assume no change in consumer behaviour following the increased heating efficiency caused by the installation of the EE measure. To account for this change a rebound effect of 20%[70] was tested, by lowering the Ceiling Price by 20%. However, this had a minimal effect on CMZs achieving value from an EE intervention. The EE interventions' assessment here is therefore based on the Ceiling Prices without the direct rebound effect.

6.2 Results

This analysis has first been carried out on the basis that the DNO must incentivise consumers to take up EE measures that would never have been carried out without the additional intervention. However, as described in chapter 4, the typical Ceiling Prices will generally be so low in relation to the costs to the consumer that they would not be expected to make an impact. A second set of analysis has therefore focussed on the case

70 The mid-point of long-run direct rebound effect for space heating in OECD countries.

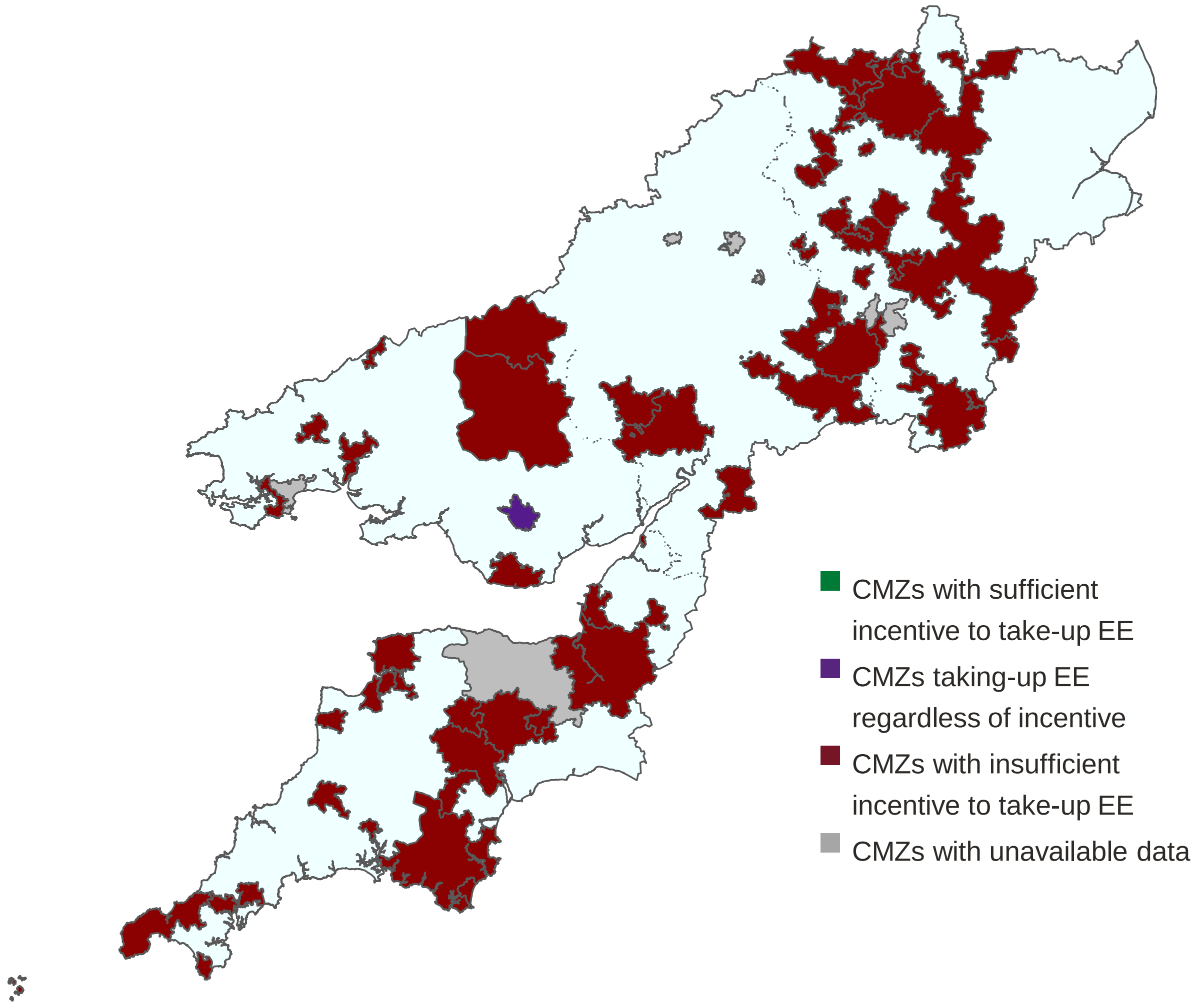
where a DNO is only attempting to bring forward EE measures that would otherwise have been installed in a couple of years. This makes it more likely that the limited funds available to the DNO can make a difference (although the proportion of properties expecting to carry out EE measures in such a short timeframe will be

6.2.1 Value to the DNO of bringing forward EE measures that consumers would not have installed

Figure 41 shows all 68 current NGED CMZs (data was unavailable for seven, shown in grey). There are no CMZs where the Ceiling Price is sufficient to provide consumers with an incentive to take up EE measures (and where they would not have done so absent the EE intervention).

There is one CMZ (Mountain Ash) highlighted in purple where benefits of EE to consumers are already calculated as outweighing the costs. This is due to the smaller average size of properties in this area: The EE data from Workstream 1 suggests that these consumers in these types of property will tend to have a greater net benefit from EE measures. However in this case there is no additional benefit for the DNO to incentivise EE uptake.

Figure 41 Map of CMZs by intervention effectiveness



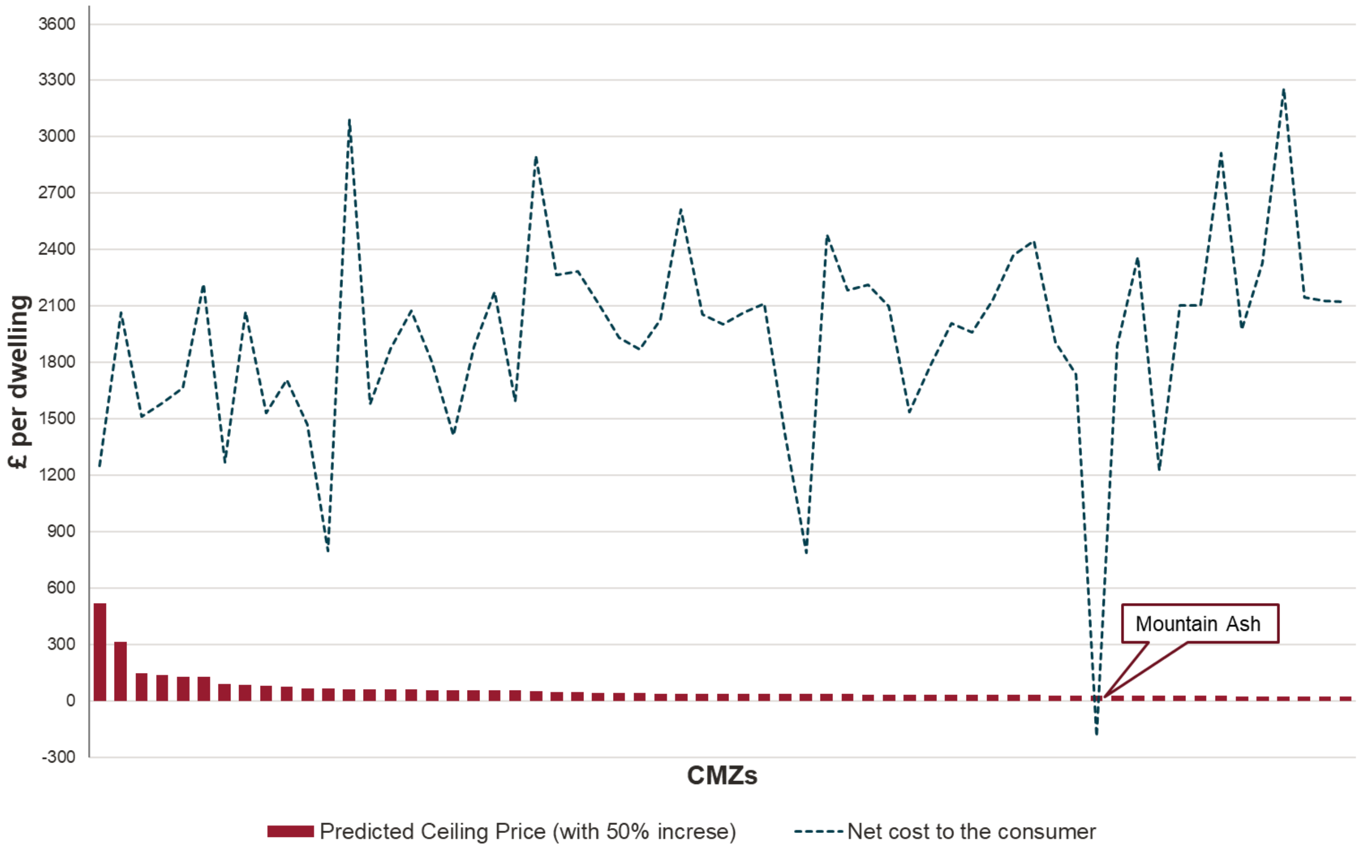
Source: Frontier Economics

This demonstrates how, due to the relatively low level of the Ceiling Price compared to the costs and benefits of EE interventions, the value to the DNO is unlikely to make the difference between whether or not measures are installed. Either there will continue to be insufficient incentives for consumers to take up EE measures *after* the DNO intervenes (as is the case in the majority of the areas shown above), or they might do so *regardless* of the DNO intervention (as in the case of Mountain Ash).

Clearly, there are a vast number of uncertainties, not least the value that consumers place on non-monetary benefits or costs, and so the results in the map 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.

Figure 42 below demonstrates this by showing the Ceiling Price and net costs to the consumer.

Figure 42 Predicted Ceiling Price vs. Net cost to the consumer



Source: Frontier Economics

As described in the preceding chapter, 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.

Figure 40 in the previous chapter showed how, in CMZs close to needing reinforcement, the LWR Ceiling Price tended to be around 50% higher than the Best View Ceiling Price. As a rough estimate of how high the

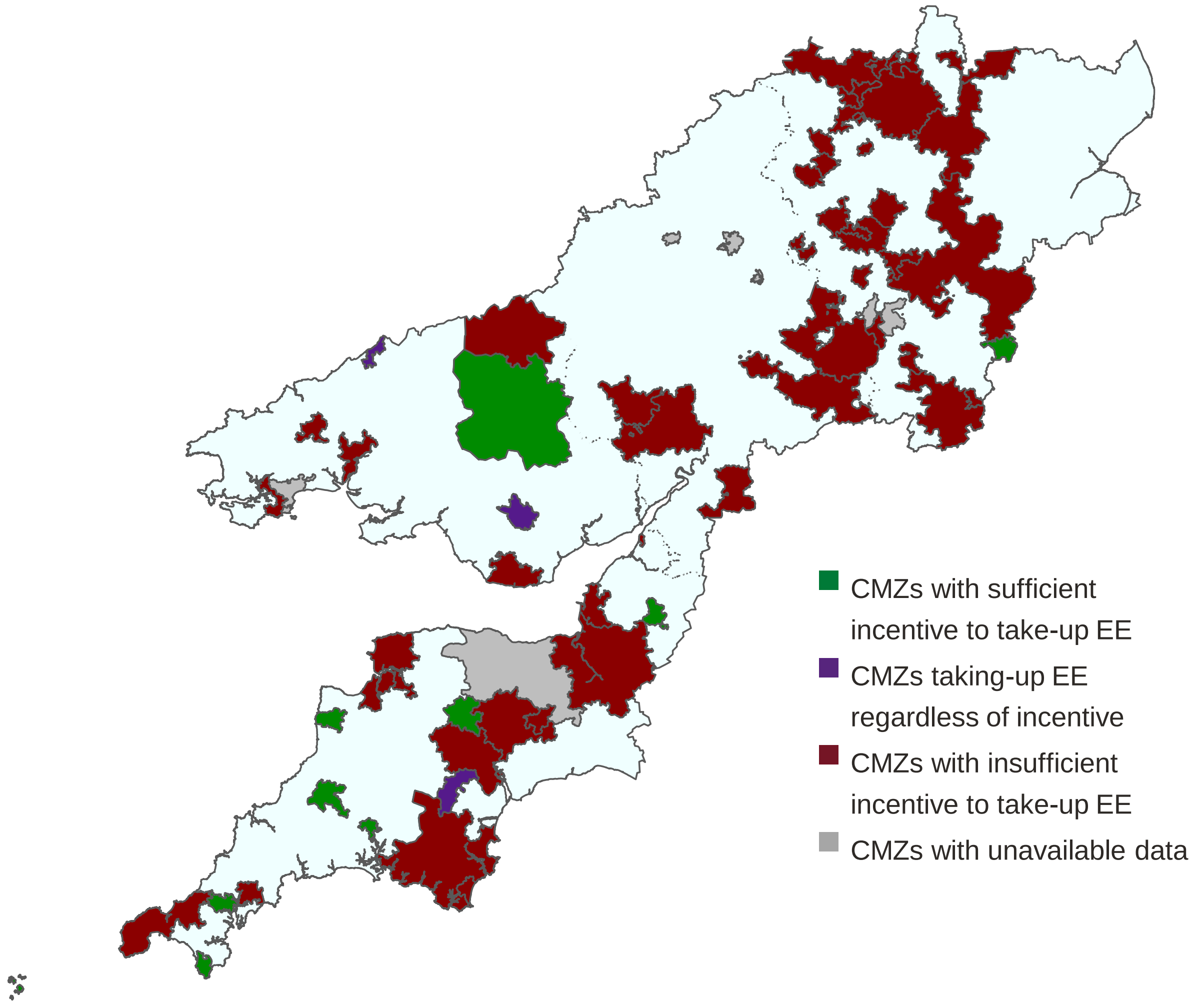
LWR Ceiling Price might be in CMZs *at the point in the future when it is highest*, the Best View Ceiling Prices have been scaled up by 50%. However, even with this scaling, there are still no CMZs where the Ceiling Price is shown as making a difference to the take-up of EE.

6.2.2 Value to the DNO of bringing forward EE measures that would have been installed two years later

As described in chapter 4, it may be possible for a DNO to obtain greater value for money by focussing on interventions that would have been installed by consumers, but too late to make a difference to the network. To illustrate a best-case scenario, we have considered the net cost to consumers if the EE intervention only needed to bring forward installation of measures by two years, and where this cost is 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 16% of all CMZs. These are highlighted in green in Figure 43.

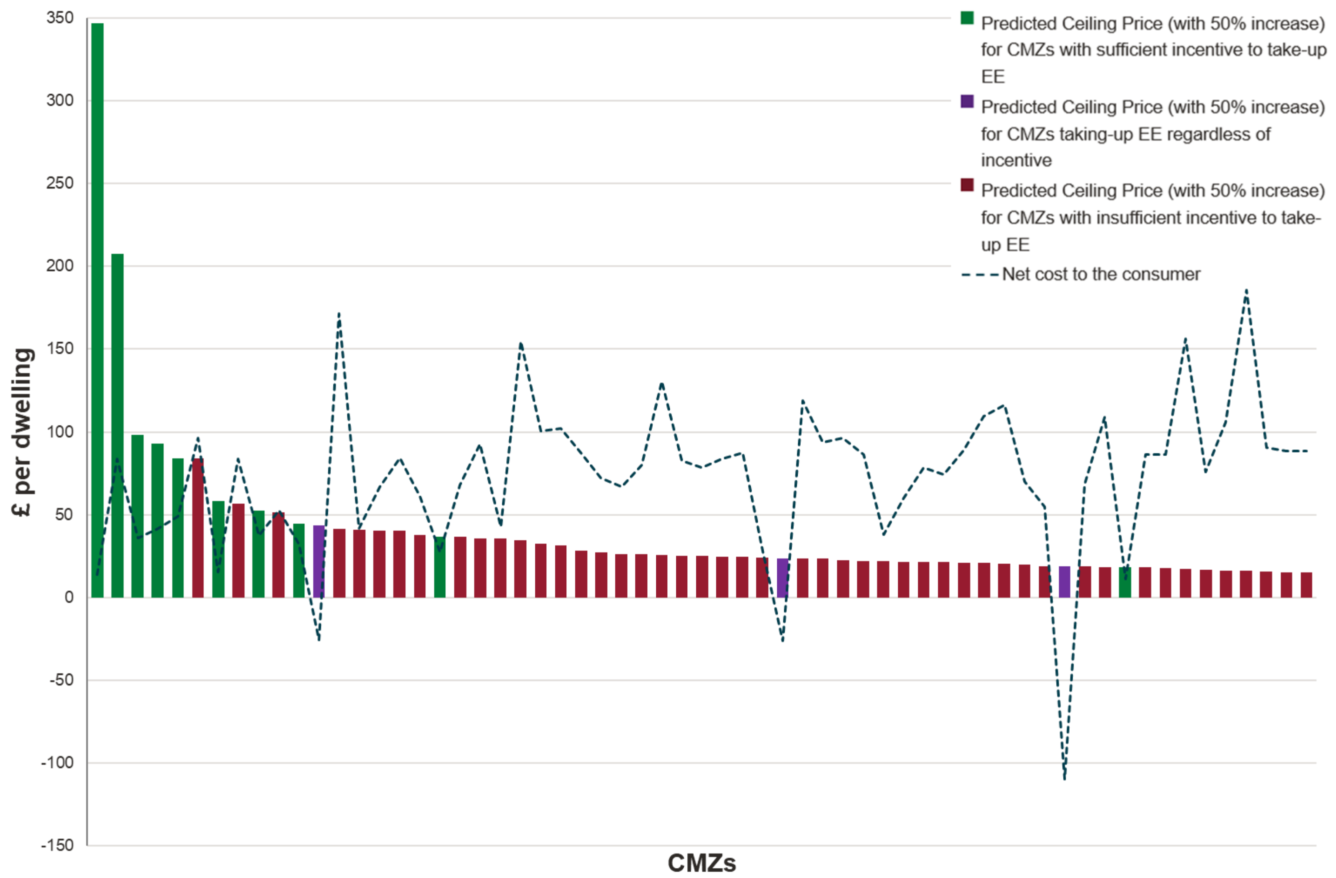
Figure 43 Map of CMZs by intervention effectiveness (bringing forward EE by 2 years)



Source: Frontier Economics

Figure 44 below illustrates the Ceiling Price and net costs to the consumer for these CMZs. Consumers in three CMZs (Aberaeron, Moretonhampstead and Mountain Ash) highlighted in purple face negative net costs to consumers *before* any DNO intervention. In these CMZs the EE measures are likely to be taken-up regardless the DNO's incentive. There are, however, 10 CMZs where a payment by the DNO of the Ceiling Price is enough to incentivise the take-up of EE when it would not otherwise be installed. This is driven by high reinforcement costs per dwelling, hence the majority of these CMZs are located in rural areas of South West and Wales as oppose to the Midlands.

Figure 44 Predicted Ceiling Price vs. Net cost to the consumer

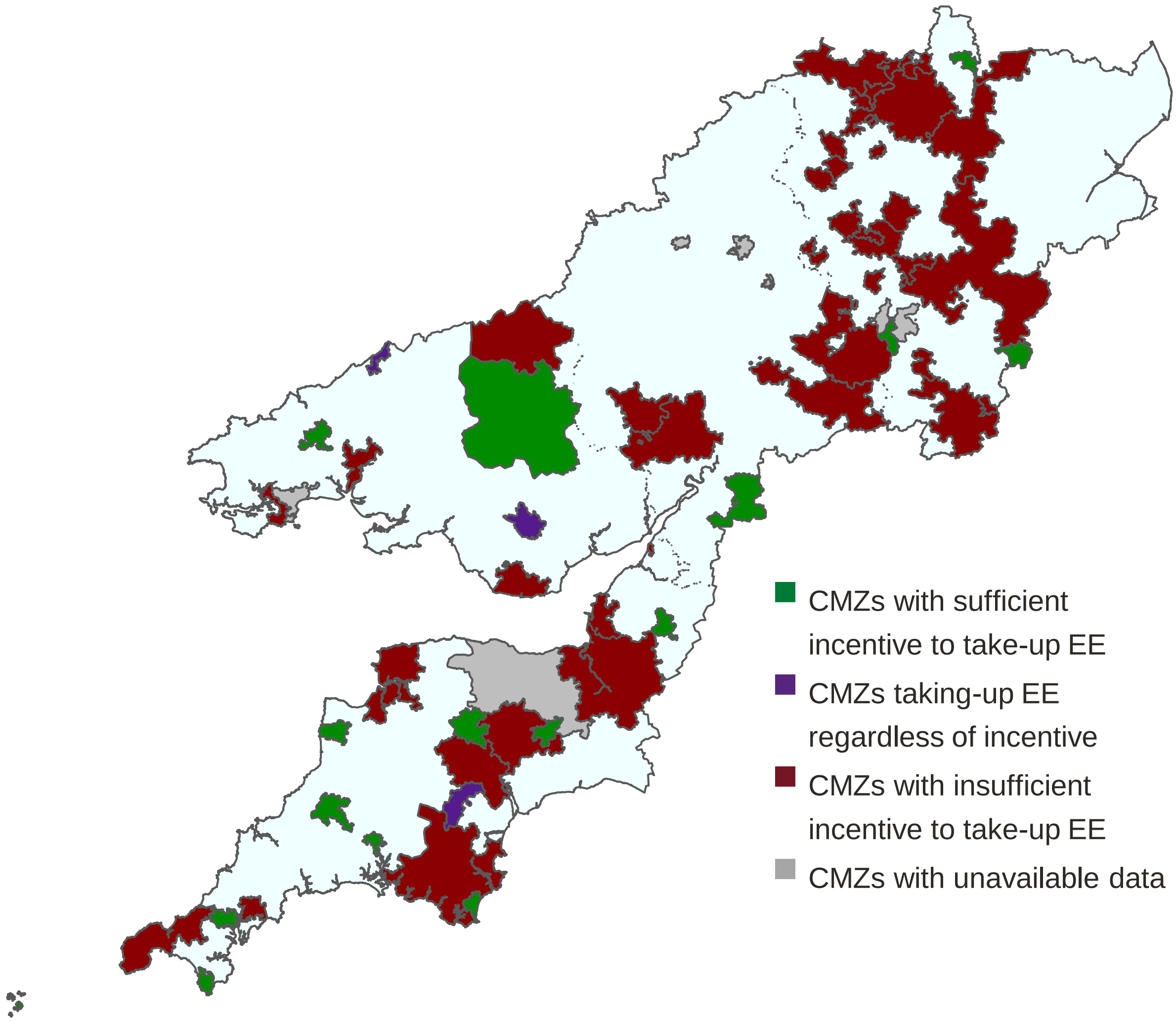


Source: Frontier Economics

If the 50% uplift to Ceiling Price is applied to proxy for the proportion of CMZs which might have sufficient value as they get closer to reinforcement,[71] this figure rises to 26% of all CMZs, shown in Figure 45.

71 As described in the sensitivity above, the LWR analysis suggests that DNOs may be willing to pay more for EE interventions as networks approach the point of reinforcement.

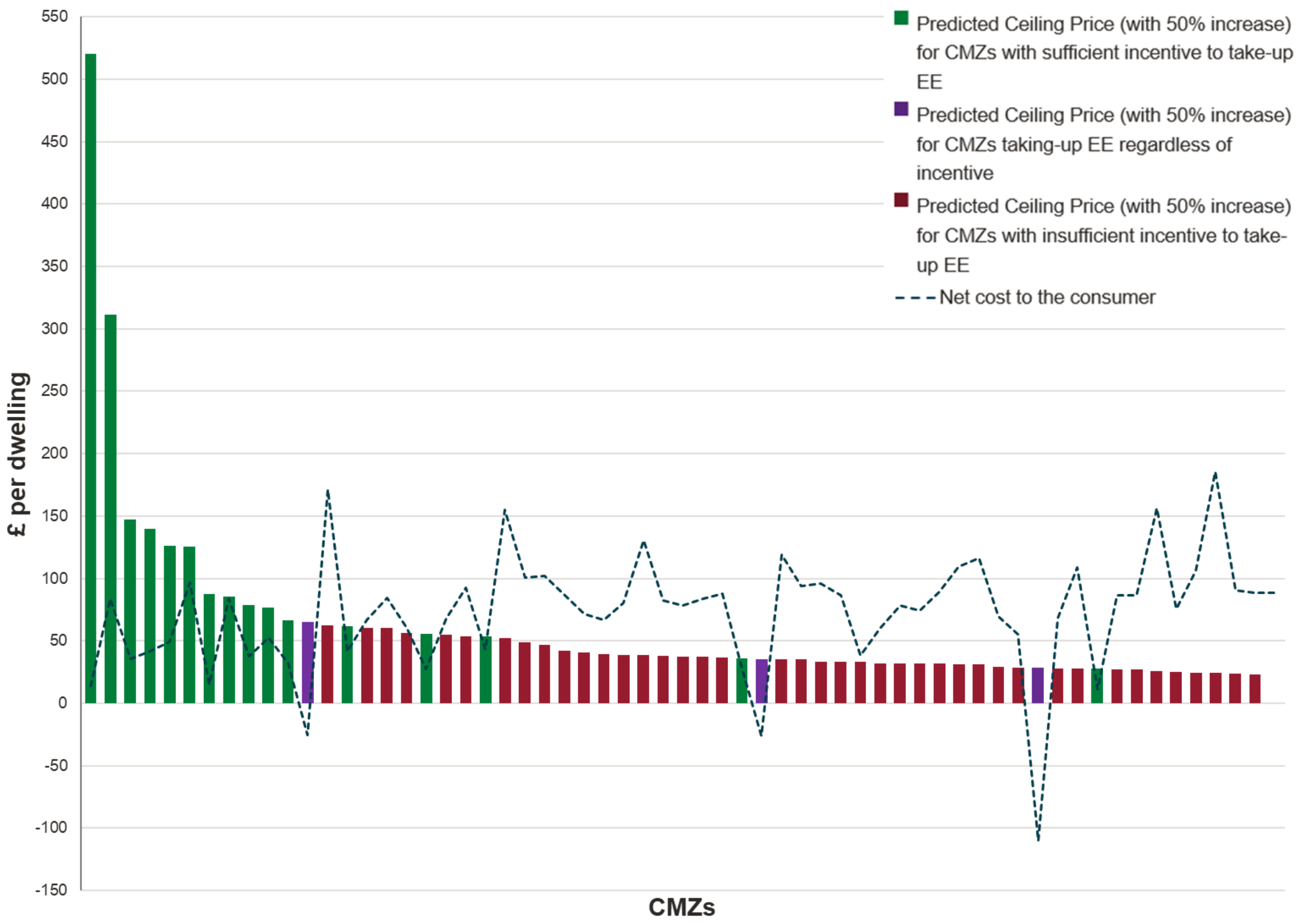
Figure 45 Map of CMZs by intervention effectiveness (bringing forward EE by 2 years), when close to reinforcement



Source: Frontier Economics

Figure 46 below shows the resulting Ceiling Price and net costs to the consumer.

Figure 46 Predicted Ceiling Price vs. Net cost to the consumer



Source: Frontier Economics

As presented in the scenarios above, there may be value to DNO interventions in some CMZs. However, EE interventions in these CMZs are limited to:

- a small proportion of CMZs (which have relatively high reinforcement costs);
- a small proportion of properties within these (medium-efficiency properties that are suitable for cavity and suspended floor insulation – roughly 1.5% of all properties); and
- the presumably small proportion of homeowners within these properties who would have carried out the retrofit two years later.

This is therefore not a form of intervention which can be broadly applied. In addition, the analysis above has been based on an extremely simple model of consumer behaviour (where consumers consider only the discounted costs of EE measures) which may not hold in practice. Therefore, while there may be some value available to the DNO, it is extremely uncertain. The following chapters describe how this value might be maximised, as well as the next steps that could be undertaken to determine how a DNO EE intervention may work in practice.

7 Ways to implement EE interventions

The analysis in the previous chapters has demonstrated the main drivers of value for EE interventions, their wider value in the electricity value chain and how these may be impacted by delays and uncertainties.

This chapter considers how a DNO might go about designing an EE intervention given the insights of this analysis. Specifically, it considers how to:

- design interventions which can bring forward EE measures which would have occurred later;
- use DNO funding to overcome other barriers to EE uptake (including awareness of non-monetary barriers), which may be greater value-for-money than simply providing funding;
- target electrically heated properties, where there is direct value to the DNO; and
- target high value properties in constrained zones that would most benefit.

7.1 Design interventions to bring forward EE measures

As seen in chapter 4, the value of EE measures to a DNO are generally very small in comparison to the capital cost of the measures themselves. It is therefore unlikely that capex-based energy efficiency 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. As demonstrated in chapter 6, such targeted interventions have the potential to unlock much greater benefits for the DNO.

In regards to intervention design, this could be achieved by a mix of the following.

- **Providing loans rather than grants to households**. Grants at the level of the Ceiling Price (at maximum a few hundred pounds, and generally less) are unlikely to affect consumers' choices. Providing a low-interest loan may be an effective way of making limited funding go further.

- **Having funding that is only available for a limited time**. If the DNO can credibly commit to any funding for a specific area only being available for a limited time (until reinforcement would otherwise be required), then the 'use or it lose it' nature of the funds may encourage more homeowners to bring forward retrofits. This will require raising public awareness (via information dissemination, detailed below).

- **Sharing information on intervention timings with local partners**. If funding for EE measures[72] is only available in a limited number of areas for a limited time, then effectively sharing this information with organisations such as local energy planners, other parties offering funding for EE, and installers may help ensure that the supply chain is primed to promote and install measures at the right point. This could

[72] Whether used to directly finance measures (e.g. via loans) or supporting other local activity aimed at increasing uptake.

involve extensions of the types of open data initiatives already used by DNOs to share information on when and where flexibility is required.

- **Targeting those properties that most likely will invest in EE in the future**. Any funding will be more effective if it can be targeted at those properties which will install EE measures but only after the point it would be useful for the DNO. This is flagged in section 8.2 as an area for further research for next steps.

7.2 Target interventions at non-monetary barriers to take-up

Given the relatively low level of the Ceiling Price compared to the capital costs of EE interventions, DNO funding may be more effective if it is targeted at non-monetary barriers to EE take-up. Although an analysis of these barriers was outside the scope of this project, areas of exploration could involve:

- **Disseminating information regarding the direct benefits of EE**. If awareness of the benefits of EE is a barrier to some installations of EE then DNOs may be able to work with local organisations to build this. Such information could involve a combination of non-personalised information (e.g. describing the broad benefits of EE) and personalised information (e.g. estimating the benefits given the details of a specific house). Local awareness-building activities could include:
  - training related tradespeople, such as ASHP installers, on the benefits of EE such that they can recommend at the point of sale;
  - personalised dashboards (online or in print) showing household efficiency and projected improvements available with an EE retrofit;
  - financing EPC surveys to raise consumers' awareness of their own home's rating and retrofit options; and
  - explaining the funding available at national and local levels for EE so that a consumer is clear what is available to them and how to take advantage of it.
- **Spreading awareness of non-monetary benefits**. As in section 4.3, there are significant non-monetary benefits from some EE interventions that could potentially be under-valued. Whilst such benefits are difficult to quantify (along with being highly uncertain and subjective) there is evidence to suggest that they are significant in comparison to DNO benefits. Making consumers more aware of these benefits would increase their likelihood of taking up EE. These activities might involve:
  - Marketing and other local initiatives to inform consumers about benefits such as reduced noise levels (when relevant – e.g. for properties which would benefit from double-glazing). This could involve targeting properties in particularly noisy areas.
  - Partnering with the health sector to make consumers more aware of the health benefits of EE retrofits. DNOs could even work with the NHS to capture the added benefit of EE measures on treatment bills. For example, various schemes are currently being trialled to 'prescribe' heat to

vulnerable people.[73] However, it is important to note that many of the biggest health benefits may come from a 'rebound effect' where consumers take the opportunity to heat their homes more and therefore do not significantly reduce the load on the network. The following chapter describes the potential trade-offs that may be involved when considering consumers in vulnerable situations.

7.3 Targeting electrically heated properties

In section 2.1 it was noted that the current analysis assumes that the DNO is able to target properties which are already using, or are about to install, an electrically powered heating system. Indeed, the presence of *any* value to the DNO depends on the property having electric heating. The approach taken by the DNO may therefore differ depending on whether the property:

- Already has electrically powered heating;
- is considering the installation of electrically powered heating; or
- does not currently have electrically powered heating but has some prospect of installing it in future.

7.3.1 Properties that already have electrically powered heating

The uncertainties to the DNO will be lowest (and therefore the potential Ceiling Price will be highest) for interventions that can be targeted at properties which already have electrically powered heating.

Electrically powered heating systems are currently typically electric resistive storage heaters with a minority of non-storage electric resistive heaters and heat pumps. Reduction of heat demand from storage heaters is however unlikely to be of value to the DNO since their power usage usually occurs in off-peak times.

As described in Box 1, EE interventions for properties that currently use direct electric heating without storage are likely to have a particularly high Ceiling Price. These properties are also more likely to be in high value CMZs, i.e. off-grid houses in rural areas with high reinforcement costs (as per section 3.2). However, while the likely location of such properties can be estimated (e.g. by considering the extent of the gas grid), the DNO will not know the heating system used by a specific property. There may therefore be scope for activities (e.g. surveys) to identify where such properties are in CMZs, and the development of specific interventions from the DNO which target these properties and can therefore make use of the higher Ceiling Price.

Although the current uptake of heat pumps is relatively low, installers are obliged to notify the DNO of new heat pumps. DNOs therefore already have a dataset of properties which could be targeted for EE measures[74] – although we understand that in practice there are likely to be heat pumps which are not registered in this way.

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[73] For example, see https://es.catapult.org.uk/project/warm-home-prescription/

[74] Note that properties that have installed a heat pump may have, as part of that process, undergone EE retrofits to enable the efficient running of the heat pump. Targeting would therefore focus on 'medium' efficiency properties within this dataset (irrespective of what their thermal efficiency was before they installed a heat pump).

7.3.2 Properties that are considering the installation of electrically powered heating

As the take-up of heat pumps increases, engaging with consumers shortly before[75] or as they are installing a heat pump will help ensure the appropriate properties are targeted. As heat pumps may be installed as part of a wider programme of works, this may be a particularly good time to install EE measures. Furthermore, considering EE measures before the heat pump is installed may permit the installation of a smaller capacity heat pump, with resulting savings for the consumer.

DNOs could engage with consumers who are about to get a heat pump. This could take the form of co-ordinating with local installers or authorities to ensure that consumers are provided with information regarding any intervention at the point they are planning their installation.

However there is a risk that EE interventions which are conditional on heat pump uptake may inadvertently incentivise early heat pump installation in constrained areas and therefore have a *negative* impact on the DNO. Although the sums of money that a DNO may be able to make available are constrained by their Ceiling Price, the various ways discussed above for how the DNO could bring forward insulation (e.g. through 'now or never' loans or sharing information) could equally bring forward the installation of heat pumps. To be most effective at reducing DNO costs, interventions will therefore need to be carefully designed to target consumers that would uptake heat pumps in the absence of the EE intervention.

7.3.3 Properties which have some prospect of installing electrically powered heating in future

At present, the vast majority of homes within GB have gas boilers, are unlikely to upgrade to a heat pump for several years, and are not in currently constrained network areas. However, many of these properties will eventually upgrade their heating system, and as demand rises an increasing proportion of them may be in constrained areas. There is therefore some value to the DNO to homes carrying out EE retrofits now – for example, measures that encourage households to become 'heat pump ready' and ensure they have a sufficient insulation in place before their boiler breaks and they consider a heat pump. As this type of funding may not be conditional on installation of a heat pump, it would not be subject to the sorts of mis-incentive described above.

However, value from EE interventions on gas powered heating is likely to have very low value. Given that the majority of these properties are anticipated to only impact the electrical network after several years, the value of their demand reductions is significantly discounted (as per section 2.5.2). Further, section 5.3.4 demonstrated that, due to its inflexibility, EE will be less valuable under more uncertainty – and the further into the future the effect of the intervention is, the more uncertain are its effects.

Nevertheless, it may be the case there are low cost actions (such as those suggested in section 7.2 around information dissemination) that are worthwhile.

75 'Shortly before' here refers to the period of time where decisions are being made about whether and how to install a heat pump. It is anticipated that EE retrofits will often be considered as a part of those decisions and it may be the case that these are installed first before the final decision to install a heat pump is made. Greater understanding of the customer journey (identified in next steps in chapter 8) will assist in targeting consumers at the beginning of this process and not half way through.

7.4 Targeting high value properties

As in section 3.2 and chapter 6, the value of EE is concentrated in a small proportion of CMZs with high reinforcement costs. Within these CMZs there is a mix of property types and retrofit options with differing degrees of cost effectiveness. For example, section 3.1.3 showed that suspended floor insulation was more cost effective than solid floor insulation. Similarly, for property type, it was seen that top floor flats were more cost effective to retrofit.

There is a tension between the scale of the intervention and the cost effectiveness of the intervention in regards the mix of property and retrofit types targeted. Specifically:

- The more targeted an intervention can be, the more it can select the most cost effective properties. This can be seen for the Gunnislake CMZ in Figure 25. In order to increase the scale of the intervention, it is necessary to target increasingly less cost efficient retrofits. Indeed, it was only by targeting more cost effective installs that a handful of CMZs were considered to present value for an EE intervention (see 6.2 above).
- Conversely, evidence suggests that there may sometimes be increasing returns to scale if deferral can be deferred for a longer time (see 3.1.2 above). There may also be fixed costs to rolling out an intervention which mean that there is an advantage to larger interventions where those fixed costs are less representative per household. Such fixed costs could include marketing, setting up processes for co-ordination with stakeholders, developing dashboards for personalised data etc.

Being able to target cost effective properties can minimise the impact of incorporating less cost efficient properties in the intervention to achieve scale. This would come close to realising a cost curve where properties are valued according to their own unique cost effectiveness. The DNO could then set target different levels of funding (whether this is used directly such as for loans, or indirectly such as information campaigns) in line with the value of the property.

Detailed gathering of property characteristics and their potential for EE savings would need to be undertaken to achieve such granular targeting. This likely ties in with raising greater consumer awareness of their home's rating and retrofit options (see 7.2 above). For example, EPC surveys and 'bottom-up' analysis of before and after heating demand profiles can both inform consumers of bill savings and predict the value of the intervention to the DNO.

8 Conclusions and next steps

This report has sought to value EE interventions from the perspective of DNOs. It has outlined NGED's current network reinforcement planning process (chapter 2) and developed a model of EE evaluation within that framework (chapter 3). Potential beneficiaries of these interventions outside of the DNO have been identified along with how that value might be captured (chapter 4). Uncertainties around the outcomes of EE interventions have been identified and models that account for this in decision making have been developed (chapter 5). Finally, we have used this to analyse where the value of EE interventions is most likely on NGED's network (chapter 6) and suggested what implications the analysis has for intervention design and planning of such interventions (chapter 7).

This final chapter seeks to:

- Summarise the main conclusions on the viability of EE interventions to DNOs; and
- Set out the next steps that would be required to confirm the viability of such interventions and potentially take them forward as part of Business as Usual (BAU) DNO practices.

8.1 Conclusions on the viability of EE interventions to DNOs

This project has demonstrated that existing processes used by DNOs to assess flexibility can be extended to cover EE interventions. However the value of such interventions to the DNO, quantified in this report by the Ceiling Price, is relatively low: Even in areas with high reinforcement costs (the main driver of value), this value will not exceed a few hundred pounds per property, and will generally be much lower.

As described in the preceding chapter, it may be possible to design an intervention that uses these limited funds to bring forward retrofits that would not otherwise have occurred. This will require careful targeting, both at the CMZ level (where more rural CMZs are likely to have the higher reinforcement costs which would permit the DNO to spend more) and at the property level (to focus on the dwellings with the most cost-effective measures).

This work has also highlighted two underlying tensions that DNOs will need to consider when designing EE interventions.

The first is a trade-off between the timing and scale of installations. As identified in section 5.1.2, 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 (section 3.1.2) or the presence of fixed costs (section 7.4).

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 was noted in 3.2 that social housing is less prevalent in high value, i.e. rural, areas).

Second, while EE interventions may help meet DNO vulnerable consumer strategies,[76] this is not always the case. As described in section 3.2, the 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. As described in section 4.3, 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 we assume 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.[77]

8.2 Next steps

There are several steps remaining in the move towards incorporating EE interventions in DNO Business as Usual (BAU) investment decisions. This report has sought to answer the question 'Does EE have value and what are the broad ways of achieving it'. The answer, as per the conclusions above, is that there is value, albeit small.

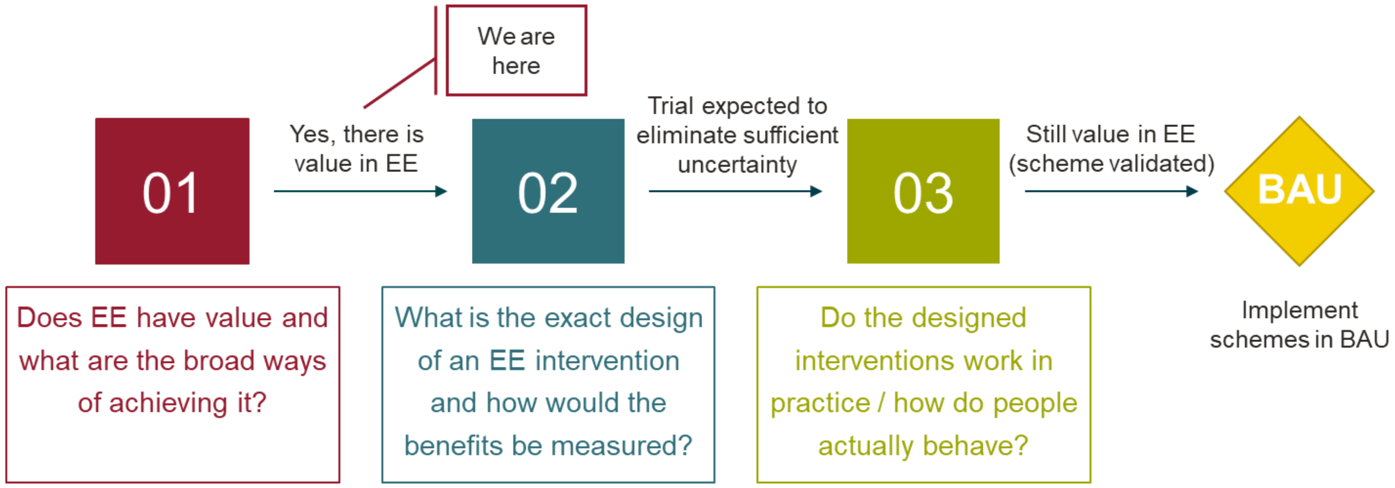
A significant number of uncertainties remain regarding whether it would be cost-effective for EE interventions to form part of BAU processes, and how this would be done, and resolving some of these may involve substantial levels of spend (for example on trials). A prudent course of action is therefore to first carry out less intensive exercises (e.g. desk-based research) to build the case for intervention, and only carry out trials etc. if the results of these studies are positive.

Figure 47 outlines the broad questions and conditions under which DNOs should proceed to the next step. The uncertainty around value decreases as further activities are carried out, but the steps but the cost of these activities increases. We then go on to describe these steps, paying attention to items highlighted in this report.

76 For example, the NGED power up schemes provides vulnerable consumers with expert advice and support in managing issues around fuel poverty, see https://www.nationalgrid.co.uk/customers-and-community/priority-services/power-up

77 Ofgem (2022) "Final Determinations Core Methodology Document".

Figure 47 Steps towards implementing EE interventions in DNO BAU



Source: Frontier

8.2.1 What is the exact design of an EE intervention and how would the benefits be measured?

Before carrying out trials (in the next stage), the form of the intervention(s) to be tested will need to be refined. The value of EE interventions to a DNO is generally very small in comparison to the capital cost of those interventions, this report has suggested that alternative uses for funding could be either aimed at bringing forward EE investment (section 7.1) or overcoming non-monetary barriers to EE take-up (section 7.2). Work will need to be carried out to develop these interventions and short-list those which are feasible. This could include:

- Working with the local supply chain to determine what the barriers are to take-up of EE measures and how these might be overcome.
- Building the business case and partnerships necessary for any models involving direct funding of interventions (for example loans). This is likely to involve engagement with financial institutions which are better placed than DNOs to offer loans.
- Should information dissemination be considered for trials then it will be needed to decide what information could be shared.
  - This will include what level of personalisation to employ - for example, the feasibility of providing consumers with estimations of benefits given the details of their specific property and energy usage, perhaps including comparisons to similar properties that underwent upgrades.
  - Thought will also be given to *how* the information can be shared. For example, are there ways of engaging a community (e.g. through the use of local ambassadors) which could increase take-up? Learnings from other innovation projects (e.g. the Net Zero Community workstream of NGED's Project VENICE, ongoing at the time of writing) may aid this aspect of intervention design.
- Further analysis could be used to determine key touch points in influencing decisions. This would allow for the DNO to more efficiently target properties that are shifting to electrical heating. This would include

determining if there are groups for which there are different customer journeys and so different interventions may be more effective – e.g. different interventions may apply to landlords of rented properties rather than owner-occupiers.

- Work could be done with the TSO to identify if there is any way of capturing the value of EE for national constraint management, as described in section 4.2.5.

- Additional insights might be derived from suppliers to determine if anything can be learned from the operation of the ECO scheme.

Further analysis ahead of trials could help target them at the properties where the gains for DNOs are likely to be greatest. This could include:

- Work to improve the datasets available to DNOs, allowing them to determine at a more detailed level the location of relevant properties (e.g. those with electric resistive heating).

- Shortlisting a set of demonstrator locations. This work could be based on the analysis carried out for chapter 6 which illustrated ways to identify areas of NGED's network that have the highest potential for EE interventions. These tools could be developed further: For example, at present it is not practical to carry out the full analysis involving the CEM and FAT to obtain a ceiling price for all CMZs, but this could be automated.

Some uncertainties could be narrowed down through the use of more sophisticated models. Some ways in which the models developed for this work could be refined include the following.

- In section 5.3, a simple two period, one uncertainty, Least Worst Regrets model was used to approximate the effect of uncertainty on Ceiling Price. If the LWR model continues to be employed then it could be developed further in granularity of periods or incorporating more sources of uncertainty beyond demand such as the availability of flexibility or the effectiveness of an intervention (detailed in section 5.2).

- Uncertainties around the rate of demand growth (section 5.2) could be addressed to a degree by developing more sophisticated modelling around uptake of EVs and heating technologies. For example, as explained in section 2.6, a 'bottom-up' assessment of future local demand profiles could lead to more accurate predictions, which would help targeting flexibility as well as EE.

Finally, regulatory barriers and constraints will need to be assessed to make sure that there are no blocks to implementation. For example, Ofgem may need to be consulted to confirm the impacts of the RIIO-ED2 final determination guidance on vulnerability strategies which prohibits a DNO from directly installing energy efficiency measures:[78] If an EE intervention were targeted at vulnerable consumers but still reduced reinforcement and flexibility costs, would this be permitted?

[78] Ofgem (2022) "Final Determinations Core Methodology Document". Para 5.92

8.2.2 Do the designed interventions work in practice and is the intervention financially viable?

If a workable intervention (or interventions) can be designed and research indicates it has a good potential to succeed then a trial can be carried out to determine whether the designed interventions work in practice. This would likely involve a number of interventions tested via randomised control trials in order to determine the cost effectiveness of the interventions. Specifically, the questions these trials will be seeking to answer are:

- **How effective are different types of interventions at bringing forward EE measures?** This would involve assessing the difference in the timing and nature of any EE retrofits carried out in houses that were and were not targeted by the interventions

- **How costly are the interventions?** For example, if direct financial support such as loans are used, different sizes of loan could be offered to different participants to determine the minimum cost required to bring forward a particular type of volume of EE retrofits.

- **What is the impact on the network?** The heating systems used by houses before and after the intervention could be recorded, to determine to what extent the retrofits are actually likely to reduce electricity demand. This will also depend on the performance of the EE measures that are installed. While much data already exists on the impact of different thermal efficiency measures in different types of houses, monitoring the trials may be useful to determine if the types of property that are targeted have a different response (for example, they may use heat pumps in a different way, or have a different rebound effect). Finally, any unintended consequences (e.g. if an intervention inadvertently encourages faster heat pump take up in constrained areas) would also need to be monitored.

Together, these results will indicate whether or not DNO EE interventions provide an overall reduction in costs to the DNO.

Trials might also help better understand other sources of uncertainty, such as the availability of flexibility (discussed in section 5.2). This might be addressed by trials whereby flexibility is over-procured in order to determine how flexibility availability varies by CMZ type.

8.2.3 Implement interventions in BAU

If trials have determined that a given intervention is financially viable, then the final step is implementing them in BAU. Broadly, this will involve:

- Bringing the tools developed for this project to target and assess EE interventions up to production standards and scale so they can be applied by DNOs across a wide area.

- Working with the Energy Networks Association (ENA) to develop standard ways of running EE interventions. This will ensure that there is common understanding within the supply chain of how to get access to any funding or help from DNOs.

- Developing relationships with players in the supply chain (e.g. confirming terms of engagement with installers), and potentially setting up open data initiatives (e.g. so that installers know where and how much money is available).
- Developing any additional markets and contractual arrangements required. For example, if an intervention involves loans for the installation of EE measures then this may require developing the arrangements that allow a DNO to announce the availability of any funding, for installers to bid for this, for EE interventions to be validated, and then paid for. If an intervention involves loans to consumers then a mechanism for recouping these loans (taking into account issues such as when consumers move house) would need to be organised (likely in partnership with financial institutions).
- Developing promotion and marketing activities (either towards consumers or the supply chain).
- Setting up any ongoing evaluation activities to ensure that, at scale, value for money is still being observed. Ongoing evaluation will also allow for updating of the intervention to ensure that it is as effective as possible.

Annex A NGED's current optioneering process

As described in chapter 2, part of this project has involved developing a suite of tools that build on existing NGED processes to assess the long-run cost-effectiveness of EE compared with traditional reinforcement and flexibility services. Their core users of these tools are the DSO Team, who are currently responsible for making strategic decisions about asset interventions.[79]

User research has therefore been carried out with this team and other relevant internal NGED stakeholders to understand their requirements for the tool. This involved a combination of interviews with members of staff, reviewing existing documents and models, and observing members of NGED staff using the tools. This annex provides a summary of the existing process for assessing reinforcement and flexibility, which the tools developed for DEFENDER build upon.

First, we set out a broad overview of the different types of network planning that NGED carried out, and summarise the process for strategic planning of the 33kV and above networks (the focus of this project). The following sections describe each stage of this process in more detail.

A.1 Overview of the existing network planning process

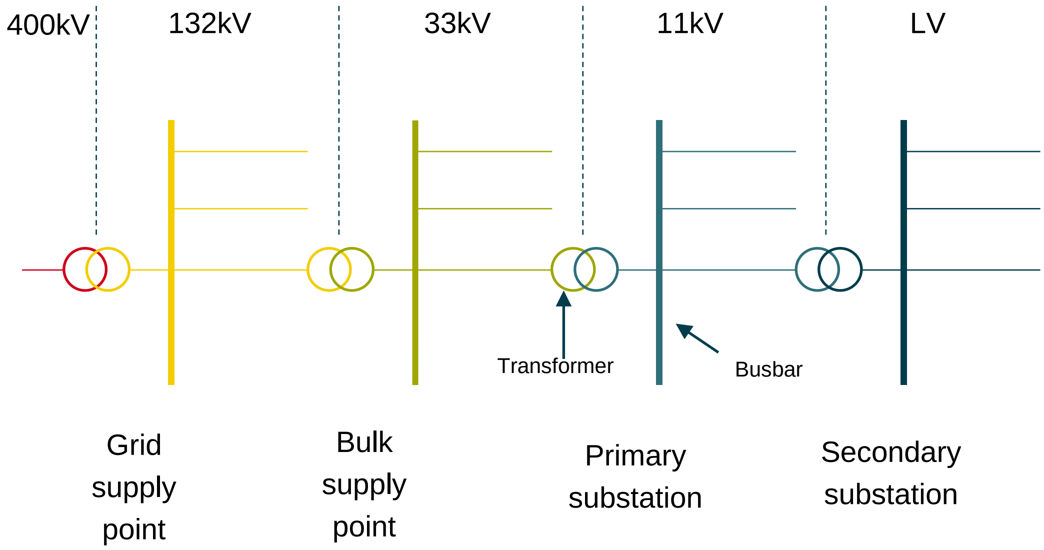
Before the options for network intervention can be assessed, the need for intervention must be established. This need can be categorised on two dimensions.

- First, whether the intervention is strategic (anticipating a future issue that has been forecast) or reactive (responding to a more immediate issue that has arisen).
  - **Strategic** interventions are planned on a 2 year cycle using the NGED investment planning process.
  - **Reactive** interventions are carried out on an ad-hoc basis, for example when a large consumer requests a new connection.
- Second, which voltage level the constraint is at.[80] Figure 48 below shows a highly simplified view of the different voltage levels on the distribution network.
  - Both strategic and reactive interventions are carried out at the 33kV and 132kV levels of the network.
  - Currently only reactive interventions are carried out at the 11kV and LV levels of the network, although there is a desire in future to make strategic interventions on these networks too.

79 Reactive (as opposed to strategic) decisions are made by separate network planning teams.

80 Although in some cases the intervention required to fix a constraint may be at a different voltage level. For example, if a 33kV transformer at a primary substation is constrained then this might be resolved by interconnecting two primaries at 11kV.

Figure 48 Different voltage levels on the distribution network



Note: This diagram shows only a small proportion of the network. In reality, each busbar would have multiple circuits coming from it, and the network may have a complex topology which includes loops

Table 7 NGED network intervention approach

	Strategic	Reactive
33kV and up	Forward looking planning system including DFES and DNOA, described below. Focus of this project.	Assessed as required (potentially using some of the same tools as the strategic processes but with different inputs). Not within the scope of this project.
11kV and below	N/A: All interventions on the 11kV and LV networks are reactive at present, although there is a desire in future to make strategic interventions on these networks.81	Assessed as required using different tools and processes. Not within the scope of this project.

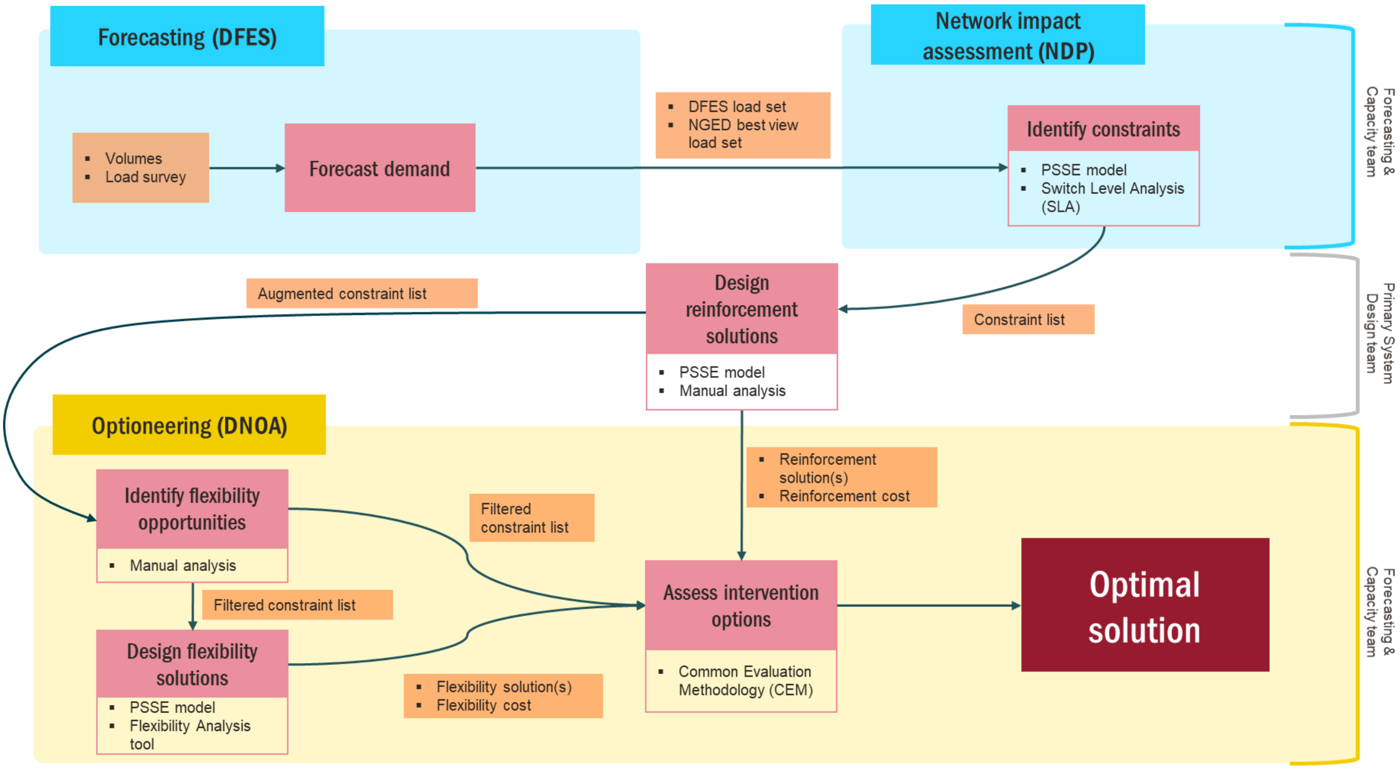
The tool(s) developed as part of this project are intended to form part of NGED's strategic network planning process for the 33kV and higher voltage levels. This process has three main parts:

- **Forecasting:** DFES volumes and load surveys of underlying demand on the NGED network are used to forecast demand on the network. The output of this step is load sets for network modelling based on the four Distributed Future Energy Scenarios (DFES) and an additional NGED 'Best View' scenario.
- **Network Impact Assessment:** Additional modelling in the Network Development Plan (NDP) is used to identify network assets that may require intervention. These studies are then passed on to the Primary System Design team to **design traditional reinforcement solutions** and costs.
- **Optioneering:** Once a set of constrained assets and potential solutions is identified, the Forecasting and Capacity team identifies constraints that may be suitable for flexibility interventions. The Flexibility Analysis Tool is used to calculate flexibility requirements and costs. Finally, the industry standard Common Evaluation Methodology (CEM) tool is used to assess the flexibility and reinforcement solutions to determine the economically optimal solution.

The network investment planning cycle takes place over a two year period. At the beginning of the period, DFES scenarios are used within the NDP to produce a list of constrained assets. These assets are then assessed using the Distribution Network Options Assessment (DNOA) every six months over the 2 year cycle. Assets are removed from the list once the constraint is resolved. The DFES scenarios are updated annually, with the most up-to-date scenarios used as an input for the DNOA process.

[81] For example, recent NGED network design policy has shifted towards including some forward-looking identification of hotspots on the 11kV and below network.

Figure 49 NGED network planning process



Source: *Frontier Economics based on NGED interviews*

The following sections describe each part of the current process in further detail.

A.2 Forecasting

NGED forecasts scenario projections for its network licence areas for each year out to 2050. The forecasts are based on an analysis of future volumes and consumer behaviour profiles.

- **DFES volume** forecasting is managed by Regen, which engages with local council and development partners. This involves projecting the volumes of different technologies and consumer types that will be connected to the network, for example the number of EVs, the number of heat pumps, and PV capacity. Volumes are forecast at an Electricity Supply Area (ESA)[82] level for the four DFES scenarios: Consumer Transformation, System Transformation, Leading the Way, and Steady Progression. An additional 'NGED Best View' scenario is developed by combining the four DFES scenarios based on stakeholder engagement (for example discussions with local councils).

82 ESAs typically represent the area served by a primary substation

- **DFES profiles** are developed for the demand and generation behaviour of consumers that are connected to the distribution network. This is done at a half-hourly level for five representative days: Intermediate Warm/Cold Peak Demand, Winter Peak Demand, Summer Peak Demand and Summer Peak Generation. These profiles are applied to the volume forecasts to provide demand load sets for the NGED network.

Energy efficiency is currently not captured in the volume stage of forecasting, for example there are no volume projections used on the number of consumers installing thermal insulation. Profiles implicitly include assumptions on the energy efficiency of domestic buildings, for example heat pump volumes can be combined with domestic demand profiles to provide an average energy demand per heat pump in each year. Over time, this average energy demand decreases in some profiles due to a combination of increased domestic energy efficiency (e.g. thermal insulation), and improvements in heat pump technologies. However the underlying assumptions on domestic energy efficiency cannot be extracted from NGED's current inputs.

A.3 Network impact assessment

The Forecasting and Capacity team identifies potential constraints on the network with PSS/E power system simulation software, using a network model which includes detailed network assets at the 33kV level. The process for identifying constraints has two steps:

1. The Switch Level Analysis tool generates a list of contingencies, which are combinations of asset outages (which could be planned or unplanned) that could occur in the network. The relevant sets of outages are based on network security of supply standards,[83] which set out the conditions under which the network must be able to maintain supply without interruptions.
2. The PSS/E model is used to test the impact of these asset faults under different demand forecast scenarios (DFES and NGED best view). The test is run for the current year, 2025, and 2028. The output of this modelling is a list of constrained assets, which may require an intervention to ensure that security of supply standards can be met. Constraints are identified in three main categories: thermal constraints in which assets are overloaded (i.e. have insufficient thermal capacity for the power flow), voltage constraints in which the network is higher or lower voltage than defined standards,[84] and fault level constraints in which the magnitude of the current that could theoretically flow into the network during a short circuit fault exceeds standards.

A.4 Reinforcement solution design

Once a set of constraints have been defined, they are passed on to the Primary System Design team. This team designs traditional reinforcement solutions using network modelling and manual engineering judgement. Costs are also calculated for the preferred reinforcement solution.

[83] ENA (2019) "Engineering Recommendation P2".

[84] The Electricity Safety, Quality and Continuity Regulations 2002 (ESQCR) requires an LV supply to be within 10% above or 6% below the standard of 230 volts.

A.5 Optioneering

Identification of flexibility

The constraint list and best reinforcement solution for each constraint are provided to the Forecasting and Capacity team. Any constraints that are unsuitable for flexibility are removed from the list at this stage using manual engineering judgement, for example fault-level[85] or condition-based constraints.

Flexibility solution design

The Flexibility Analysis Tool is used to calculate flexibility requirements for each constraint on the 'filtered' constraint list. For each constraint, the calculation process is as follows:

1. The user inputs seasonal capacity for the constrained asset.[86]
2. Demand is forecast under five scenarios by applying scalar multipliers ('coefficients')[87] to historic actual half-hourly demand over the previous 12 – 24 months on the constrained asset.
3. The tool calculates the amount of flexibility that would be required to bring demand below the asset's capacity throughout the year under each forecast scenario. This includes an over-procurement percentage (typically 20% - 40%) to account for uncertainty around the amount of flexibility that can actually be procured from the market, and uncertainty around the reliability of procured flexibility services.
4. Each flexibility solution is costed based on an availability payment (£/MW/h), and a utilisation payment (£/MWh).

The output of the tool is the flexibility requirements and costs for each constrained asset. This is calculated in capacity terms and utilisation terms, i.e. how many hours of flexibility is expected to be required under each scenario.

Intervention option assessment

The Common Evaluation Methodology (CEM) tool is used to compare the costs and benefits of the flexibility and reinforcement solutions for each constrained asset. This is an industry standard tool, which is produced by the Energy Networks Association (ENA) as part of the Open Networks Project and used by all DNOs.[88] NGED uses the CEM in the following way:

85 A fault-level constraint exists if part of the network would be unable to cope with the current if a short circuit fault were to occur. In general, these types of constraints would require actions such as upgrading circuit breakers, and cannot be solved with flexibility.

86 In some instances, flexibility – or energy efficiency – might solve a constraint on one network (e.g. the transformers at a primary substation) as well as on a higher-voltage network (e.g. the grid transformers at the bulk supply point). The flexibility analysis tool could not look at both constraints at once, but might be run separately for each one, with the results combined in the CEM, described below.

87 The multiplier comes from each of the DFES and NGED best view scenarios. The multiplier is determined at the Local Authority level.

88 The current CEM in use by NGED is the CEM V1. The next DNOA round will use the CEM V2, and consultation is currently underway for the CEM V3.

1. The user inputs the baseline reinforcement costs as upfront capex, based on the Primary System Design team analysis.
2. The user inputs the flexibility volume and costs under each of the five demand scenarios, based on the Flexibility Analysis Tool outputs. The flexibility volume inputs include availability volumes (average capacity procured each year in MVA, hours per day of availability required, and days per year of availability required), and annual expected volume of utilisation in MWh. Flexibility costs can include an availability price in £/MW/h, a utilisation price in £/MWh, and any fixed costs associated with the flexibility scheme.
3. The model calculates the annual total cost of flexibility under each demand scenario. It compares this to the cost of reinforcement for a range of deferral strategies of 1 to 5 years, in 1 year increments. All costs are discounted at the social discount rate. The tool also has the functionality to calculate the optimal flexibility contract length given uncertainty around demand using a 'Least Worst Regrets'[89] method and a 'Weighted Average'[90] method. However, this functionality is not currently used by NGED.
4. The output of the tool is the comparison of flexibility and reinforcement costs under different deferral strategies. For each demand scenario, this shows the number of years for which flexibility can cost-effectively defer reinforcement.
5. The final optimal intervention decision is made by comparing the cost-effective flexibility schemes across each scenarios. NGED typically choose to procure the flexibility length under the 'NGED Best View' scenario.

In addition to a cost comparison, the CEM has functionality to include a wider set of costs and benefits for each option. This includes carbon impact, electricity losses, and consumer disruption. There are several reasons why these features are not used. The carbon impact functionality is not used because the underlying calculation methodology does not include the impact of deferred embedded emissions from reinforcement, which NGED engineers did not consider to be an appropriate approach. Losses and consumer disruption are not used within the CEM tool because they require network modelling to accurately calculate, which is not currently part of the optioneering process.

The outcomes of the CEM tool are published in the DNOA publication on a 6 monthly basis. They are also passed on to the commercial flexibility procurement team, NGED Flexible Power. In cases where insufficient flexibility is procured from the market, conventional reinforcement may still be required.

Currently, NGED is using version 1 of the CEM. This includes some functionality to account for the impact of uncertainties: The user can enter multiple scenarios, and the tool can provide the costs and benefits of interventions for any scenario in isolation, a probability-weighted average of scenarios, or a 'least-worst-regrets' calculation which determines the intervention which minimises the losses if a scenario occurs which is least suited to the intervention. NGED does not currently use this functionality. CEM 2 has recently

89 This approach calculates the maximum benefit that could have been achieved under a given scenario and subtracts the benefit actually achieved under a particular intervention. It calculates the flexibility contract length that provides the 'least worst' regret across all modelled scenarios.

90 This approach allows the user to apply probabilities to each demand scenario, and then calculate the weighted average NPV by intervention strategy. This identifies the optimal contract length given the probability inputs.

been released and will be used by NGED in the next DNOA round. This includes a number of additional features, such as the ability to visualise a simplified option value of interventions. The ENA Open Networks project is currently consulting on the next version of the CEM, which may include a more complete treatment of uncertainty under a real options approach, which allows multiple scenarios to branch off, and accounts for the additional value of interventions such as flexibility which can help buy time until there is more certainty. However NGED has previously been concerned that such an approach requires a large number of assumptions to be made on the probability of different scenarios occurring, which may be hard to justify and keep track of.