SDRC 8.2

NETWORK INVESTMENT TOOL REPORT

SAVE
Solent Achieving Value from Efficiency

Scottish & Southern Electricity Networks

Solent Achieving Value from Efficiency

Solent Achieving Value through Efficiency (SAVE) is an Ofgem funded project run by Scottish and Southern Electricity Networks (SSEN) and partnered by the University of Southampton (UoS), DNV GL and Neighbourhood Economics (NEL). The innovative programme evaluates the potential for domestic customers to actively participate in improving the resilience of electricity distribution networks and thereby defer the need for traditional reinforcement. The government has forecasted an increase in electricity demand of 60% by 2050 meaning peak demand is likely to grow to six times higher than what the network was designed for.

CONTENTS

List of Tables

List of Figures

EXECUTIVE SUMMARY

The range of benefits that energy efficiency measures and demand reduction activity can provide to Distribution Network Operators (DNOs) and to consumers have become clearer, more widespread and better established in recent years. To this end, the Solent Achieving Value from Efficiency (SAVE) project was developed to investigate how energy efficiency and customer engagement can produce load reductions for domestic customers. These approaches were specifically investigated as a cost-effective, predictable and sustainable tool for managing peak and overall demand as an alternative to network reinforcement.

The SAVE project has developed a Network Investment Tool (NIT) as a forward-looking software interface with a future Distribution System Operator (DSO) in mind. The NIT brings together three purposely designed models (Network Model, Pricing Model and Customer Model) to provide a robust assessment and selection of the most cost-efficient approach for managing electricity distribution network constraints. The NIT considers the effectiveness of different types and degrees of energy efficiency and engagement interventions—as well as more traditional techniques for network reinforcement—as potential approaches for a more cost efficient, appropriate and sustainable management of networks by DNOs (and as they evolve into DSOs).

This SDRC: 8.2- NIT report has shown how the Network Model, Pricing Model and Customer Model are able to connect within the NIT environment to provide additional evidence for planners to make more informed investment choices. This allows planners to better decide when to use customer engagement and energy efficiency measures as opposed to traditional technology-based measures and smart solutions.

A number of wider findings have been identified from the application of the NIT to a series of case study examples explored in this report:

- **A SAVE intervention could be part of an optimal network investment strategy if load growth is low and the network is heavily loaded.** In instances in which these characteristics are present, a SAVE intervention would be effective in deferring network reinforcement. A network that is highly loaded indicates that some sort of network intervention will be required soon. However, if load growth is low, traditional reinforcement is not required immediately; the SAVE intervention could be the more cost-effective option.

- **A SAVE intervention is most effective when larger traditional network reinforcement is required within a network intervention strategy.** The higher cost of larger network reinforcements would mean that even a short deferral of the traditional reinforcement can result in significantly more favourable Net Present Values. For this reason, the NIT recommended SAVE interventions more frequently when they can defer large network reinforcement projects. Here SAVE interventions act as a first solution, followed by traditional reinforcement.

- **There is a relationship between a high uptake of electric heating in an area and the effectiveness of SAVE interventions.** The time periods where SAVE has been proven to be effective can be seen to correlate with peaks in electric heating. As a result over the short and medium-term the SAVE interventions can successfully mitigate against the load growth. However, when the projected load demand growth is achieved over a long period, SAVE is unlikely to be effective.

- **SAVE interventions may be more effective in areas that already have electric heating.** Load growth forecasts used within the network investment tool are mainly impacted by electrification of heating and vehicles. The slower the annual uptake of electrification, the longer SAVE will be able to defer traditional reinforcement; and hence results in a higher Net Present Value. If heating in a given area is already primarily electric, the annual increase in consumption will be lower than other networks as it will only be (in the scenarios used) driven by electric vehicles.

- **An evolution of SAVE interventions may be able to support if load growth creates a new, later peak.** Uptake of LCTs, especially electric vehicles, has the potential to create a new, later peak after the traditional peak period. In this case, some of the current SAVE interventions may have limited impact as they targeted peaks that occurred between 16:00 and 20:00 (data-informed and price signal trials in particular). Future SAVE-like interventions could trial messaging at different hours of the day to determine how customers' capacity to shift their consumption changes.

- **A SAVE intervention would not be part of an optimal investment strategy if load growth is high and the network is heavily loaded.** When these network characteristics are present, a SAVE intervention would be ineffective. The combination of high load growth and a heavily loaded network indicates that significant network reinforcement would be required imminently. The achievable load reduction from the SAVE intervention would be insignificant in comparison to the high load growth. As a result, when these characteristics are present within the network, traditional reinforcement strategies would be recommended. It should be noted that for a 'very high' load growth scenario, on certain substations, the NIT is not always able to recommend interventions, as no combination of reinforcement assets available to the NIT would be able to meet the load.

- **A key finding from the NIT was the ability to easily track and evaluate the urgency of network intervention across the network.** The ever-evolving data set of network issues and solutions allows the formulation of a 'live watch list' of Low Voltage investment plans. The NIT has been able to illustrate the earliest time that network intervention would be required per low voltage substation, if the highest load growth scenario is realised.

The NIT was purposely designed to be a flexible and evolving tool, not a static one. Some opportunities DNOs may which to consider to develop the NIT environment to fit their business needs and maximise benefits include:

- **Growth scenarios:** The NIT's Low Voltage (LV) multi-scenario environment allows up to four growth scenarios[1] to be studied. Future iterations of the NIT could modify these growth scenarios or add completely new ones as new data or load growth predictions become available. The adaptability of the NIT allows the growth scenarios to contain a wide variety of characteristics; these can be utilised to model different areas of the network or to include new LCT technologies such as: residential energy storage, hydrogen for heating, multiple types of electric vehicle chargers or multiple electric vehicles per home, multiple heat electrification types, sophisticated smart appliances that respond to system signals and more. The flexibility inherent within the NIT in being able to assess varying growth scenarios and load profiles presents a key opportunity.

- **Load profiles and customer types:** Customer types have been created within the Customer Model that forms part of the NIT environment to represent the differing characteristics of households and the resulting variability in peak demand consumption. In the future, the NIT could be updated with new customer data or additional load profiles. These could be used to improve on the current data, show consumption patterns in different (non-Solent) regions or reflect future changes in consumption habits. SSEN is already investigating how the NIT could be expanded to allow a greater number of load profiles (and therefore customer types).

1 Low, Medium, High and Very High load growth scenarios have been used in the NIT with varying degrees of uptake of electric vehicles, heat pumps and solar photovoltaics.

- **New interventions and technology:** While the NIT includes the interventions tested in the SAVE project, these do not reflect all the demand-side interventions possible now or in the future. The NIT could be easily expanded to include a wider variety of interventions or types of energy efficiency. This could include smart interventions (such as smart electric vehicle charging), supplier-led Time of Use pricing, or the deployment of new energy efficient technologies. Suppliers of new technology or interventions could utilise real-world smart meter data to develop load profiles showing the impact of their product and these load profiles could then be imported into the NIT to show DNOs how their product could assist in network management and feed in to planning decisions.

- **Interoperability between substations and voltage levels:** At present, the NIT assesses each substation in isolation and does not provide connectivity across substations or determine how the interventions may impact High Voltage (HV) or Extra High Voltage (EHV) networks. This means that benefits of SAVE interventions to the HV or EHV networks are not reflected in the tool. SSEN has developed a separate tool that models the HV and EHV networks which could be expanded from its current state to run load flow studies in the same way the Low Voltage NIT does. This would allow network planners to predict the impact of SAVE interventions across multiple substations and on the higher voltage networks.

- **Benefit stacking and social impact:** At present, the NIT looks at one intervention per model run. However, its highly likely that deploying multiple interventions at the same time (such as LED lighting in conjunction with banded pricing) would result in larger peak reductions than either measure alone. The tool does not account for any social benefits of the SAVE interventions (such as carbon savings or air quality improvements from reduced power generation). Including social benefits in the analysis would likely provide a stronger indication that SAVE interventions are the preferred approach. This means that the NIT is conservative in reporting the benefits of the SAVE interventions.

- **Reinforcement and investment strategies:** The NIT has been designed to SSEN's own network design policies on reinforcement and investment, which themselves are based on current industry standards and engineering best practice. While other DNOs generally follow similar design policies, the tool has been specifically designed to be easily adaptable to other design and reinforcement policies if needed. In the future, additional investment strategies could be added to the NIT to reflect changing priorities of Distribution System Operators and/or additional sources of funding. Additionally, the methodology and data of the NIT are easily transferable to other networks, even if they use different network planning software. Forward looking DSO's are encouraged to dissect the NIT and integrate the modules of most value into their business processes.

2

INTRODUCTION

2.1 Background

The range of benefits that energy efficiency measures and demand reduction activity can provide to Distribution Network Operators[2] (DNO) and to consumers is becoming more widely known and established.

The Office of Gas and Electricity Markets (Ofgem) has previously calculated that a 5% reduction in energy use at peak will result in energy market cost reductions of £219m per annum, some of which would benefit customers in the form of lower energy bills. At the same time, a 5% reduction at peak will result in infrastructure cost savings of between £143m and £275m. This directly correlates to savings for the customer, in addition to the direct savings from lower household energy consumption.[3]

However, some reviews of global energy efficiency-based learnings (e.g. SDRC 1)[4] have found evidence that technology on its own is not able to produce the most consistent, sustainable route to a more efficient use of energy but that a combination of technology and customer engagement is required to achieve the most effective outcome(s).

The overall purpose of the SAVE project has been to investigate and understand what approach(es) could lead to the most significant load reduction and at lowest cost. And the objective of the project has then been to trial and establish the extent to which energy efficiency measures can be considered as a cost-effective, predictable and sustainable tool for managing peak and overall demand as an alternative to network reinforcement.

The SAVE project has used existing evidence and thinking (e.g. the above findings by Ofgem) to robustly test energy efficiency and customer engagement using a randomised control trial (RCT) of over 4,000 households in the Solent region. The project has only targeted domestic customers. The measures that have been trialled include: deploying energy efficient technology, offering a commercial incentive, coaching trials and taking an innovative approach towards customer engagement. For additional details on the SAVE methods, see SDRC's: 8.3: LED report; SDRC 8.4/8.7 data informed and price signals report; and SDRC 8.8 community energy coaching report.[5]

2.2 Network Investment Tool framework

In order to support its purpose and objectives, the SAVE project has developed a Network Investment Tool (NIT). The NIT has been designed as a forward-looking tool, with a Distribution System Operator (DSO) in mind.[6] In broad terms, the NIT provides the means to assess and then select a cost-efficient methodology for managing electricity distribution network constraints. The NIT considers the effectiveness of different types and degrees of energy efficiency and engagement interventions—as well as more traditional techniques for network reinforcements and 'smart' solutions—as potential approaches for a more cost efficient, appropriate and sustainable management of networks by DNOs (and as they evolve into DSOs).

The NIT has been designed to serve the needs of a number of different types of specific users within the present structure of a DNO (and within a future DSO), which include: LV network planners, who seek to mitigate problems on LV feeders and distribution transformers; HV and EHV network planners, who are responsible for ensuring that the HV network and EHV network remains within capacity limits; and, LV connections planning engineers, who are responsible for connecting new customers to the distribution network.

2 The ongoing transition to a smarter electricity system and the flexibility revolution will add significantly to these benefits, as Distribution Network Operators (DNO) transition to Distribution System Operators (DSO). www.ssen.co.uk/SmarterElectricity/

3 Assessing the Impacts of Low Carbon Technologies on Great Britain Distribution Networks (Ofgem 2012). www.ofgem.gov.uk/publications-and-updates/assessing-impact-low-carbon-technologies-great-britains-power-distribution-networks

4 See SDRC 1, section 4: Review of UK and international learning on energy efficiency and behavioural change. https://save-project.co.uk/reports-and-presentations/

5 Available at https://save-project.co.uk/reports-and-presentations/

6 The requirement for Distribution Network Operators to evolve into Distribution System Operators is a consequence of electricity delivery moving from what has effectively been a 'one-way street' towards a much more complex interconnected environment with multiple consumption and production scenarios and technologies. The NIT has been purposed with this evolution in mind to support the DNO/DSO transition process and the identification of the most effective and efficient solutions to present and future network challenges.

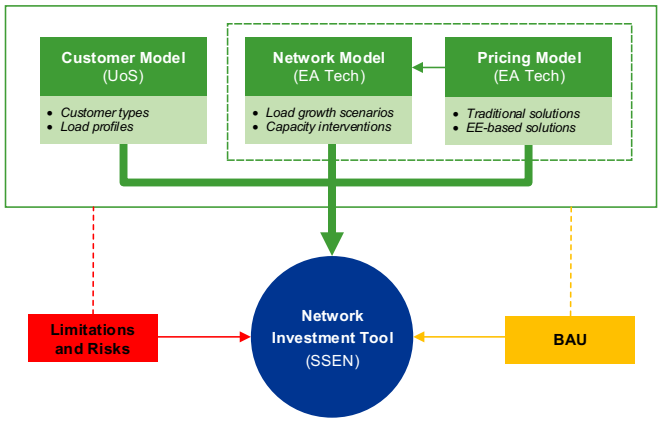
The NIT is based on a set of three comprehensive models, namely:

- Network Model.
- Pricing Model.[7]
- Customer Model.

All three of these models have been developed as part of the SAVE project with the aim to deliver an integrated overall software-based solution so that a DNO (and then a DSO) can manage the distribution network challenges they are faced with more effectively and with alternative options to traditional reinforcement. More specifically, the NIT and its underlying suite of three models have been designed to facilitate informed investment choices between using 'smart' interventions, customer engagement and energy efficiency measures as opposed to traditional technology-based measures (including reinforcement) and solutions. The NIT has been structured to run the three models described above with SAVE project data on a series of case study network conditions and associated variations of customer types/ profiles (see section 2 and thereafter).

An overview of the NIT's overall structure is provided in Figure 2.1, which depicts the modelling environment (comprising the three models) and two other components, 'business as usual (BAU)' and 'limitations and risks' which form part of the overall environment in the sense of framing and constraining the NIT's inputs and outputs and its overall utility.

Figure 2.1 Overview of Network Investment Tool environment.



A summary of the purpose, structure and anticipated output of the models within the NIT environment is provided below.

2.2.1 Network Model and Pricing Model

The Network Model simulates real-time operation and management of LV electricity distribution networks. It calculates the point in time at which a network under investigation would reach the limit of its capacity across a set of different load growth scenarios and different capacity interventions. The Network Model has been developed by EA Technology. The Pricing Model ranks the economic investment performance of traditional asset-based solutions for network infrastructure development against non-traditional network solutions whilst considering the technical constraints associated with the operation and management of the network. The Network Model allows analysis of LV, HV and EHV networks. The Pricing Model has been developed EA Technology and SSEN.

It should be noted that while the Network Model and the Pricing Model are referred to as separate entities, they are accessed by users within the same MS Excel environment for ease of use and simplicity of structure.

The Network Model and Pricing Model's MS Excel user interface[8] is supported by a backing store, which is implemented as a database in MS Access.[9] Users are provided with the functionality to undertake different types of analysis through a tabular based approach (via 18 MS Excel tabs). The types of analysis available to users are shown below in Box 1, under a network model and pricing and incentive model[10] functionalities. Network data, customer data, growth assumptions or study settings are then able to be manipulated through a further 13 MS Excel tabs and within the same environment and output reports are published in the tabs listed in each of the analysis areas.

7 Note: the pricing model operates within the same MS Excel environment as the network model.
8 While users of the Network Model and Pricing Model will interact mostly with the MS Excel interface, the underlying business logic is embedded within a Dynamic Link Library (DLL) that interfaces with the Excel environment, the load flow engines and the MS Access backing store.
9 Customer Model inputs (developed by the University of Southampton) are loaded into the Network Model and Pricing Model environment through the backing store. See section 1.2.2 for Customer Model description and detail
10 The incentive model is a subset within the pricing model which explicitly looks at the impact of different price points within dynamic pricing (potentially in future, tariff) based mechanisms using elasticity curves of price vs response.

Box 1. Type of analysis modes available to users.

Network Model functionality

- Single Assessment: allows users to review duty on a network, based on specified season and type of day. Suited to studying base case conditions without any network development.
- Future Assessment: allows users to study technical effect of one single growth scenario, which can be either those specified by BEIS or custom growth assumptions set by user.

Pricing Model functionality

- Multi-Scenario analysis: to help users understand the best way to manage an LV secondary network across different growth scenarios by investigating which capacity interventions are best selected when and what is the cheapest or least risky approach to take.
- Smart feasibility: to enable users to assess whether a user-supplied electricity storage installation can be used as an alternative to solutions presented within the costing output.
- Standalone pricing report: allows users to calculate requirements of cost signals as a standalone report outside of multi-scenario assessment process.
- HV/EHV module: to help users understand whether SAVE based interventions can provide technical and economically feasible alternative to capital reinforcement of the HV or EHV system.

The Network Model is described in detail in SDRC 7.3/8.5.[11] Further specification and detail on both the Network Model and Pricing Model can be found in the 'Customer Model, Network Model and Pricing Model report' (SDRC 8.5/8.6). SDRC 8.5/8.6 is centred around the interaction and information flows between each model that makes up the NIT. Whilst in this report (SDRC 8.2) we focus on the outputs and interpretation of results from the NIT based on a number of case studies.

2.2.2 Customer Model

In broad terms, the Customer Model represents the behaviour of trial participants in response to energy efficiency interventions. It provides customer behaviour data to the Network Model and then into the NIT environment. The Customer Model has been developed by the University of Southampton (UoS) and a complete specification and detail on its development and subsequent use can be found in SDRC 2.3.[12]

The objective of the Customer Model is to provide half-hourly demand profiles that can be applied to the modelling of loads on network assets. The Customer Model provides two output elements:

- firstly, a number of electricity demand profiles with which to represent the 'baseline' load of a number of customer types; and,
- secondly, 'intervention profiles' to provide corresponding profiles with which to represent the change in load under intervention conditions for each customer type.

11 See SDRC 7.3/8.5, Network Model and Pricing Model https://save-project.co.uk/reports-and-presentations
12 See SDRC 2.2 and 2.3, Customer Model. https://save-project.co.uk/reports-and-presentations/

Customer types[13] were developed to represent the differing levels of demand associated with a number of household characteristics, i.e. number of occupants, dwelling size and primary heating type. Customer types were chosen and developed in a practical sense (see SDRC 2.3) to balance the following constraints: model fit, to provide maximum predictive power of consumption during peak hours; maximise number of households per type that can be drawn from SAVE sample; and, minimise number of customer types to avoid over-complex implementation and constraints within the Network Model (which is limited to importing fifty demand profiles). The definitions of the customer types were aligned to match the categories within census data (see Nomis, https://www.nomisweb.co.uk), which involved recoding responses to SAVE's household survey[14] for household size, number of bedrooms and primary heating fuel. Customer demand profiles[15] were then generated from household electricity demand data collected from the large-scale SAVE sample of households, aggregated according to customer type.

Intervention profiles were generated from statistical modelling of the impact of a number of treatments aimed at reducing demand during peak hours (16:00 to 20:00) and tested using RCT runs during 2017 and 2018. The intervention profiles represent the treatment effects (change in electricity demand) observed for each customer type under the SAVE project's trial conditions.

The SAVE sample has been designed to be representative of households within the 'Solent' region[16] in order to produce findings that are able to be generalised to a wider population.[17] The processes for sampling and the allocation of participants to treatment and control groups were also randomised to avoid the introduction of self-selection or other biases. The Customer Model therefore provides load profiles for customers that can be applied to modelling across the region.

2.3 Network Investment Tool Report

The aim of this NIT report (SDRC 8.2) is to show how the Network Model, Pricing Model and Customer Model come together within the NIT environment (alongside BAU processes and software limitations). This report provides a set of evidence-based case studies in relation to different scenarios and particular network condition set ups and customer types/profiles. This NIT report directly supports the SAVE project objective to "produce a Network Investment Tool for DNOs".

The consumption demand profiles[18] for the different customer types in the Customer Model are fed into the Network Model[19] and then into the Pricing Model. If an overload is detected, the economic impacts of a chosen SAVE intervention[20] are compared to traditional reinforcement and other smart solutions within one of four specific scenarios. Each scenario has a particular set of growth assumptions in relation to the rate of penetration and uptake of three Low Carbon Technologies (LCTs): electric vehicles (EV), solar photovoltaic panels (PV) and heat pumps (HP).[21]

13 Note: due to the small number of non-gas customers within the SAVE sample, the definition of customer types was initially proposed using two variables: household size and dwelling size. However, analysis showed that there is variation in peak-hours electricity demand and profile shape in relation to primary heating (which was found to be the third-ranked variable for predicting peak-hours consumption). The customer types were therefore also disaggregated by fuel type to capture this variation and to provide a better representation of demand profiles for households using electric and other non-gas heating.

14 The SAVE project carried out an initial recruitment survey then annual update surveys to understand customer demographics and energy appetite.

15 The process of developing the Network Model (SDRC 7.2) provided a number of alignment requirements for the Customer Model and for the customer type demand profiles. This resulted in the development of a Census Interface module within the Network Model to provide the functionality to apply 'customer type' demand profiles to the Network Model (see SDRC 8.5/8.6).

16 County of Hampshire and the unitary authorities of Southampton, Portsmouth and the Isle of Wight.

17 The SAVE sample was designed by the University of Southampton to be representative of households in the Solent area by using a best practice framework and a randomised control trial (RCT) design approach (See SDRC 2.2) that involved the recruitment of a large and representative random household sample of four equal groups from the Solent Area (and where one of these groups was a control). The actual size of the required sample was established through statistical power analysis, which indicated that the SAVE project would require in the region 1,000-1,200 households per sample group and thus a total of 4,000-4,800 households to ensure that an intervention effect size of 6% or larger would be effectively detectable.

18 Where the demand at a specific time/day is modelled as an effectively random variable with a 'Normal' probability distribution and provided as mean and standard deviation values.

19 Where the consumption demand profile mean and standard deviation values provided by the Customer Model are taken to be the "" ('mean') and "" ('enhanced') values of the ACE 49 standard and DEBUT engine. For more detail on the ACE 49 standard see: ACE 49; ENA, 1981. "Report on Statistical Method for Calculating Demands and Voltage Regulations on LV Radial Distributions Systems", Energy Networks Association, 1981. This document outlines a standard for designing LV networks including a process for the treatment of diversity between customers.

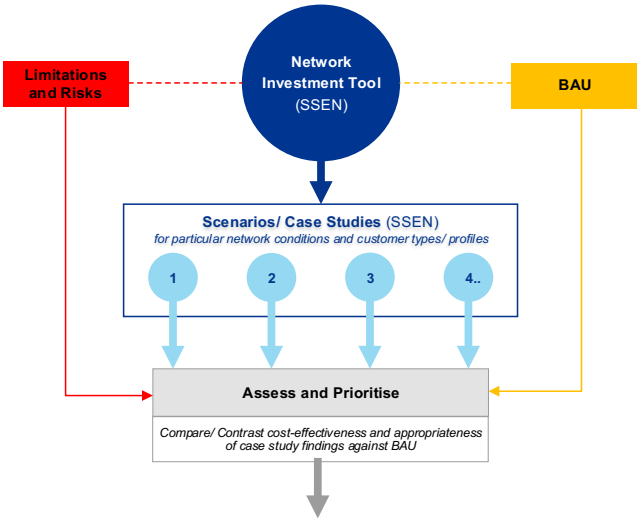
20 Note: in addition to the four 'core' SAVE interventions (LED engagement, data informed engagement, price signals, community energy coaching) there are also three traditional based intervention choices available (splitting of existing feeder, reinforcement of feeder or uprating of source transformer).

21 The details to this process are provided in SDRC 8.5/8.6

The case studies have been selected within the above framing (see Section 2.2) to broadly set out and provide additional evidence for the making of more informed investment choices between using customer engagement and energy efficiency measures as opposed to traditional technology-based measures and smart solutions.

An overview of the components and outputs of the NIT report is shown below in Figure 2.2.

Figure 2.2 SDRC 8.2 Network Investment Tool (NIT) report: components, process and output.



The NIT report has been structured as follows:

- **Section 3:** Sets out the scenarios and case studies.
- **Section 4:** Reviews the case study findings.
- **Section 0:** Assesses the findings against Business as Usual
- **Section 6:** Discusses the NIT's limitations and opportunities for further development.
- **Section 7:** Provides a summary of key findings.

Note: The NIT has not been designed with a particular DNO in mind. The approach and the internal 'structure' of the NIT has been developed so that it could be picked up and used by other DNOs (and ultimately, as part of their evolution into DSOs) through a process of integration and alignment with their specific network, pricing and customer detail, data, GIS systems, etc.

This SDRC 8.2 report contains the use of terminology that is specific to the context of the NIT and this report:

DNO and DSO: Throughout this report Distribution Network Operators and Distribution System Operators are both referred to. The former (DNO) is used when referring to the NIT supporting existing processes, whilst the latter (DSO) refers to future business as usual processes that the NIT can facilitate.

- **Model:** An individual software package designed to provide functionality to the DNO. SAVE has three models: A Customer Model, a Network Model and a Pricing Model.
- **Tool:** The combination of all three SAVE models, integrated and controlled through a single interface. SAVE has one tool, the NIT.
- **Module:** A process of operation within a model/series of models to provide a meaningful output to the user, the NIT has four main modules: single scenario, future scenario, multi-scenario and HV/EHV.
- **Scenario:** A combination of LCT uptake rates expected to occur over the years up to 2060 (although users can choose an earlier end-point for studying within the NIT).
- **Smart Solution:** A non-traditional means of network reinforcement such as battery storage, including SAVE interventions.
- **Strategy:** An approach to addressing a network constraint using a defined methodology within the Pricing Model.

3

NETWORK INVESTMENT TOOL CASE STUDIES

3.1 Case study setup/scenarios

The Network Model contains two assessment functionalities: single assessment and future assessment. The Pricing Model combines with the Network Model to provide users with a multi-scenario analysis[22] functionality through the NIT to give an understanding of the most efficient and cost-effective way to manage capacity interventions on a LV network under differing growth scenarios. The specific interventions available within the NIT include the following: SAVE interventions (community coaching[23], data informed engagement[24], pricing signals[25] and low energy lightbulbs[26]); transformer uprating; overlaying the overloaded sections of circuit with a higher rated construction; and, splitting of the feeder to create two new feeders from the original single feeder.

The Network Model's single assessment functionality (see SDRC 8.5 and 8.6 for more detail)[27] is suited to studying base case conditions without any associated network development. This functionality provides users with the ability to review the load on a network, based on a specified season and type of day. The case studies presented in this report all use a winter weekday as the day type, as this is when the SAVE interventions were trialled and the time of year network capacity is most likely to peak.

The Network Model's future assessment functionality (see SDRC 8.5 and 8.6 for more detail)[27] enables users to understand the technical effect that a particular uptake scenario and network setup might have on the network's infrastructure. The user can select LCT uptake scenarios as either those predefined based on future energy scenarios or custom growth assumptions.

The Pricing Model's multi-scenario analysis functionality and reporting output through the NIT provide an abutting sequence of capacity interventions (in relation to a network overload problem) that would ensure the network could remain within capacity over a set of time intervals. The Network Model calculates the timing interval between different capacity intervention by incrementally applying the growth parameters set by the LCT growth assumptions to understand when different sections of the studied LV network run out of capacity. When the Pricing Model detects that a branch is overloaded, it determines the next intervention required by applying three different investment strategies:

- **All-Knowing Strategy:** reviews the network problem at the end of the planning horizon (i.e. 40 years) and works backwards to understand the date when the first overloads are observed on each of the LV feeders or transformer. This strategy uses the Network Model to identify the minimum set of assets that should be built to have sufficient capacity from the year of first overload until the end of the planning horizon. The strategy can make use of physical network interventions and also non-network SAVE interventions[28]. It uses a SAVE intervention when the Network Model proves that there are sufficient respondents to eliminate an overload for a period of time and also that the cost of implementing the SAVE intervention is less than the interest earnt on deferring the capital investments over the same period of time.

- **Flexibility Minimum Strategy:** reviews the network problem at a user nominated network 'design date' which may be earlier than the end of the planning horizon. It works backwards from the network design date to understand the date when first overloads are observed on each of a networks LV feeders or transformer. It uses the Network Model to identify the minimum set of assets that should be built to have sufficient capacity from the year of first overload until the network design date. This strategy will respond to overloads observed between the network design date and the end of the planning horizon by sizing physical interventions that only last for 3 years of growth at a time. The strategy can only make use of physical network interventions, not SAVE interventions.

22 The Pricing Model considers both LV network and HV Networks as part of its analysis and provides a multi-scenario report output—which tests different interventions for technical and economic performance. Because the economic performance of a strategy is linked to which interventions are implemented when, the pricing model is able to consider how the timing of different interventions changes the overall techno-economic outcome of the network overload problem at hand.

23 which represents the action of coaching local communities to act in manner that helps defer/avoid reinforcement.

24 which represents data led engagement with customers as a means to defer/avoid network reinforcement.

25 which represents application of price signals as a means to influence customers to not use electricity at times that drive reinforcement requirements.

26 which represents the action of engaging with customers to install low energy lightbulbs as a means to defer/avoid network reinforcement

27 Available at https://save-project.co.uk/reports-and-presentations/

28 Which consist of: transformer uprating; overlaying overloaded sections of circuit with higher rated construction; splitting of feeder to create two new feeders from the original single feeder; and the SAVE interventions: community coaching, data informed engagement, pricing signals or low energy lightbulbs.

- **Flexibility Maximum Strategy:** like Flexibility Minimum, this also reviews the network problem at a user nominated network design date. It identifies the minimum set of assets that should be built to have sufficient capacity from the year of the first overload until the network design date. This strategy also responds to overloads observed between the network design date and the end of the planning horizon by sizing physical interventions that last for 3 years of growth at a time. The strategy can make use of physical network interventions and also non-network SAVE interventions. This strategy uses a SAVE intervention when the Network Model proves that there are sufficient respondents to eliminate an overload for a period of time and also that the cost of implementing the SAVE intervention is less than the interest earnt on deferring the capital investments the same period of time.

3.1.1 Growth scenarios

Four growth scenarios can be applied through the Pricing Model as part of the NIT's multi-scenario analysis functionality.[29] The four scenarios used for the purpose of this report's case studies are: Low Growth, Mid Growth, High Growth and Very High Growth. A key facet of the NIT is that these scenarios may be custom built by the user or can be selected from a set of pre-loaded predictions. This allows the NIT to assess a large variation of potential load growth predictions.

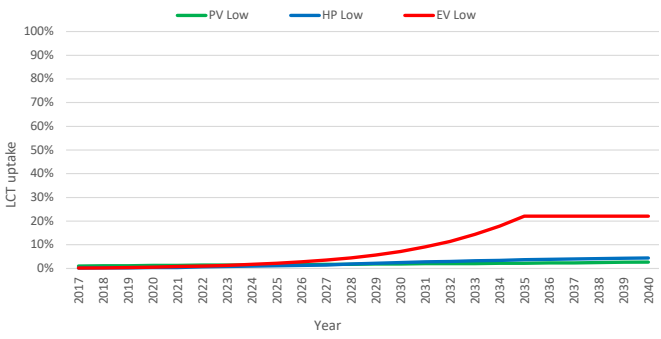
The four scenarios used for the case studies in this report have been defined to capture the variation of load growth possibilities that could be expected to occur in practice. The scenarios are based upon National Grid's Future Energy Scenarios (FES)[30] at a regional level and a defined set of predictions for the take up rates of various LCTs, which are categorised as either 'low', 'medium' or 'high' for: EVs, heat pumps and solar PV. The scenario parameters used for the case studies are shown below in Table 3.1.

Table 3.1 Growth rate scenario parameters used in NIT for the case studies.

Scenario		Load Growth					LCT Distribution			
Name		Rate (%)	LCT prob.	PV take up	HP take up	EV take up	Weighting	PV size	HP size	EV size
1	**Low Growth**	0%	SSEN RFES	Low	Low	Low	Even Distribution	3.5	4000	7000
2	**Mid Growth**	0%	SSEN RFES	Low	Low	Medium	Even Distribution	3.5	4000	7000
3	**High Growth**	0%	SSEN RFES	Low	Medium	Medium	Even Distribution	3.5	4000	7000
4	**Very High Growth**	0%	SSEN RFES	Low	Medium	High	Even Distribution	3.5	4000	7000

The uptake characteristics for the Low Growth load scenario are shown in Figure 3.1 (with low PV uptake, low HP uptake and a low EV uptake which has been capped at 2035). We've assumed uptake of household EV chargers will peak around 2035; after this the LV network is unlikely to support further adoption. It's likely that by 2035 there will be an abundance of out-of-home EV charging options (such as converted petrol stations).

Figure 3.1 LCT uptake for Low Growth scenario (Custom).

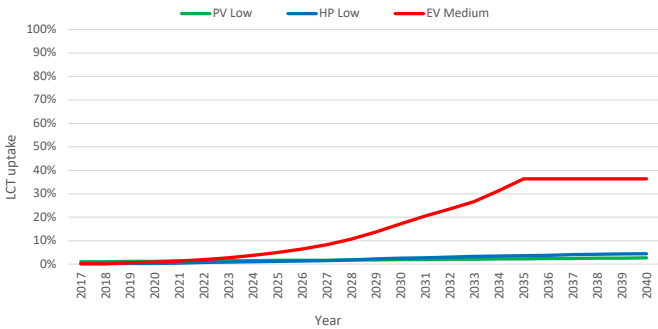


29 which helps users to identify what could be the most efficient to manage an LV secondary network across different growth scenarios by investigating which capacity interventions are best selected when and what is the cheapest or least risk approach to take.

30 The FES have been developed by National Grid to "... identify a range of credible scenarios across gas and electricity on a GB-wide basis. In order to support planning of the GB electricity transmission system, [National Grid] split the GB-level data down into regional data sets using best available data. These data sets are published in November as part of the Electricity Ten Year Statement (ETYS)". See http://fes.nationalgrid.com/fes-document/

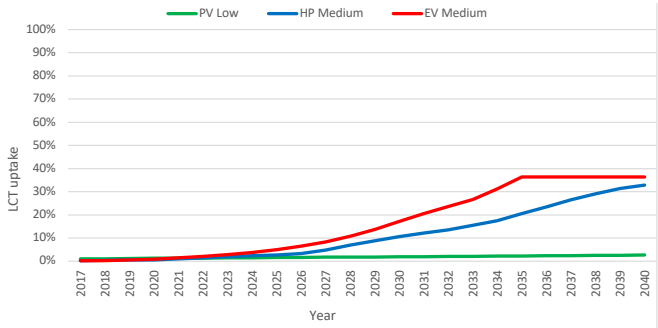
The uptake characteristics for the Mid Growth scenario are shown in Figure 3.2 (with low PV uptake, low HP uptake and a medium EV uptake which has been capped at 2035).

Figure 3.2 LCT uptake for Mid Growth scenario (Custom).



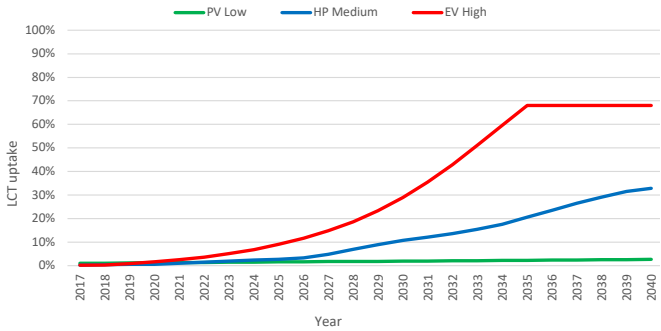
The uptake characteristics for the High Growth scenario are shown in Figure 3.3 (with low PV uptake, medium HP uptake and a medium EV uptake which has been capped at 2035).

Figure 3.3 LCT uptake for High Growth scenario (Custom).



The uptake characteristics for the Very High Growth scenario are shown in Figure 3.4 (with low PV uptake, medium HP uptake and a high EV uptake which has been capped at 2035).

Figure 3.4 LCT uptake for Very High Growth scenario (Custom).



The control panel settings used in the NIT's multi-scenario analysis for each substation used for the case studies is shown below in Table 3.2 (NIT users can define their own LCT system parameters, such as kW, kWh, VA, timings, financial, etc.).

Table 3.2 NIT control panel set up for case studies.

Start Year	2019
End Year	2040
Interest Rate	5.00%
Number of Scenarios	4
PV Size (kW - Default)	3.5
HP Size (kWh - Default)	4000
EV Charger size (VA - Default)	7000
Network Design Year	2029
Winter Peak Only?	Yes
Intervention Period (years)	3

3.1.2 Costing scenarios

The case studies have each utilised two different costing setups for the SAVE interventions:

- All SAVE intervention costs are directly covered by the DNO.
- SAVE intervention costs are entirely covered through another non-DNO funding mechanism.

As discussed in Section 0, partnerships or third party delivery may be able to substantially reduce the costs of the SAVE interventions to the DNO. Exact levels of external funding are uncertain and will vary based on many factors specific to the project. For this reason, the NIT models two extremes: full funding by the DNO and full funding from an external party. This provides evidence of two circumstances that will show the full range of funding options.

3.1.3 Costs and Net Present Value

All costs in this report are presented as net present value (NPV)[31] whereby NPV calculates the current monetary value of a project's future cash flows. NPV assumes that money is more valuable in the present than in the future and discounts future cash flows based upon a particular rate of interest.

It should be noted that the costs determined through the NIT and set out in the case studies of this report are an estimation and provided mainly as a means of comparison between interventions. While these costs use the best available data at the time of report writing, they are not indicative of actual future costs and should be used in a comparative sense against one another.

3.1.4 Assessment Timeframe

The case studies have been based on four assessment years (2025, 2030, 2035 and 2040) to enable the NIT to illustrate the evolution of load growth and to subsequently identify the most appropriate network intervention strategies.

3.1.5 Regret Analysis

The NIT examines a variation of load growth scenarios in conjunction with a range of different network intervention strategies. One of the function within the NIT to help identify optimal investment solutions to potential network load issues is the application of regret analysis.

Regret analysis is used to identify which strategy may be best placed to manage the network in the face of future uncertainty and when there is likely to be a need to intervene in network management. With the underlying idea being that the NIT will allow more informed planning forecasting, more cost-effective network management and identification of where/when smart (including SAVE) interventions may be applicable over traditional measures of network management.

Within the NIT, regret analysis examines all three of the different investment strategies with the possibility that each growth scenario may occur. Using this foundation, the regret analysis assesses the growth scenarios collectively to calculate the highest potential overspend for each intervention strategy at each of the assessment years (2025, 2030, 2035 and 2040).

Regret analysis has been applied to each of the case studies to illustrate the effectiveness and utility of the NIT and how it can assess the optimal network intervention strategy in a variety of situations. The examples used assume each load growth scenario has an equal probability of occurring. Full results of the regret analysis are available in Appendix 8.1.

3.2 Case Studies

Six case studies have been developed to illustrate the application and utility of the NIT. These are set out and described below.

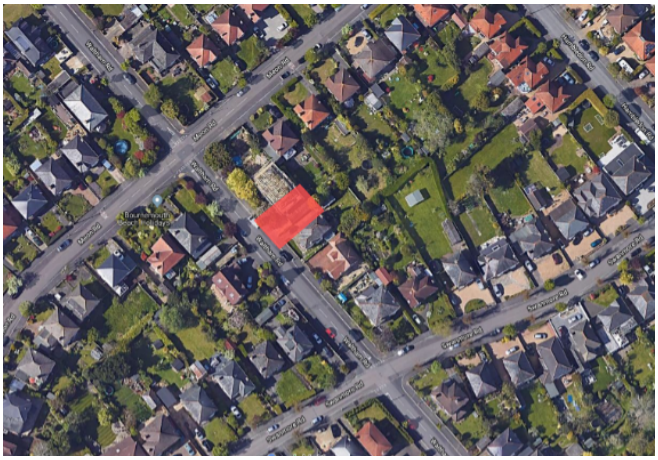
3.2.1 Case Study 1: Waltham Road

Case Study 1 (CS1) presents the findings of a multi-scenario analysis conducted for the Waltham Road substation, in Bournemouth. Waltham Road is a 'typical' urban substation with around 230 households that are mostly equally distributed across 6 feeders. Census data indicates the majority of households are either 3 or 4+ bedroom detached houses with 95% of the properties having gas as the main source of space and water heating. The area currently has one EV registered and the predicted uptake is calculated as 'high'. There is also a high predicted uptake for heat pumps.

The substation winter peak load has been calculated to be 46.7% (~230kVA) of the transformer rating, with the most heavily loaded feeder operating at 50%. There have been no thermal or voltage issues seen to date on the network in this area.

31 Corporate Finance Institute. What is Net Present Value (NPV)? https://corporatefinanceinstitute.com/resources/knowledge/valuation/net-present-value-npv/

Figure 3.5 Waltham Road Substation (red) with the surrounding area.



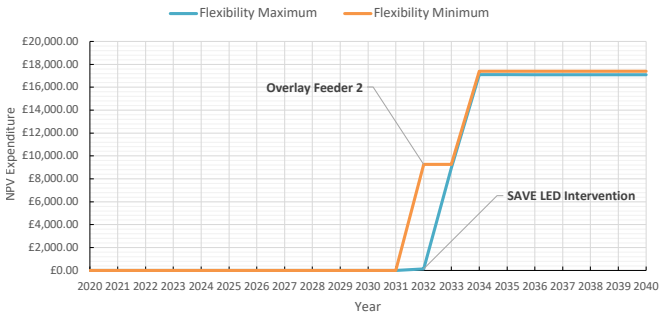
The NIT's multi-scenario analysis for CS1 has calculated differing load growth scenarios and intervention solutions along with two different costing setups for the SAVE LED intervention:

- **Case Study 1.1 (CS1.1):** all SAVE LED intervention costs are directly covered by the DNO.
- **Case Study 1.2 (CS1.2):** SAVE LED intervention costs are covered through another non-DNO mechanisms and source.

A multi-scenario analysis for CS1.1 has shown that traditional network reinforcement is optimal for all load growth scenarios. **Due to costs, the NIT would not recommend the SAVE interventions for any of the scenarios.**

The analysis for CS1.2 has shown that when the cost of the LED intervention is covered externally, the **SAVE intervention is an effective solution** to defer network reinforcement for 1-2 years in the **low growth scenario**. This approach is shown in Figure 3.6.

Figure 3.6 The use of the SAVE LED intervention as a network reinforcement deferring tool for low growth.



Running the NIT's multi-scenario analysis[32] for CS1 has revealed the following findings:

- The **low growth** scenario indicates that the first network intervention would be required in 2032, in CS1.2 this shifts to 2033, as shown in Figure 3.6;
- For **mid growth**, intervention is required in 2029;
- Whereas for **high growth**, an intervention would be needed in 2028; and,
- For **very high growth**, the network intervention would be required as soon as 2027.

The low growth scenario would require a replacement of the feeder. Whilst for mid, high and very high growth a replacement of both feeder and transformer would eventually be required to manage the increased load growth. If the low load growth scenario would be realised, the cost of the required intervention is around £18k. Whereas, to manage the very high load growth scenario there is an indication that a new substation would be required (i.e. 2000 MVA transformer intervention), this results in costs of about £340k.

In addition to the findings above, regret analysis was also conducted for CS1. In comparison to the analysis above, regret analysis examined the different load growth scenarios collectively rather than individually, to predict the optimal network intervention strategy that factors risk and opportunity together (see section 0). This analysis is calculated at each of the assessment years (2025, 2030, 2035 and 2040). The results of the regret analysis for CS1.1 and CS1.2 are shown below in Table 3.3, with the optimal strategies highlighted in green.

32 See SDRC 8.5_8.6 to see how this has been run.

Table 3.3 Regret analysis for CS1.1 and CS1.2

	Network Intervention Strategy					
	CS1.1			CS1.2		
Assessment Year	**Flexibility Minimum**	**Flexibility Maximum**	**All Knowing**	**Flexibility Minimum**	**Flexibility Maximum**	**All Knowing**
2030	£0	£0	£210k	£0	£0	£210k
2035	£28k	£28k	£55k	£28k	£28k	£55k
2040	£53k	£53k	£835	£53k	£53k	£406

For CS1 the earliest network intervention is required is in 2027, because of this the 2025 assessment is excluded from Table 3.3. The regret analysis for CS1.1 and CS1.2 has shown that up to 2030 following the All Knowing strategy would result in a potential maximum overspend of £210k in comparison to the optimal approaches; Flexibility Minimum and Flexibility Maximum which show no regret.

Furthermore by 2035, considering all the differing load growth scenarios, Flexibility Maximum and Flexibility Minimum are still the optimal strategies. Following these approaches would lead to a potential overspend £27k lower than if the All Knowing strategy would be implemented.

However, the regret analysis for the final assessment year (2040) in CS1.1, has shown that the All Knowing Strategy is the optimal approach. The regret analysis incorporates all scenarios of growth and the maximum potential overspend for the All Knowing strategy is just £835. For Flexibility Maximum and Flexibility Minimum, the corresponding figure is in excess of £50k.

As shown in Table 3.3, the regret analysis for CS1.2 is almost identical to CS1.1. The only difference can be seen in 2040. In CS1.2 the All Knowing strategy is just £400, whilst the overspend of the Flexibility Maximum and Flexibility Minimum remains over £50k.

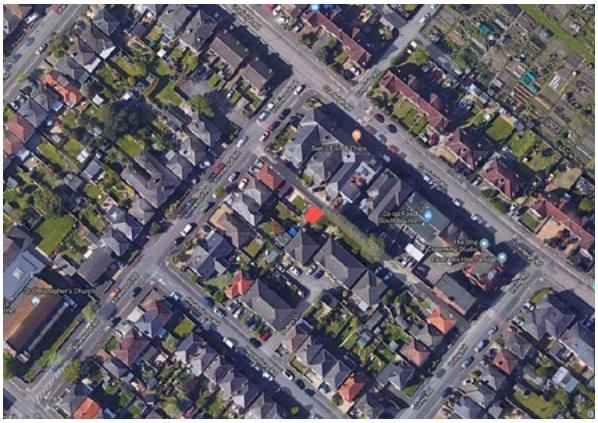
CS1 has provided a representative typical urban substation, with no existing network issues in the area. It has shown that for similar network areas the SAVE LED intervention would be effective during periods of low growth when the costs are sourced from outside of the DNO. Furthermore, CS1 has shown that when high load growth is realised in practice, even in areas with no existing issues, significant network investment would be required to reinforce the network.

Full results for CS1 can be found in Appendix 8.1.1.

3.2.2 Case Study 2: Arnewood Road

Case Study 2 (CS2) presents the findings of a multi-scenario analysis conducted for the Arnewood Road substation in Bournemouth. Arnewood Road is a 'typical' urban substation. The majority of the 243 households are 3 bedrooms, detached or semi-detached with 94% of the properties being gas heated. The area currently has three EVs registered and the predicted EV uptake is calculated as very high. Furthermore, there is a high predicted uptake of heat pumps.

Figure 3.7 Arnewood Road Substation (red) with the surrounding area.



The households are equally distributed across 5 feeders. The substation winter peak load has been calculated to be 41.6% (~200kVA) of the transformer rating, with the most heavily loaded feeder operating at 32% of capacity. There are no existing thermal or voltage issues on the network in this area.

The **multi-scenario analysis** has revealed the following findings:

- For the **low growth scenario**, no intervention action would be required in the timeframe examined (2040);
- The **mid growth scenario**, first network intervention would be required in 2035;
- Whereas for **high growth**, intervention requirement shifts to 2033; and,
- For **very high growth**, significant network intervention would be required in 2030.

The analysis for CS2 have shown that for mid, high and very high growth, network intervention would be necessary after a period of significant EV uptake in the area. The calculated implication of this would be a shift in peak demand consumption from 16:00-20:00 to 20:30-21:00. The purpose of the SAVE interventions (LED and banded pricing) was to shift peak demand outside of the 16:00 to 20:00 period, so in CS2 the **SAVE interventions would not address** this new peak. Furthermore, the calculated consumption reduction from the SAVE interventions would be insignificant in relation to the load growth from EV uptake. This is true regardless of whether the cost of SAVE interventions is borne by the DNO or externally.

The NIT analysis for CS2 illustrates that for low, mid and high growth, for all assessment years, the different strategies (All Knowing, Flexibility Maximum and Flexibility Minimum) would all recommend identical network interventions. The result of this is that the regret analysis in this instance is only assessing the differing techniques towards network intervention in a very high growth scenario. This analysis is shown below in Table 3.4.

Table 3.4 Regret analysis for CS2.

Network Intervention Strategy			
Assessment Year	Flexibility Minimum	Flexibility Maximum	All Knowing
2030	£0	£0	£72k
2035	£0	£0	£58k
2040	£2.8k	£2.8k	£0

The regret analysis for CS2 identified the following findings:

- Up to 2030, the All Knowing strategy would accrue excess costs of over £70k in comparison to the alternative strategies;
- By 2035, even with the increased network interventions, Flexibility Maximum and Flexibility Minimum are still the optimal solutions, All Knowing overspends by almost £60k;
- In 2040, the All Knowing strategy is the optimal approach, the alternative strategies overspend by £2.8k.

The regret analysis findings from the analysis of CS2 are as expected. The All Knowing strategy was designed with the goal of the final assessment year (2040) and as such excessively reinforces at the earlier assessment dates in comparison to the alternative strategies. The result of this is that Flexibility Maximum and Flexibility Minimum would be the optimal approach. However, by 2040, All Knowing becomes the optimum strategy as it has the lowest figure.

CS2 provides a representation of an urban network with no existing issues, lightly loaded feeders but with a very high existing LCT uptake. The analysis of CS2 has shown that for similar examples the SAVE LED intervention would not be part of the optimal strategy. The eventual load growth associated with LCT uptake would result in a shifting of the peak demand and excessive load growth in relation to the potential achievable reductions through SAVE. For similar areas of the network it would be more effective to use traditional network reinforcement.

Full results for CS2 can be found in Appendix 8.1.2.

3.2.3 Case Study 3: Allan Way

Case Study 3 (CS3) presents the findings of a multi-scenario analysis conducted for the urban Allan Way substation, North Acton. The majority of the properties in the area are 3 or 4 bedrooms, detached or semi-detached (94% of the households are gas heated). Currently, there is one EV registered and the predicted uptake is high. Furthermore, the projected potential heat pump uptake is high.

The substation is classified as non-typical due to the high number of households; there are 485 households unequally distributed across 4 feeders. The households are distributed across the feeders so that two are highly loaded, one is moderately loaded, and one is lightly loaded.

Figure 3.8 Allan Way substation (red) and the surrounding area.

The substation winter peak load is calculated at 65% (~520kVA) of the transformer rating. The most heavily loaded feeder is at 94% of capacity; even with a small LCT uptake, this feeder will be marginally above thermal and voltage limits due to its long lengths and small cross sections of conductors.

The multi-scenario analysis for CS3 revealed the following findings:

- The feeder which is at its thermal and voltage limits would require network intervention in 2019;
- After this initial intervention, the subsequent necessary intervention for low growth would be in 2029;
- For mid growth, 2026;
- For high growth, this shifts to 2027;

And for very high growth, an extensive replacement or duplication of the network would be required.

In all scenarios of load growth, both feeders and transformer replacement are required. The network intervention necessary in low growth would cost around £200k. For mid, high and very high growth a new substation (2000 MVA transformer) would be required. The cost for this measure for mid growth would be about £340k and for high growth, £495k. The NIT was unable to calculate the costs for very high growth due to the very high level of reinforcement necessary.[33]

In CS3 the existing network is very highly loaded; in conjunction with a high predicted uptake in customers, and the subsequent load growth, this would result in the SAVE interventions not being a feasible solution to defer network reinforcement. The regret analysis for CS3 is shown in Table 3.5.

Table 3.5 Regret analysis for CS3

Network Intervention Strategy			
Assessment Year	Flexibility Minimum	Flexibility Maximum	All Knowing
2025	£0	£0	£140k
2030	£0	£0	£147k
2035	£33k	£33k	£31k
2040	£33k	£33k	£3k

The analysis revealed the following findings:

- Up to 2030, Flexibility Maximum and Flexibility Minimum would be the optimal strategy, the All Knowing results in a significant unnecessary network overspend;
- However, 2035 and 2040, the optimal strategy would be All Knowing as the overspend, in comparison to the alternative approaches, is £2k lower in 2035, and £30k lower in 2040.

CS3 has illustrated a non-typical substation; non-typical in that a high number of households are distributed disproportionally across feeders causing a proportion to be very heavily loaded. This situation is likely replicated across different areas of the network. The implications of this situation have been shown to require significant network intervention in all scenarios of load growth.

The NIT has effectively shown in CS3 that for areas of the network that have disproportionally heavily loaded feeders the resulting load growth expected would result in significant network intervention required imminently.

Full results for CS3 can be found in Appendix 8.1.4.

33 None of the solutions within the NIT would be able to mitigate the expected load growth. However, in flagging this, the NIT is prompting a planner to identify other solutions. It is anticipated, at this point, the planner would run a "future scenario" assessment for just this scenario, in order to get a better understanding of the scale of the technical impacts.

3.2.4 Case Study 4: Beechwood Avenue

Case Study 4 (CS4) presents the findings of a multi-scenario analysis conducted for the Beechwood Avenue substation, in Sunbury-on-Thames. This is an urban substation and the majority of the properties are detached or semi-detached, with over 65% having 3 or 4+ bedrooms (96% of households are gas heated). The location currently has three EVs registered and the predicted uptake is very high.
In addition, the projected heat pump uptake is high.

The substation in CS4 is classified as 'non-typical'; in this example, there are a high number of households that are unevenly distributed across the six feeders. The distribution of the 522 households across the feeders is such that one feeder is highly loaded, two are moderately loaded, and three are lightly loaded.

Figure 3.9 Beechwood Avenue substation (red) with the surrounding area.

The substation winter peak load has been calculated to be 90% (~450kVA) of the transformer rating, with the most heavily loaded feeder operating at 88%. There are no existing thermal issues on the network in this area.

The multi-scenario analysis for CS4 revealed the following findings:

- For the low growth scenario, the first network intervention would be required in 2028;
- In the mid growth scenario, this would shift to 2024;
- In the high growth scenario, network intervention would be required in 2023;
- For very high growth, the analysis indicates that existing network capacity is insufficient and that a major network overhaul would be required.

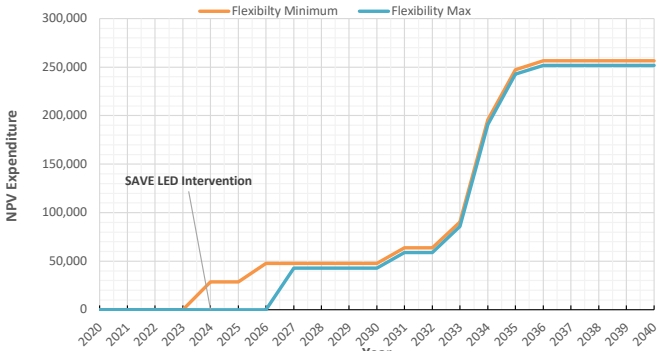
The analysis for CS4 has illustrated that for all load growth scenarios the replacement of both the feeder and the transformer would be necessary. The network intervention required for low growth results in costs between £41k-£56k. If mid-, high- or very high growth scenarios are realised, the costs would be significantly higher as a new substation (i.e. 2000 MVA transformer) would be required. For mid growth, expenditure would be around £260k-£360k, whilst the high growth scenario, network intervention would cost between £485-£640k. In the case that very high growth would be realised, it's likely that the entire network would require replacement or duplication. The extent of network intervention required would be so significant that the NIT was unable to predict the financial impact.

The NIT multi-scenario analysis for CS4 has calculated differing load growth scenarios and intervention solutions along with two different costing setups for the SAVE LED intervention:

- Case Study 4.1 (CS4.1): all SAVE LED intervention costs are directly covered by the DNO.
- Case Study 4.2 (CS4.2): SAVE LED intervention costs are entirely covered through another non-DNO mechanism and source.

In both instances, the **SAVE LED intervention is cost effective** only under the mid growth scenario, where it could defer higher network reinforcement costs and result in a more optimal NPV. The LED intervention would effectively defer network reinforcement (the new transformer mentioned above) for up to 3 years in both cases. When the cost is borne by the DNO, the SAVE LED intervention would be part of network intervention under the All Knowing strategy only. When the cost is covered by an external party, the LED intervention is cost-effective under both the All Knowing and Flexibility Maximum network strategies. Figure 3.10 illustrates the effectiveness of the SAVE LED intervention at deferring network intervention in the Flexibility Maximum, in comparison to the Flexibility Minimum, for CS4.2.

Figure 3.10 The use of the SAVE LED intervention as a network reinforcement deferring tool for mid growth scenario (CS4.2).



However, for the high growth scenario the SAVE LED intervention would be ineffective; the analysis has shown the demand reduction achieved would be insignificant in relation to the year on year load growth associated with the LCT uptake in the area. The NIT also highlighted the SAVE LED intervention would not be part of the optimal strategy for low growth[34].

CS4 has shown that for all scenarios but low growth, significant and costly network intervention would be required. The analysis has shown the SAVE LED intervention would be part of the All Knowing strategy for mid growth; the use of the intervention upfront would result in a less fragmented, and less disruptive, network intervention approach later in the assessment period. The effectiveness of the intervention is illustrated in Figure 3.11 and Figure 3.12 for CS4.1.

Figure 3.11 Network intervention for mid growth scenario without SAVE LED intervention (Flexibility Minimum strategy).

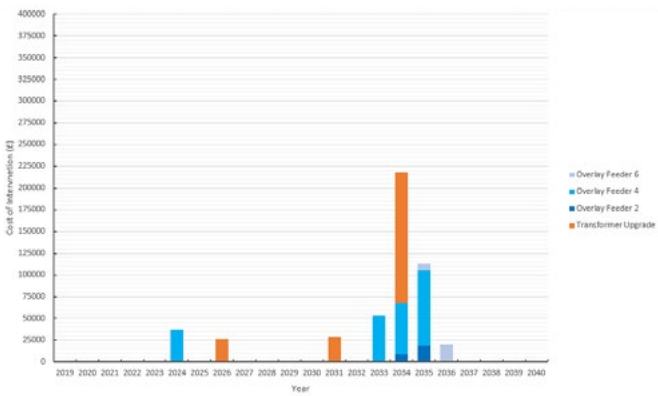
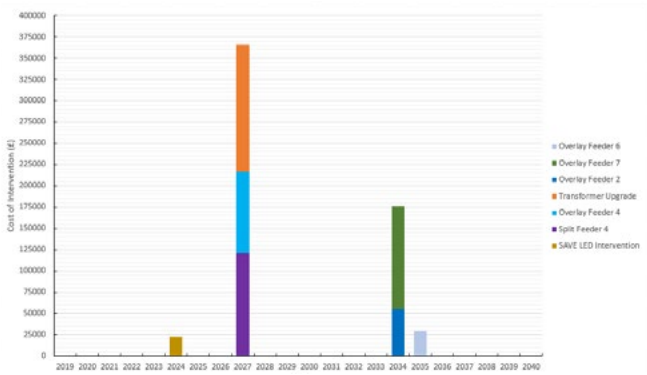


Figure 3.12 Optimal network intervention for mid growth scenario with the SAVE LED intervention (All Knowing strategy).



The regret analysis for CS4 is shown in Table 3.6.

34 This is because the asset replacement required in low growth is not as extensive and hence the NPV of deferral is not available

Table 3.6 Regret analysis for CS4.

	Network Intervention Strategy					
	CS4.1			CS4.2		
Assessment Year	**Flexibility Minimum**	**Flexibility Maximum**	**All Knowing**	**Flexibility Minimum**	**Flexibility Maximum**	**All Knowing**
2025	£29k	£0k	£359k	£29k	£0	£359k
2030	£0	£0	£271k	£4.7k	£0	£270k
2035	£15k	£15k	£184k	£15.1k	£15.7k	£183k
2040	£15k	£15k	£156k	£15.1k	£15.7k	£156k

The regret analysis for CS4.1 revealed the following findings:

- In 2025, Flexibility Maximum is the optimal approach, and hence should mid load growth materialise the use of SAVE LED's would be optimal;
- By 2030, Flexibility Maximum and Flexibility are the optimal strategy, All Knowing approach accrues £271k in excess expenditure;
- For 2035 and 2040, Flexibility Maximum and Flexibility Minimum remain the clear optimal approaches in comparison to the All Knowing approach (which while not 'optimal' in 2040 is the cheapest in terms of total cost when considering that the NPV reflects an earlier spend profile).

The regret analysis for CS4.2 (the costs of the SAVE LED intervention are covered externally) produced the following findings:

- In 2025, the same results are found for CS4.1, Flexibility Maximum is the optimal approach;
- For 2030, the impact of souring the LED intervention from outside are shown, with Flexibility Maximum becoming the exclusive optimal strategy in comparison to the results of CS4.1. Flexibility Minimum is now £4.7k more expensive in comparison;
- However, for 2035 and 2040, Flexibility becomes the optimal strategy.

CS4 is representative of an area that despite having no existing network issues has a very heavily loaded feeder and a substation with a winter peak load close to the total capacity. The projected load growth in the area is predicted to require substantial network reinforcement in all growth scenarios other than low. For very high load growth the NIT has shown that substantial network reinforcement would be required; likely a significant overhaul of the network in the area.

Full results for CS4 can be found in Appendix 8.1.4.

3.2.5 Case Study 5: Heritage Centre

Case Study 5 (CS5) presents the findings of the multi-scenario analysis for the substation at Heritage Centre, Wiltshire. The majority of the 67 properties are 4 bedrooms detached or semi-detached. This substation is in a semi-rural area; it is a modern substation designed to the most recent standards for households with electric heating. In CS5, 100% of the households have air source heat pumps for heating and water; no households use natural gas for heating. As the substation is already at 100% heat pump uptake, the analysis will only examine the uptake of EVs in the area. The location currently has two EVs registered, with a very high predicted uptake.

Figure 3.13 Heritage Centre substation (red) with the surrounding area

The substation distributes the 67 households across 3 feeders. The substation winter peak load is calculated at 66% (~330kVA) of the transformer rating. In addition, the most heavily loaded feeder is at 65% of capacity. There are no existing thermal or voltage issues on the network.

The multi-scenario analysis for CS5 revealed the following findings:

- Without reinforcement, the substation can effectively support EV uptake up to 45%;
- Only in the realisation of the very high growth scenario would network reinforcement be required within the assessed timeframe (up to 2040);
- In this situation, reinforcement would be required to take place in 2032.

As shown network intervention would not be required in low, mid, or high growth scenarios for CS5. Due to this, the regret analysis exclusively examines the intervention strategies implemented from 2032, only if very high growth is realised. The findings from the regret analysis for CS5 are shown in Table 3.7.

Table 3.7 Regret analysis for CS5

	Network Intervention Strategy		
Assessment Year	Flexibility Minimum	Flexibility Maximum	All Knowing
2035	£1.8k	£1.8k	£0
2040	£1.8k	£1.8k	£0

In both the assessment years (2035 and 2040), the All Knowing approach would be the optimal strategy. For each case, enacting the Flexibility Maximum or Flexibility Minimum strategies would result in an overspend of nearly £1.8k. This is as expected as the All Knowing strategy is designed with the later assessment years as the aim and the delay before the minor reinforcement required in CS5 resonates with the design.

The characteristics of the substation in CS5, a substation requiring low network intervention, would mean the **SAVE interventions are not feasible.**

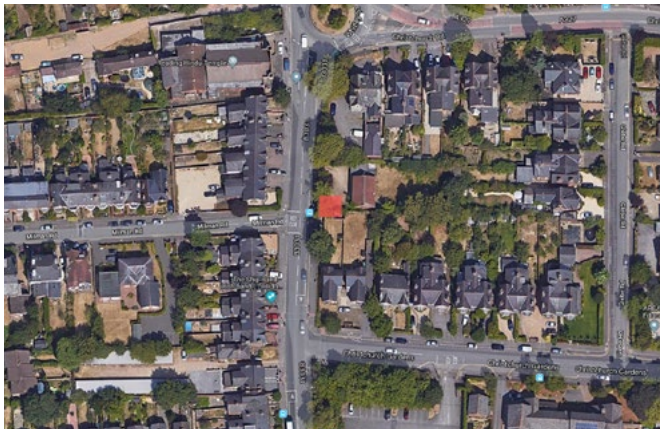
CS5 is representative of an area that has a high proportion of heat pumps and a low number of households distributed across feeders. Applied broadly this illustrates that similar areas of the network would only require reinforcement if very high load growth is realised, even if there is a high EV uptake.

Full results for CS5 can be found in Appendix 8.1.5.

3.2.1 Case Study 6: Christchurch Garden

Case Study 6 (CS6) presents the multi-scenario analysis for the substation at Christchurch Gardens, Reading. The urban substation is in the centre of Reading with 62% of properties 1 or 2 bedrooms. 32% of households are heated electrically, 61% gas heated, and the remaining 7% are heated by another source (e.g. oil). The area currently has six EVs registered and the predicted uptake is high.

Figure 3.14 Christchurch Garden substation (red) with the surrounding area.



The substation in CS6 is considered non-typical due to the high number of households; 527 households are fairly evenly spread across 6 feeders. The substation winter peak load is calculated at 42% (~420 kVA) of the transformer rating, and the most heavily loaded feeder is at 68% of capacity. There are no existing thermal or voltage issues on the network in the area.

The NIT multi-scenario analysis for CS6 has calculated differing load growth scenarios and intervention solutions along with two different costing setups for the SAVE LED intervention:

- Case Study 6.1 (CS6.1): all SAVE LED intervention costs are directly covered by the DNO.
- Case Study 6.2 (CS6.2): SAVE LED intervention costs are entirely covered through another non-DNO mechanism and source.

In both instances, the **SAVE LED intervention is part of the optimal network strategy in the high growth scenario.**

In CS6.1, the analysis has shown the SAVE LED intervention is part of the optimal network intervention strategy under the All Knowing strategy only. The intervention, taking place in 2027, would effectively defer reinforcement for up to 2 years. Figure 3.15 and Figure 3.16 illustrate the effectiveness of the SAVE LED intervention at deferring network intervention.

The exclusion of the SAVE LED intervention from the Flexibility Maximum was due to the resulting fragmented implementation of network reinforcement and the detrimental implications this would have on the NPV.

For CS6.2, the LED intervention would be optimal within the Flexibility Maximum and the All Knowing strategies and would defer reinforcement for up to 2 years.

The SAVE LED intervention would not be recommended for low and mid growth for either costing setups (CS6.1 and CS6.2). This is due to the fact that the specific (traditional) network intervention successful deferred by the SAVE intervention (extensive overlay of feeder 2) in the high growth scenario would not be present under the low and mid growth scenarios.

Figure 3.15 Network intervention for high growth scenario without the SAVE LED intervention (Flexibility Minimum, CS6.1)

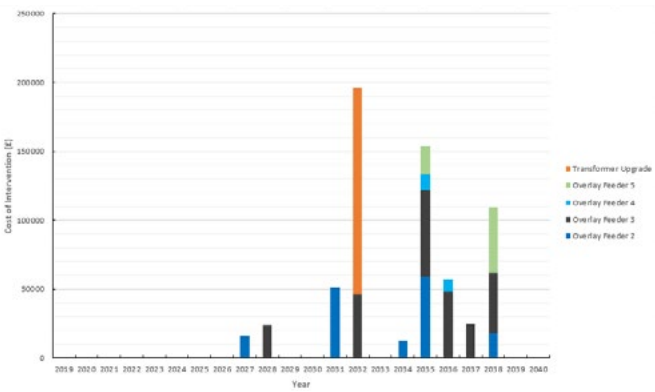
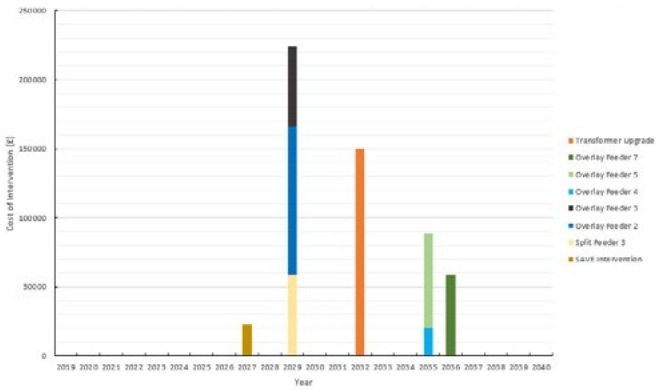


Figure 3.16 Optimal network intervention for high growth scenario with the SAVE LED intervention (All Knowing, CS6.1)



The multi-scenario analysis for CS6 has revealed the following findings:

- For the low growth scenario, first network intervention would be required in 2033;
- For mid growth, intervention is required in 2029;
- For high growth, intervention would be necessary in 2027, with the use of the SAVE LED intervention this shifts further to 2029;
- And for very high growth, an extensive replacement or duplication of the network would be required.

The analysis revealed that for mid, high and very high growth scenarios both feeder and transformer replacement would be required. In addition, a new substation (i.e. 2000MVA transformer) would be necessary for the three growth scenarios. The cost of the interventions for mid growth would be £145k and for high growth, £300k-£315k. For the very high growth scenario, the NIT was unable to calculate the predicted financial impact due to the extremely high level of reinforcement necessary. The NIT illustrates that if very high growth would be realised a planner should run a future assessment to identify an alternative solution.

In the low growth scenario, only a feeder replacement would be necessary. The cost of the intervention required would be between £36k to £38k depending on the investment strategy.

As the NIT was unable to calculate the interventions for the very high scenario, this was excluded from the regret analysis. The regret analysis of CS6.1 and CS6.2 revealed findings shown in Table 3.8.

Table 3.8 Regret analysis for CS6 **Table 3.8 Regret analysis for CS6**

	Network Intervention Strategy					
	CS6.1			CS6.2		
Assessment Year	**Flexibility Minimum**	**Flexibility Maximum**	**All Knowing**	**Flexibility Minimum**	**Flexibility Maximum**	**All Knowing**
2030	£690	£0	£112k	£0	£0	£49k
2035	£0	£0	£37k	£10.5k	£0	£4.2k
2040	£16k	£16k	£1.6k	£79k	£68k	£1.6k

The regret analysis for CS6.1 has shown the following:

- In 2030, Flexibility Maximum is the optimal strategy, £690 more cost efficient than Flexibility Minimum, and £112k better than the All Knowing;
- For 2035, following the All Knowing strategy would lead to an increased potential overspend of 37k, in comparison to the alternative strategies;
- By 2040 however, the All Knowing strategy is now the optimal approach. It is 16k more cost efficient than the alternative strategies.

Meanwhile the regret analysis for CS6.2 illustrated the following:

- In 2030, implementing the All Knowing strategy would lead to an increased overspend of £49k in relation to the optimal alternative approaches;
- By 2035, the Flexibility Maximum is the recommended strategy, £4.2k more cost efficient than All Knowing and £10.5k than Flexibility Minimum;
- For the last assessment year, 2040, All Knowing is the optimal solution. It is £67k more cost efficient than Flexibility Minimum, and £77k, in comparison to Flexibility Minimum.

CS6 is representative of a network area that has a typical distribution of households across feeders in conjunction with a mixed heating supply. The analysis has shown that in this similar instance the SAVE LED intervention would be effective under a high load growth scenario. Implemented the SAVE LED intervention would effectively defer network reinforcement by up to 2 years. However, the analysis has shown if a very high load growth is achieved then significant network intervention would be required; the extent of intervention would be to such an extent that the NIT was unable to calculate the recommended network intervention strategy.

Full results for CS6 can be found in Appendix 8.1.6.

4

REVIEW OF CASE STUDIES

Section 3 provided BaU ready evidence of the functionality of the NIT through six case studies. In each example, the NIT predicted network issues and identified the optimal intervention strategy for various growth scenarios.

Each of the case studies chosen provided a variety of characteristics that are representative of broader network traits. This ensures the findings are likely to be replicated across the wider network and are relevant to the utilisation of the NIT. Table 4.1 below provides a summative overview of the case studies and their characteristics.

Table 4.1 Overview of the case studies

		CS1	CS2	CS3	CS4	CS5	CS6
Number of Households		230	243	485	522	67	527
Feeders		6	5	4	6	3	6
Most Heavily Loaded Feeder (%)		50%	32%	94%	88%	65%	68%
Winter Peak Load on Transformer (%)		46.7%	41.6%	65%	90%	66%	42%
Households Heated by Gas (%)		95%	94%	94%	96%	0% (100% HP)	61% 32% electric
LCT Uptake	EV (current)	High (1)	V. High (3)	High (1)	V. High (3)	V. High (2)	High (6)
	HP	High	High	High	High	100% (N/A)	High
SAVE Applicable? (by Growth Scenario)	Low	(X)[35]					
	Mid				X		
	High						X
	V. High						

35 (X) – indicates only when the costs are covered from a source other than the DNO.

The longitudinal summary above shows that the optimal strategy varies based on the substation chosen, load growth scenario and assessment timeframe. As DNO's improve their forecasting and gain more certainty around the trajectory of LCTs, a planner may choose to run less scenarios through the tool. This will allow the DNO to better determine which investment strategy is the least risky.

SAVE interventions were part of the optimal intervention for half of the case studies. In the examples presented, SAVE would be effective at deferring network reinforcement for 1 to 3 years. This delay would be beneficial to the DNO in terms of both NPV gained on deferring reinforcement and wider social benefits (see Section 5).

SAVE interventions were found to be most effective when a given substation was experiencing low load growth and a heavily loaded network. The decision to implement SAVE interventions needs to balance the rate of LCT uptake and current network load. These aspects are important as they contribute to the time in which a SAVE intervention can be useful; if network planners wait too long to implement SAVE, the reduction achieved would be insignificant in comparison to additional load from LCT uptake. If the initial load growth is too high, the load reduction achievable through the SAVE intervention (to defer reinforcement) would be insignificant.

The following sections illustrate how network characteristics influence the recommendation to implement SAVE interventions.

4.1 Load growth and network loading

A SAVE intervention would be part of the optimal network strategy if:

- **Load growth is low and the network is heavily loaded.**

In instances in which these characteristics are present, the SAVE intervention would be effective in deferring network reinforcement. A network that is highly loaded indicates that some sort of network intervention will be required soon. However, if load growth is low, traditional reinforcement is not necessary immediately; the SAVE intervention could be more cost-effective.

The consumption demand reduction achieved through the SAVE intervention would effectively mitigate the low load growth, thus deferring traditional reinforcement by up to 3 years. This would result in a more favourable NPV in the long term. Furthermore, the delay achieved from the SAVE intervention could ensure a more cohesive network intervention strategy could be formulated. This means the reinforcement strategy will be less fragmented; leading to less disruption to customers and financial savings for the DNO.

Conversely, a SAVE intervention would not be part of the optimal strategy if:

- **Load growth is high and the network is heavily loaded.**

When these network characteristics are present, the SAVE intervention would be ineffective. The combination of high load growth and a heavily loaded network indicates that significant network reinforcement would be required imminently. The achievable load reduction from the SAVE intervention would be insignificant in comparison to the high load growth. As a result, when these characteristics are present within the network, traditional reinforcement strategies would be recommended.

Additionally, when analysing the 'very high' load growth scenario, the NIT is sometimes unable to recommend interventions, as no combination of reinforcement assets available to the NIT meet the load growth. The NIT effectively flags when and where this occurs, prompting a planner to identify other solutions that can manage the observed load growth. In order to gain a better understanding of the scale of the technical impacts, the planner would need to run a 'Future scenario' assessment and look at this scenario individually. Where this occurs, SAVE interventions would not be effective.

- **Load growth is low and the network is lightly loaded.**

For lightly loaded networks with low load growth, a SAVE intervention would not be required. The low load growth in conjunction with a lightly loaded network implies that network reinforcement would not be required in the short-term or medium-term. The network reinforcement will be necessary only when high load is expected due to an increasing LCT uptake[36]. However, the subsequent load increase from the LCT uptake would outstrip the achievable reductions from the SAVE intervention.

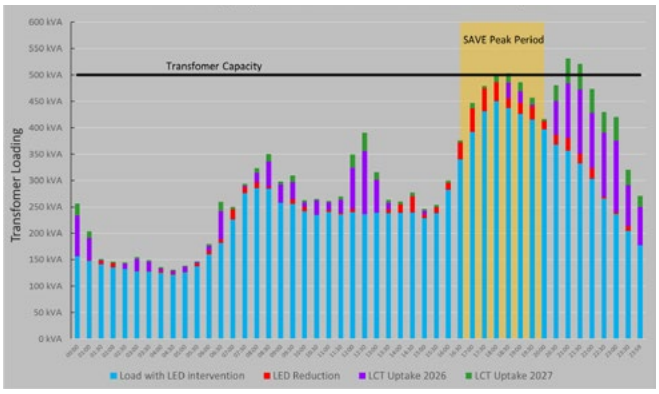
36 It is expected for all growth rates LCT uptake will eventually outstrip the load demand reduction achievable via SAVE. See Figure 3.1.

The above-mentioned scenarios provide some clear guidance on when SAVE interventions could make an impact on deferring or avoiding network reinforcement. There are cases where the impact of a SAVE intervention is ambiguous. For example, in a mid-growth and medium loaded network scenario, the effectiveness of SAVE interventions highly depends on the pace of the load growth and its impact on the capacity of the network.

- **Load growth has created a new, later peak.**

Uptake of LCTs, especially EVs, has the potential to create a new, later peak after the traditional peak period. In this case, the SAVE interventions will have limited impact as they were only designed to address peaks that occur between 16:00 and 20:00. SAVE was designed to address the peak period of current load profiles, not future load profiles. Figure 4.1 shows an example; this figure shows how the load profile of CS4 (Beechwood Ave.) changes over time. Here the SAVE intervention (reduction shown in red) is enough to offset load growth until 2026 (show in purple) but not later (2027 shown in green), as there is a new, later peak after 21:00 due to EV uptake.

Figure 4.1 Transformer capacity with SAVE LED intervention and medium LCT uptake



This shows the need for additional intervention measures, such as smart EV charging or extending the peak period to later in the day. However, the later a peak occurs, the less useful SAVE is, as the SAVE interventions rely primarily on customer engagement and behaviour. (For example, if most customers are asleep when the network peaks, they have limited ability to shift their consumption in response to a price signal.) Future SAVE-like interventions could explore how automation can reduce late peaks by shifting load from EV chargers or electric heating.

4.2 Network reinforcement type

The SAVE interventions were frequently found to be part of the optimal network intervention strategy when certain traditional network reinforcements are required. A SAVE intervention would be most effective when larger traditional network reinforcement is required within a network intervention strategy. The higher cost of larger network reinforcements means that even a short deferral of the traditional reinforcement can result in significantly more favourable NPVs. For this reason, the NIT recommends SAVE interventions more frequently when they can defer large network reinforcement projects. Here SAVE interventions act a first solution, followed by traditional reinforcement.

4.3 Areas with high penetration of electric heating

The NIT shows a relationship between a high uptake of electric heating in an area and the effectiveness of SAVE interventions. The likelihood of SAVE being an effective solution depends on the time when intervention is required.

Frequently, networks with a high penetration of electric heating have been specifically designed to accommodate a high load. Because of this, network intervention is generally not necessary in the short-term or medium-term. In these cases, by the time the network load is close to capacity, the corresponding increase in load from LCTs is often greater than the reduction achievable from the implementation of the SAVE interventions (see exponential pattern of LCT uptake forecasted in Figure 3.1 LCT uptake for Low Growth scenario (Custom).Figure 3.1 - Figure 3.4).

However, if the network in question is already highly loaded (and close to capacity), the SAVE intervention may be effective as part of the optimal network intervention strategy. In this instance, heat pump penetration is already very high, so subsequent load demand growth will be only due to EV uptake (in the scenarios used). This means the overall rate of growth is likely to be lower than areas experiencing both EV and heat pump uptake. As a result of this slower load growth rate, the SAVE intervention can effectively mitigate against the load growth for a short period. Delaying traditional network reinforcement will increase the long term NPV.[37]

As has been shown by the contrasting examples, the required timing of interventions is crucial to the effectiveness of the SAVE intervention in areas with high penetration of electric heating. If load growth is low but intervention is required in the short- or medium-term, then the SAVE intervention can successfully mitigate against the load growth.

37 Section 4.1 describes where this is seen in the case studies.

4.4 Investment strategy and regret analysis

As detailed in Section 3.1.1, the NIT uses regret analysis to identify which investment strategy is best placed to manage the network in the face of future uncertainty.

The regret analysis examines all three of the different investment strategies (All Knowing, Flexibility Minimum and Flexibility Maximum) with the possibility that each growth scenario may occur. Using this foundation, the regret analysis assesses the growth scenarios collectively to calculate the highest potential overspend for each intervention strategy at each of the assessment years (2025, 2030, 2035 and 2040). Different investment strategies can greatly impact the regret analysis for a given assessment years.

The All Knowing strategy frequently results in extensive network reinforcement in early years to accommodate high network loads in the later years. This means that different assessment years can result in very different regrets for the All Knowing strategy. The case studies reveal that following the All Knowing strategy would frequently result in a high potential overspend for the earlier assessment years (2025, 2030, and sometimes 2035).

For example, the All Knowing strategy may recommend a single, more expensive intervention once instead of multiple interventions. This means that in 2025, this single, more expensive intervention may look like a stranded asset, as it would result in a higher than required network capacity. However, by 2040, the All Knowing would be the optimal strategy as it is meeting the demand without any additional reinforcement. These results are as expected per the design; the All Knowing strategy is intended to work back from the final assessment year (2040).

As designed, if a SAVE intervention was not recommended by the Flexibility Maximum strategy, the Flexibility Minimum would produce an identical network intervention strategy. However, in the case studies the All Knowing would often include a SAVE intervention. This indicates if a marginally (financially) riskier strategy with more extensive reinforcement was implemented (meaning a higher upfront investment), the SAVE interventions would likely feature more prominently.

4.5 Future case studies: 'Live Watch List'

A key finding from the NIT was the ability to easily track and evaluate the urgency of network intervention across the network. The ever-evolving data set of network issues and solutions allows the formulation of a 'live watch list' of LV investment plans. The NIT illustrates the earliest time that network intervention would be required per LV substation, if the highest load growth scenario is realised.

The continuously evolving, 'live' nature of this data has numerous benefits. Live data for substations across the network enables the DSO to have a network-wide plan for required interventions. Using the data, the DSO can accurately predict future expenditure and develop a long-term budget. The adaptability of the tool enables this budget planning to respond to any real-world implications, such as economic factors, social factors and governmental policy.

Examples of economic factors that may have an impact on budget and planning within the NIT include but are not limited to:

- NPV is heavily influenced by the interest rate. The DNO can use the NIT and the Live Watch List to examine the implications of a changing interest rate and evaluate whether it is preferential to delay reinforcement, where possible.
- Energy prices can change from one year to another, or even hourly (such as a time of use tariff), which will affect the business case and the NPV of a reinforcement. The Live Watch List provides visibility on the impact of energy prices on the different areas of the network and facilitates decision making.
- Broad changes in the national economy and other factors might also result in changes that affect the revenues of the DSO. For example, projects such as Targeted Charging Review, led by Ofgem, could also affect decision making on network interventions.

In addition, the Live Watch List has social benefits as well as economic. It allows the DSO to better engage with communities by identifying which type of customers are located close to specific LV assets that appear on the intervention watch list (and therefore may require intervention). The identification of these communities allows the DSO to tailor the customer engagement approach towards the area. The DSO can disperse relevant advice to encourage a reduction in consumption. The existence of the evolving live data set also allows the DSO to further predict the effectiveness of customer engagement approaches offered. Furthermore, by the time network intervention is eventually required, the DSO has had ample time to actively prepare customers for network intervention; helping reduce overall disruption.

Finally, the Live Watch List allows the DSOs to respond in advance of changes to government policy. The DSO can closely monitor the impact of a government policy on load growth or customers' behaviour and re-assess whether reinforcement will be required sooner or later than initially expected. For example, a government regulation on insulation in housing would massively affect the load growth of residential areas and may reduce load growth due to EV uptake. As such, an intervention in a residential area could be de-prioritised, based on the NIT outcomes.

5

BUSINESS AS USUAL

5.1 Network planning

In the past, network planning has mainly been driven through load growth from new connections, namely because growth from existing connections has historically been small (and in some cases, negative, as lighting, appliances and equipment get more efficient). However, as the UK Government pursues a low carbon agenda that encourages electrification of heat and transport, load on electricity networks is predicted to rise rapidly. This will require DNOs to develop new planning strategies and overhaul their existing processes.

This NIT will allow network planners better visibility of their current network loads and how those loads will evolve in the future. The NIT allows DNO planners to make informed investment decisions based on real world customer and network data.

Currently, the NIT can provide the following:

- **Prediction of required investment:** The NIT can highlight how much investment is required to support future load growth. The tool can be run by network type (urban, rural, etc.) to show how this may vary by area. This will allow DNOs to assess how many substations will need updating in the next price control review and the investment required.
- **Prediction of overloads:** The NIT shows where overloads occur under various loading scenarios and for how long. This can help network planners better understand the longevity of network assets.
- **Impact of LCTs:** The NIT shows the penetration of LCTs that can be accommodated with current network equipment. This will allow DNOs to predict what areas of their networks will be most impacted by the uptake of LCTs and to plan accordingly.
- **Consistency:** While past network planning may have used assumptions about the location and make-up of end-users, the NIT uses real world census data. The tool also uses load profiles derived from over 4,000 real households. This results in a more consistent and realistic approach in network planning.
- **Reinforcement methods:** The NIT shows the most cost-effective way to manage capacity interventions under various growth scenarios. It reviews both traditional reinforcement interventions (such as a transformer upgrade or feeder overlay) and SAVE interventions to determine what approach is most suitable and when.

5.1.1 Constraint managed zones

DNOs currently procure flexibility by tendering with third parties for various forms of network management and incentivising this through both availability and utilisation payments. Within SSEN this is referred to as a constrained managed zone (CMZ). To date, SSEN has released five CMZs, all focused on reinforcement deferral. Value of the service provision is calculated as the NPV of postponing network reinforcement for up to six years. Past CMZs have not seen responses that include domestic demand side response (DSR) or energy efficiency like the interventions trialled in SAVE. The development of Social Constrain Managed Zones (SCMZ) seeks to remove barriers to entry for non-traditional demand response, such as SAVE interventions.

The NIT will provide DNOs direct insight into the level of demand response they could expect from domestic DSR and energy efficiency interventions as well as what parts of the network could best utilise this kind of intervention. Again, the tool uses real world customer and network data to realistically predict intervention impact and cost savings. DNOs can use the NIT to determine where to establish SCMZs and which interventions are likely to be cost effective. DNOs can even use the NIT to evaluate and validate SCMZ tender responses to ensure they are realistic and cost-effective.

5.2 Partnership or third party delivery of SAVE interventions

Delivery of SAVE interventions by a third party or through a partnership may be preferable for a number of reasons:

- Lower cost to DNO
- Regulatory barriers
- Greater visibility and trust with (vulnerable) customers
- Increased uptake of socially optimal flexibility solutions

5.2.1 Lower costs

DNOs may be able to procure SAVE-like interventions through third party competitive procurement. Competitive procurement in itself may lead to cost reductions, while some third parties will be able to access funding sources not available to DNOs. This means a smaller amount of the SAVE cost would need to be borne by the DNO.

5.2.1.1 Benefit stacking

DNOs may wish to specifically work with organisations who have access to additional funding or revenue streams. For example, an Energy Service Company (ESCO) may be able to utilise funding from government schemes (such as the Energy Company Obligation, or ECO, scheme[38]) or encourage customers to partly finance energy efficiency measures. Local groups such as charities or councils may also have their own funding to contribute, further lowering the cost to the DNO.

Partnering with other utilities may also allow DNOs to share costs. For example, a DNO could partner with a water utility to roll out LEDs and water saving devices at the same time. This would greatly reduce the cost of the installation staff, since costs are split between two parties without drastically increasing the time required on-site.

DNOs should explore the most economical way to deliver SAVE interventions through partnerships or third party delivery. For this reason, all case studies were run with two funding circumstances: (1) where the DNO bears the full cost of the SAVE intervention and (2) where all funding for the SAVE intervention comes from outside parties. The results present the full range of funding options available to DNOs in a BAU scenario (see full results in section 3).

5.2.2 Regulatory barriers

There are some potential regulatory considerations to DNO deployment of SAVE interventions as economic and best practice considerations. Potential barriers stem from electricity distribution standard licence conditions (SLCs) and relate specifically to the installation of an electricity monitor. The SLCs do not allow a DNO to own equipment that is installed 'behind the meter' in customer premises. This is not likely to be necessary for all SAVE interventions, however, household monitoring is essential to the deployment of SAVE's Banded Pricing intervention. While DNOs could seek a license derogation, a simpler option would be to have a third party deliver this service and own the electricity monitors or access the data from smart meters.

To access the benefits of SAVE interventions whilst satisfying license requirements and maximising returns under RIIO, DNOs need to ensure that (1) a particular solution delivers net benefits to connected customers, and (2) the solution is delivered so that its potential benefits are maximised.

For additional information about the regulatory barriers faced by a BAU deployment of SAVE interventions, see the SAVE Regulatory Report.[39]

5.2.3 Greater visibility and trust with customers

Focus groups conducted by the SAVE project showed that many customers do not understand what a DNO is or what DNO responsibilities are. The lack of awareness around DNOs makes it more difficult for householders to understand why they may be getting information from DNOs about SAVE interventions. Historically, DNOs have had limited interaction with customers. For these reasons, DNOs may not be best placed to lead delivery of customer-centric interventions such as SAVE. While a DNO may be involved in SAVE interventions, communication of these interventions needs to be clearly managed.

Third party delivery can actively address these issues. It is important that customers trust and know the organisation delivering SAVE interventions. Partnerships with councils, local or charitable organisations may be more successful than a DNO-led intervention. These kinds of organisations are often already known in a community and may know the best routes to customer engagement.

5.2.3.1 Vulnerable customer engagement

Through engaging customers more actively through domestic DSR mechanisms (in particular the DNO led approach to energy efficiency rollout outlined in SDRC 8.3) a DNO can both better engage existing priority service register[40] (PSR) customers and engage customers that might benefit from being on the PSR register. This is not only socially optimal and improves a DNO's reputation with their customers but can be reported to Ofgem as evidence of part of a DNO's 'customer service and social obligations' commitment under RIIO.

5.3 Increased uptake of socially optimal flexibility solutions

Mechanisms trialled on SAVE such as energy efficiency trials may offer socially optimal external benefits not traditionally captured by the DNO. For different mechanisms, these external benefits (or costs) may vary. One example, aligning with wider political targets, may be carbon reductions. Whilst a DNO cannot currently quantify such mechanisms it should consider such factors as part of its wider corporate social responsibility (CSR). Likewise, the DNO may be able to identify some delivery partners whose business models directly address the social benefits that are 'external' to the DNO's revenue streams. By partnering with such organisations, this benefit could theoretically reduce the cost of rollout and hence applicability of SAVE interventions.

38 Additional information about ECO is available at Ofgem's website here: https://www.ofgem.gov.uk/environmental-programmes/eco
39 DNV GL. SAVE Regulatory Report. 2018. https://save-project.co.uk/reports-and-presentations/
40 The PSR is set up to help identify those most in need in cases of outages and/or extreme weather.

6

NETWORK INVESTMENT TOOL LIMITATIONS AND OPPORTUNITIES FOR FUTURE DEVELOPMENT

As with any tool that is subject to external constraints and is based on a combination of complex models, the NIT has some inherent limitations. These relate primarily to the confines of the NIT's constituent models (Network, Pricing and Customer models) and how they interact. However, this also provides opportunities to develop the model environment further to improve and maximise its benefits. Where limitations exist, the report also includes the mitigating steps that begin to address many of these issues.

The NIT is not a static tool but is designed to be easily adaptable to other networks, technologies, and growth scenarios. In the future, it can be updated with new data to reflect emerging patterns and trends. While the load growth scenarios, LCT uptake rates and investment strategies reflect a snapshot of current thinking, these can easily be expanded upon or updated in the future. A key benefit of the NIT is that it was designed to be as flexible as possible so as to be useful to a wider range of stakeholders and applications.

The sections below discuss the key opportunities and limitations in the NIT as currently designed. Full discussions of the limitations of each constituent model are available in other SDRCs.[41]

6.1 Growth scenarios

To recognise that it can be problematic, or indeed incorrect, to commit to a single growth forecast, the LV multi-scenario environment allows up to four growth scenarios to be studied. A design choice was made to limit the number of scenarios that could be studied simultaneously to avoid excessive computation time which would make the NIT unwieldy. Four scenarios are commensurate with the number of scenarios being used by other utilities (e.g. National Grid's future energy scenarios document). For SAVE analysis we have created low, medium, high and very high load growth scenarios that include varying degrees of uptake of EVs, solar PV and heat pumps.

As with any prediction of the future, assumptions were required about technology deployment, customer behaviour, and uptake rates (among others). There is inherent uncertainly around these assumptions and they may need to be updated in the future. As with any model that uses forecasts, it is expected that the veracity of these data sets will develop and improve as (over time) more information becomes available on the key variables in the NIT.

Future iterations of the NIT could modify these growth scenarios or add completely new ones as new data or load growth predictions become available. The adaptability of the NIT allows the growth scenarios to contain a wide variety of characteristics; these can be utilised to model different areas of the network or to include new LCTs. Future LCTs could include: residential energy storage, hydrogen for heating, multiple types of EV chargers or multiple EVs per home, multiple heat electrification types, sophisticated smart appliances that respond to system signals and more.

As currently designed, the NIT allows for three LCT types. These are: a single size of solar PV array, one EV type and one heat pump. The NIT does contain the ability to modify the profiles of the LCTs between assessment runs but it lacks the function of changing this within an assessment run. Any modifications require overwriting the existing LCT profile. For example, if a user wanted to view the impact of two sizes of EV chargers, they would have to replace either the heat pump or solar PV profile in order to use two EV profiles.

This is noted as a limitation as it may not properly take account of the likely deployment of LCTs but presents an opportunity to further develop the tool to make input assumptions on LCT uptake more dynamic and, perhaps, more reflective of reality.

41 See: SDRCs 2.1, 2.2 and 2.3 (for Customer Model); SDRCs 7.1, 7.2 (for Network Model); SDRC 7.3 and 8.5 (Network Model and Pricing Model report); and, SDRC 8.5 and 8.6 (Customer Model, Network Model and Pricing Model report).

SSEN is already working on improving predictions of LCT uptake using data from Green City Vision (in Swindon) and Transition and LEO (in Oxford)[42]; smart meters also present an opportunity for improvement. With the wider deployment of smart meters across the UK, there will be a wealth of high-quality, real-world data that can be used to update the assumptions on LCT uptake (and therefore load growth).

The flexibility inherent within the NIT in being able to assess varying growth scenarios and load profiles presents a key opportunity.

6.2 Load profiles and customer types

Currently, customer types were created within the Customer Model to represent the differing characteristics of households and the resulting variability in peak demand consumption. This is an improvement on the previous process of modelling network demand. A key feature within SAVE was a sample size large enough to detect statistically significant treatment impacts; however, in some cases the groupings of uncommon characteristics of customers caused small sample size within sub-groups (customer types), thus, the project could not be confident these were representative of the demand profiles for all customers. This issue is of particular concern within households heated with fuels other than gas, as these represented only 10% of the overall sample. More data is needed for the uncommon household types, especially those that are electrically heated.

In the future, the NIT could be updated with new customer data or additional load profiles. These can be used to improve on the current data, show consumption patterns in different (non-Solent) regions or reflect future changes in consumption habits. SSEN is already investigating how the NIT can be expanded to allow a greater number of load profiles (and therefore customer types).

SSEN will also investigate the best way to collect data to improve upon the customer types and load profiles, especially for uncommon customer types like homes with electrical heating.

6.3 New interventions and technology

The NIT includes the interventions tested in the SAVE project. However, these do not reflect all the demand-side interventions possible now or in the future. The tool can easily be expanded to include a wider variety of interventions or types of energy efficiency. This could include smart interventions such as smart EV charging, supplier-led Time of Use (TOU) pricing, or the deployment of new energy efficient technologies. These providers of new technology or interventions could utilise real-world smart meter data to develop load profiles showing the impact of their product. These load profiles can then be imported into the NIT to show DNOs how their product could assist in network management and feed in to planning decisions.

6.4 Interoperability between substations and voltage levels

Currently, the NIT looks at each substation in isolation. The NIT does not take a holistic view of the LV network to provide connectivity across substations or how the interventions may impact HV or EHV network. This means that the benefits of SAVE interventions to the HV or EHV networks are not reflected in the tool.

SSEN has developed a separate module that models the HV and EHV networks (see SDRC 8.5/8.6). For the purpose of the SAVE project, the functionality of the HV/EHV module has been limited to dealing with network problems that are thermal loading problems under winter peak import conditions that can be resolved to a radial simplification. This module assumes that the HV or EHV planning engineer has already determined the cheapest capital intervention and wishes to understand whether SAVE interventions can be used to defer this capital scheme. The HV/EHV module has also been developed with the intention of using it to study electrical demand dominated areas, it is not expected to cover network problems caused by too much generation.

The HV/EHV module could be expanded from its current state to run load flow studies in the same way the LV NIT does. This would allow network planners to predict the impact of SAVE interventions across multiple substations and on the HV and EHV networks.

42 For additional information, see http://news.ssen.co.uk/news/all-articles/2019/april/ssen-announces-ground-breaking-innovation-project-to-inform-the-future-of-local-energy-systems/

6.5 Benefit stacking and social impact

Currently, the tool cannot deploy multiple interventions; it can only look at one intervention per model run. However, it is highly likely that deploying multiple interventions at the same time (such as LED lighting in conjunction with banded pricing) would result in larger peak reductions than either measure alone. This presents an upside against any modelled single intervention scenario.

Additionally, the tool does not account for any social benefits of the SAVE interventions (such as carbon savings or air quality improvements from reduced power generation). While the UK Government provides some high-level guidance on how to quantify social benefits in the Green Book[43], the Government does not indicate how these may be applicable to DSOs. Including social benefits in the analysis would likely provide a stronger indication that SAVE interventions are the preferred approach.

This means that the benefits of the SAVE interventions are likely underreported in the outputs of the NIT.

6.6 Reinforcement and investment strategies

The NIT is designed to SSEN's own network design policies on reinforcement and investment, which themselves are based on current industry standards and engineering best practice. While other DNOs generally follow similar design policies, the tool has been specifically designed to be easily adaptable to other design and reinforcement policies if needed.

Further investment strategies can be added to the NIT in the future to reflect changing priorities of DSOs and/or additional sources of funding. Additionally, the methodology and data of the NIT are easily transferable to other DSOs' networks, even if they use different network planning software. Other DSOs are encouraged to dissect the NIT and integrate the modules of most value into their business processes.

43 HM Treasury. 2018. The Green Book: appraisal and evaluation in central government. https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

7

CONCLUSIONS

This SDRC: 8.2- NIT report has shown how the Network Model, Pricing Model and Customer Model are able to connect within the NIT environment (and alongside BAU processes and software limitations) to provide additional evidence for the making of more informed investment choices between using customer engagement and energy efficiency measures as opposed to traditional technology-based measures and smart solutions.

Six representative case studies selected for analysis, under four potential future scenarios (low, medium, high and very high growth), were discussed within this report and have provided the following insight:

- **For a representative typical urban substation with no existing network issues (Waltham Road, case study 1),** it has been shown by the NIT that a SAVE-type intervention can be effective during periods of low growth when the costs of these interventions are sourced from outside of the DNO.

- **For an urban network with no existing issues and lightly loaded feeders with a very high LCT uptake (Arnewood Road, case study 2),** it has been shown by the NIT that a SAVE-type intervention should not be part of the optimal investment strategy. The eventual load growth associated with Low Carbon Technology (LCT)[44] uptake would result in a shifting of the peak demand and excessive load growth in relation to the potential reductions achievable through a SAVE intervention. For such network areas it would be more effective to use traditional network reinforcement approaches than SAVE.

- **For a non-typical substation with a high number of households that are distributed disproportionally across feeders causing a proportion to be very heavily loaded (Allan Way, case study 3),** it has been shown by the NIT that this would require significant network intervention in all scenarios of LCT-based load growth. Furthermore, the NIT showed that for areas of the network that have disproportionally heavily loaded feeders the resulting load growth expected would result in a significant and rapid network intervention requirement. In this case, SAVE interventions were not able to address the network issues.

- **For a network with a very heavily loaded feeder and a substation with a winter peak load close to its total capacity (Beechwood Avenue, case study 4),** it has been shown by the NIT that the projected load growth would require substantial network reinforcement in all growth scenarios other than for low growth. The SAVE LED intervention is cost effective under the mid growth scenario, where it could defer higher network reinforcement costs and result in a more optimal NPV.

- **For a network area with a high proportion of heat pumps and a low number of households distributed across feeders (Heritage Centre, case study 5),** the NIT shows that the network would only require reinforcement if a very high load growth is realised, even if there were a high electric vehicle uptake. SAVE interventions were not feasible for this case study.

- **For a network area with a typical distribution of households across feeders in conjunction with a mixed heating supply (Christchurch Gardens, case study 6),** the NIT has shown that a SAVE-type intervention could be effective under a high load growth scenario.

These case studies have provided a number of high-level findings:

- **A SAVE intervention could be part of an optimal network investment strategy where load growth is low and the network is heavily loaded.** In instances in which these characteristics are present, a SAVE intervention would be effective in deferring network reinforcement for up to three years. A network that is highly loaded indicates that some sort of network intervention will be required soon. However, if load growth is low, traditional reinforcement is not necessary immediately; the SAVE intervention would be more cost-effective.

44 Electric Vehicle, Heat Pump and solar photovoltaics.

- **A SAVE intervention would be most effective when larger traditional network reinforcement is required within a network intervention strategy.** The higher cost of larger network reinforcements would mean that even a short deferral of the traditional reinforcement can result in significantly more favourable NPVs. For this reason, the NIT recommended SAVE interventions more frequently when they can defer large network reinforcement projects. Here SAVE interventions act as a first solution, followed by traditional reinforcement.

- **There is a relationship between a high uptake of electric heating in an area and the effectiveness of SAVE interventions.** The likelihood of SAVE being an effective solution depends on the time when intervention is required. The contrasting examples used for the case studies showed that the required timing of intervention is crucial to the effectiveness of the SAVE intervention in areas with high penetration of electric heating. If load growth is low but intervention is required in the short- or medium-term, then the SAVE intervention can successfully mitigate against the load growth.

- **A SAVE intervention would not be part of an optimal investment strategy if load growth is high and the network is heavily loaded.** When these network characteristics are present, a SAVE intervention would be ineffective. The combination of high load growth and a heavily loaded network indicates that significant network reinforcement would be required imminently. The achievable load reduction from the SAVE intervention would be insignificant in comparison to the high load growth. As a result, when these characteristics are present within the network, traditional reinforcement strategies would be recommended. It should be noted that for a 'very high' load growth scenario, the NIT is sometimes unable to recommend interventions, as no combination of reinforcement assets available to the NIT would be able to meet the load.

- **No short- or medium-term intervention would be required for lightly loaded networks with low load growth.** The low load growth in conjunction with a lightly loaded network implies that network reinforcement would not be required in the short-term or medium-term. The network reinforcement will be necessary only when high load is expected due to an increasing LCT uptake. However, the subsequent load increase from the LCT uptake would outstrip the achievable reductions from the SAVE intervention.

- **A SAVE intervention will have limited impact if load growth creates a new, later peak.** Uptake of LCTs, especially EVs, has the potential to create a new, later peak after the traditional peak period. In this case, some of the current SAVE interventions may have limited impact as they targeted peaks that occurred between 16:00 and 20:00 (data-informed and price signal trials in particular). Future SAVE-like interventions could trial messaging at different hours of the day to determine how customers' capacity to shift their consumption changes.

- **A key finding from the NIT was the ability to easily track and evaluate the urgency of network intervention across the network.** The ever-changing data set of network issues and solutions allows the formulation of a 'live watch list' of LV investment plans. The NIT has been able to illustrate the earliest time that network intervention would be required per LV substation, if the highest load growth scenario is realised.

The NIT was designed to be highly flexible and adaptable, and should not be viewed as a static tool. As such, there are a number of areas in which the tool has inbuilt flexibility to allow DNOs to tailor it their own needs:

- **Growth scenarios:** The NIT's LV multi-scenario environment allows up to four growth scenarios to be studied. Future iterations of the NIT could modify these growth scenarios or add completely new ones as new data or load growth predictions become available. The growth scenarios in the NIT contain a wide variety of characteristics; these can be utilised to add new LCTs or to model different areas of the network. Future LCTs may include hydrogen heating, other electric heating types, smart appliances, residential energy storage, multiple types of EV chargers or multiple EVs per home, and more.

- **Load profiles and customer types:** The NIT could be updated with new customer data to update or create additional load profiles. These could be used to improve on the current data, show consumption patterns in different (non-Solent) regions or reflect future changes in consumption habits. SSEN is already investigating how the NIT could be expanded to allow a greater number of load profiles (and therefore customer types).

- **New interventions and energy efficient technology:** The NIT currently includes all interventions tested in the SAVE project, however, these do not reflect all the demand-side interventions currently possible or in the future. The NIT could be easily expanded to include a wider variety of interventions or types of energy efficiency such as smart interventions (smart EV charging), supplier-led Time of Use pricing, or the deployment of new energy efficient technologies. Providers of new technology or interventions could utilise real-world smart meter data to develop load profiles showing the impact of their product. These load profiles could then be imported into the NIT to show DNOs how their product could assist in network management.

- **Interoperability between substations and voltage levels:** At present, the NIT assesses each substation in isolation and does not take a holistic view of the LV network to provide connectivity across substations or how the interventions may impact HV or EHV network. SSEN has developed a separate module that models the HV and EHV networks. The HV/EHV tool could be expanded from its current state to run load flow studies in the same way the LV NIT does. This would allow network planners to predict the impact of SAVE interventions across multiple substations and on the HV and EHV networks.

- **Benefit stacking and social impact:** At present, the NIT looks at one intervention per model run. It is highly likely that deploying multiple interventions at the same time would result in larger peak reductions than either measure alone. This presents an upside against any modelled single intervention scenario. Additionally, the tool does not currently account for any social benefits of the SAVE interventions (such as carbon savings or air quality improvements from reduced power generation). Including social benefits in the analysis would likely provide a stronger indication that SAVE interventions are the preferred approach. This means that the benefits of the SAVE interventions are likely underreported in the outputs of the NIT.

Reinforcement and investment strategies: The NIT has been designed to SSEN's own network design policies on reinforcement and investment, which themselves are based on current industry standards and engineering best practice. While other DNOs generally follow similar design policies, the tool has been specifically designed to be easily adaptable to other design and reinforcement policies if needed. In the future, additional investment strategies could be added to the NIT to reflect changing priorities of DSOs and/or additional sources of funding. Additionally, the methodology and data used in the NIT are easily transferable to other networks, even if they use different network planning software.

8

APPENDICES

8.1 Detailed case study results

The detailed results from the six NIT case studies presented in section 3 are set out below.

8.1.1 Caste Study 1: Waltham Road

Table 8.1 Regret tables for CS1.1

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 2	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2030	All Knowing	£ -	£ 31,432.36	£ 75,754.44	£ 286,190.82
	Flexibility Min	£ -	£ 20,611.70	£ 22,161.65	£ 75,636.25
	Flexibility Max	£ -	£ 20,611.70	£ 22,161.65	£ 75,636.25
	Minimum	£ -	£ 20,611.70	£ 22,161.65	£ 75,636.25
	Maximum	£ -	£ 31,432.36	£ 75,754.44	£ 286,190.82

	Regret					Worst Regret
	All Knowing	£ -	£ 10,820.66	£ 53,592.79	£ 210,554.57	£ 210,554.57
	Flexibility Min	£ -	£ -	£ -	£ -	£ -
	Flexibility Max	£ -	£ -	£ -	£ -	£ -
					Least Worst Regret	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 3	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2035	All Knowing	£ 18,232.45	£ 51,806.87	£ 101,608.87	£ 286,190.82
	Flexibility Min	£ 17,398.22	£ 66,430.09	£ 129,527.70	£ 231,071.95
	Flexibility Max	£ 17,398.22	£ 66,430.09	£ 129,527.70	£ 231,071.95
	Minimum	£ 17,398.22	£ 51,806.87	£ 101,608.87	£ 231,071.95
	Maximum	£ 18,232.45	£ 66,430.09	£ 129,527.70	£ 286,190.82

	Regret					Worst Regret
	All Knowing	£ 834.23	£ -	£ -	£ 55,118.87	£ 55,118.87
	Flexibility Min	£ -	£ 14,623.22	£ 27,918.83	£ -	£ 27,918.83
	Flexibility Max	£ -	£ 14,623.22	£ 27,918.83	£ -	£ 27,918.83
					Least Worst Regret	£ 27,918.83

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 4	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2040	Regret	£ 18,232.45	£ 51,806.87	£ 101,608.87	£ 286,190.82
	Flexibility Min	£ 17,398.22	£ 66,430.09	£ 129,527.70	£ 340,152.21
	Flexibility Max	£ 17,398.22	£ 66,430.09	£ 129,527.70	£ 340,152.21
	Minimum	£ 17,398.22	£ 51,806.87	£ 101,608.87	£ 286,190.82
	Maximum	£ 18,232.45	£ 66,430.09	£ 129,527.70	£ 340,152.21

	Regret					Worst Regret
	All Knowing	£ 834.23	£ -	£ -	£ -	£ 834.23
	Flexibility Min	£ -	£ 14,623.22	£ 27,918.83	£ 53,961.39	£ 53,961.39
	Flexibility Max	£ -	£ 14,623.22	£ 27,918.83	£ 53,961.39	£ 53,961.39
					Least Worst Regret	£ 834.23

Table 8.2 Regret tables for CS1.2

		Low Growth	Mid Growth	High Growth	Very High Growth	
Assessment Year 2	Strategy	Outcome	Outcome	Outcome	Outcome	
		Scenario1	Scenario2	Scenario3	Scenario4	
2030	All Knowing	£ -	£ 31,432.36	£ 75,754.44	£ 286,190.82	
	Flexibility Min	£ -	£ 20,611.70	£ 22,161.65	£ 75,636.25	
	Flexibility Max	£ -	£ 20,611.70	£ 22,161.65	£ 75,636.25	
	Minimum	£ -	£ 20,611.70	£ 22,161.65	£ 75,636.25	
	Regret					Worst Regret
	All Knowing	£ -	£ 10,820.66	£ 53,592.79	£ 210,554.57	£ 210,554.57
	Flexibility Min	£ -	£ -	£ -	£ -	£ -
	Flexibility Max	£ -	£ -	£ -	£ -	£ -
					Least Worst Regret	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth	
Assessment Year 3	Strategy	Outcome	Outcome	Outcome	Outcome	
		Scenario1	Scenario2	Scenario3	Scenario4	
2035	All Knowing	£ 17,498.73	£ 51,806.87	£ 101,608.87	£ 286,190.82	
	Flexibility Min	£ 17,398.22	£ 66,430.09	£ 129,527.70	£ 231,071.95	
	Flexibility Max	£ 17,091.79	£ 66,430.09	£ 129,527.70	£ 231,071.95	
	Minimum	£ 17,091.79	£ 51,806.87	£ 101,608.87	£ 231,071.95	
	Regret					Worst Regret
	All Knowing	£ 406.94	£ -	£ -	£ 55,118.87	£ 55,118.87
	Flexibility Min	£ 306.43	£ 14,623.22	£ 27,918.83	£ -	£ 27,918.83
	Flexibility Max	£ -	£ 14,623.22	£ 27,918.83	£ -	£ 27,918.83
					Least Worst Regret	£ 27,918.83

		Low Growth	Mid Growth	High Growth	Very High Growth	
Assessment Year 4	Strategy	Outcome	Outcome	Outcome	Outcome	
		Scenario1	Scenario2	Scenario3	Scenario4	
2040	All Knowing	£ 17,498.73	£ 51,806.87	£ 101,608.87	£ 286,190.82	
	Flexibility Min	£ 17,398.22	£ 66,430.09	£ 129,527.70	£ 340,152.21	
	Flexibility Max	£ 17,091.79	£ 66,430.09	£ 129,527.70	£ 340,152.21	
	Minimum	£ 17,091.79	£ 51,806.87	£ 101,608.87	£ 286,190.82	
	Regret					Worst Regret
	All Knowing	£ 406.94	£ -	£ -	£ -	£ 406.94
	Flexibility Min	£ 306.43	£ 14,623.22	£ 27,918.83	£ 53,961.39	£ 53,961.39
	Flexibility Max	£ -	£ 14,623.22	£ 27,918.83	£ 53,961.39	£ 53,961.39
					Least Worst Regret	£ 406.94

8.1.2 Case Study 2: Arnewood Road

Table 8.3 Regret tables for CS2

		Low Growth	Mid Growth	High Growth	Very High Growth	
Assessment Year 2	Strategy	Outcome	Outcome	Outcome	Outcome	
		Scenario1	Scenario2	Scenario3	Scenario4	
2030	All Knowing	£ -	£ -	£ -	£ 87,701.89	
	Flexibility Min	£ -	£ -	£ -	£ 15,494.00	
	Flexibility Max	£ -	£ -	£ -	£ 15,494.00	
	Minimum	£ -	£ -	£ -	£ 15,494.00	
	Maximum	£ -	£ -	£ -	£ 87,701.89	
	Regret					Worst Regret
	All Knowing	£ -	£ -	£ -	£ 72,207.89	£ 72,207.89
	Flexibility Min	£ -	£ -	£ -	£ -	£ -
	Flexibility Max	£ -	£ -	£ -	£ -	£ -
					Least Worst Regret	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth	
Assessment Year 3	Strategy	Outcome	Outcome	Outcome	Outcome	
		Scenario1	Scenario2	Scenario3	Scenario4	
2035	All Knowing	£ -	£ 12,139.96	£ 13,384.30	£ 117,170.83	
	Flexibility Min	£ -	£ 12,139.96	£ 13,384.30	£ 58,477.12	
	Flexibility Max	£ -	£ 12,139.96	£ 13,384.30	£ 58,477.12	
	Minimum	£ -	£ 12,139.96	£ 13,384.30	£ 58,477.12	
	Maximum	£ -	£ 12,139.96	£ 13,384.30	£ 117,170.83	
	Regret					Worst Regret
	All Knowing	£ -	£ -	£ -	£ 58,693.72	£ 58,693.72
	Flexibility Min	£ -	£ -	£ -	£ -	£ -
	Flexibility Max	£ -	£ -	£ -	£ -	£ -
					Least Worst Regret	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth	
Assessment Year 4	Strategy	Outcome	Outcome	Outcome	Outcome	
		Scenario1	Scenario2	Scenario3	Scenario4	
2040	All Knowing	£ -	£ 12,139.96	£ 16,787.61	£ 140,676.27	
	Flexibility Min	£ -	£ 12,139.96	£ 16,787.61	£ 143,512.23	
	Flexibility Max	£ -	£ 12,139.96	£ 16,787.61	£ 143,512.23	
	Minimum	£ -	£ 12,139.96	£ 16,787.61	£ 140,676.27	
	Maximum	£ -	£ 12,139.96	£ 16,787.61	£ 143,512.23	
	Regret					Worst Regret
	All Knowing	£ -	£ -	£ -	£ -	£ -
	Flexibility Min	£ -	£ -	£ -	£ 2,835.96	£ 2,835.96
	Flexibility Max	£ -	£ -	£ -	£ 2,835.96	£ 2,835.96
					Least Worst Regret	£ -

8.1.3 Case Study 3: Allan Way

Table 8.4 Regret tables for CS3

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 1	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2025	All Knowing	£ 114,200.00	£ 115,600.00	£ 218,350.00	£ -
	Flexibility Min	£ 70,850.00	£ 72,150.00	£ 78,030.00	£ -
	Flexibility Max	£ 70,850.00	£ 72,150.00	£ 78,030.00	£ -
	Minimum	£ 70,850.00	£ 72,150.00	£ 78,030.00	£ -
	Maximum	£ 114,200.00	£ 115,600.00	£ 218,350.00	£ -

Regret	Least Regret	Least Regret	Least Regret	Least Regret	Worst Regret
All Knowing	£ 43,350.00	£ 43,450.00	£ 140,320.00	£ -	£ 140,320.00
Flexibility Min	£ -	£ -	£ -	£ -	£ -
Flexibility Max	£ -	£ -	£ -	£ -	£ -
				Least Worst Regret	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 2	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2030	All Knowing	£ 171,760.51	£ 204,918.43	£ 468,465.47	£ -
	Flexibility Min	£ 84,456.66	£ 107,956.47	£ 321,317.25	£ -
	Flexibility Max	£ 84,456.66	£ 107,956.47	£ 321,317.25	£ -
	Minimum	£ 84,456.66	£ 107,956.47	£ 321,317.25	£ -
	Maximum	£ 171,760.51	£ 204,918.43	£ 468,465.47	£ -

Regret					Worst Regret
All Knowing	£ 87,303.85	£ 96,961.96	£ 147,148.22	£ -	£ 147,148.22
Flexibility Min	£ -	£ -	£ -	£ -	£ -
Flexibility Max	£ -	£ -	£ -	£ -	£ -
				Least Worst Regret	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 3	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2035	All Knowing	£ 193,165.77	£ 341,438.26	£ 493,409.64	£ -
	Flexibility Min	£ 226,414.76	£ 364,187.41	£ 461,686.14	£ -
	Flexibility Max	£ 226,414.76	£ 364,187.41	£ 461,686.14	£ -
	Minimum	£ 193,165.77	£ 341,438.26	£ 461,686.14	£ -
	Maximum	£ 226,414.76	£ 364,187.41	£ 493,409.64	£ -

Regret					Worst Regret
All Knowing	£ -	£ -	£ 31,723.50	£ -	£ 31,723.50
Flexibility Min	£ 33,248.99	£ 22,749.16	£ -	£ -	£ 33,248.99
Flexibility Max	£ 33,248.99	£ 22,749.16	£ -	£ -	£ 33,248.99
				Least Worst Regret	£ 31,723.50

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 4	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2040	All Knowing	£ 193,165.77	£ 341,438.26	£ 493,409.64	£ -
	Flexibility Min	£ 226,414.76	£ 364,187.41	£ 490,084.90	£ -
	Flexibility Max	£ 226,414.76	£ 364,187.41	£ 490,084.90	£ -
	Minimum	£ 193,165.77	£ 341,438.26	£ 490,084.90	£ -
	Maximum	£ 226,414.76	£ 364,187.41	£ 493,409.64	£ -

Regret					Worst Regret
All Knowing	£ -	£ -	£ 3,324.74	£ -	£ 3,324.74
Flexibility Min	£ 33,248.99	£ 22,749.16	£ -	£ -	£ 33,248.99
Flexibility Max	£ 33,248.99	£ 22,749.16	£ -	£ -	£ 33,248.99
				Least Worst Regret	£ 3,324.74

8.1.4 Case Study 4: Beechwood Avenue

Table 8.5 Regret tables for CS4.1

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 1	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2025	All Knowing	£ -	£ 39.94	£ 411,515.78	£ -
	Flexibility Min	£ -	£ 28,833.76	£ 52,241.61	£ -
	Flexibility Max	£ -	£ 39.94	£ 52,241.61	£ -
	Minimum	£ -	£ 39.94	£ 52,241.61	£ -
	Maximum	£ -	£ 28,833.76	£ 411,515.78	£ -

Regret	Least Regret	Least Regret	Least Regret	Least Regret	Worst Regret
All Knowing	£ -	£ -	£ 359,274.17	£ -	£ 359,274.17
Flexibility Min	£ -	£ 28,793.83	£ -	£ -	£ 28,793.83
Flexibility Max	£ -	£ -	£ -	£ -	£ -
				Least Worst Regret	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 2	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2030	All Knowing	£ 41,092.28	£ 265,606.81	£ 411,515.78	£ -
	Flexibility Min	£ 22,533.69	£ 47,666.82	£ 139,943.50	£ -
	Flexibility Max	£ 22,533.69	£ 47,666.82	£ 139,943.50	£ -
	Minimum	£ 22,533.69	£ 47,666.82	£ 139,943.50	£ -
	Maximum	£ 41,092.28	£ 265,606.81	£ 411,515.78	£ -

Regret					Worst Regret
All Knowing	£ 18,558.60	£ 217,940.00	£ 271,572.28	£ -	£ 271,572.28
Flexibility Min	£ -	£ -	£ -	£ -	£ -
Flexibility Max	£ -	£ -	£ -	£ -	£ -
				Least Worst Regret	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 3	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2035	All Knowing	£ 41,092.28	£ 363,537.54	£ 640,040.13	£ -
	Flexibility Min	£ 56,283.81	£ 247,391.36	£ 456,266.66	£ -
	Flexibility Max	£ 56,283.81	£ 247,391.36	£ 456,266.66	£ -
	Minimum	£ 41,092.28	£ 247,391.36	£ 456,266.66	£ -
	Maximum	£ 56,283.81	£ 363,537.54	£ 640,040.13	£ -

Regret					Worst Regret
All Knowing	£ -	£ 116,146.18	£ 183,773.48	£ -	£ 183,773.48
Flexibility Min	£ 15,191.52	£ -	£ -	£ -	£ 15,191.52
Flexibility Max	£ 15,191.52	£ -	£ -	£ -	£ 15,191.52
				Least Worst Regret	£ 15,191.52

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 4	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2040	All Knowing	£ 41,092.28	£ 363,537.54	£ 640,040.13	£ -
	Flexibility Min	£ 56,283.81	£ 256,518.69	£ 484,051.74	£ -
	Flexibility Max	£ 56,283.81	£ 256,518.69	£ 484,051.74	£ -
	Minimum	£ 41,092.28	£ 256,518.69	£ 484,051.74	£ -
	Maximum	£ 56,283.81	£ 363,537.54	£ 640,040.13	£ -

Regret					Worst Regret
All Knowing	£ -	£ 107,018.86	£ 155,988.39	£ -	£ 155,988.39
Flexibility Min	£ 15,191.52	£ -	£ -	£ -	£ 15,191.52
Flexibility Max	£ 15,191.52	£ -	£ -	£ -	£ 15,191.52
				Least Worst Regret	£ 15,191.52

Table 8.6 Regret tables for CS4.2

		Low Growth	Mid Growth	High Growth	Very High Growth	
Assessment Year 1	Strategy	Outcome	Outcome	Outcome	Outcome	
		Scenario1	Scenario2	Scenario3	Scenario4	
2025	All Knowing	£ -	£ 39.94	£ 411,515.78	£ -	
	Flexibility Min	£ -	£ 28,833.76	£ 52,241.61	£ -	
	Flexibility Max	£ -	£ 39.94	£ 52,241.61	£ -	
	Minimum	£ -	£ 39.94	£ 52,241.61	£ -	
	Maximum	£ -	£ 28,833.76	£ 411,515.78	£ -	
	Regret	Least Regret	Least Regret	Least Regret	Least Regret	Worst Regret
	All Knowing	£ -	£ -	£ 359,274.17	£ -	£ 359,274.17
	Flexibility Min	£ -	£ 28,793.83	£ -	£ -	£ 28,793.83
	Flexibility Max	£ -	£ -	£ -	£ -	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth	
Assessment Year 2	Strategy	Outcome	Outcome	Outcome	Outcome	
		Scenario1	Scenario2	Scenario3	Scenario4	
2030	All Knowing	£ 41,092.28	£ 248,055.05	£ 411,515.78	£ -	
	Flexibility Min	£ 22,533.69	£ 47,666.82	£ 139,943.50	£ -	
	Flexibility Max	£ 22,533.69	£ 42,884.74	£ 139,943.50	£ -	
	Minimum	£ 22,533.69	£ 42,884.74	£ 139,943.50	£ -	
	Maximum	£ 41,092.28	£ 248,055.05	£ 411,515.78	£ -	
	Regret					Worst Regret
	All Knowing	£ 18,558.60	£ 205,170.32	£ 271,572.28	£ -	£ 271,572.28
	Flexibility Min	£ -	£ 4,782.08	£ -	£ -	£ 4,782.08
	Flexibility Max	£ -	£ -	£ -	£ -	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth	
Assessment Year 3	Strategy	Outcome	Outcome	Outcome	Outcome	
		Scenario1	Scenario2	Scenario3	Scenario4	
2035	All Knowing	£ 41,092.28	£ 345,985.78	£ 640,040.13	£ -	
	Flexibility Min	£ 56,283.81	£ 247,391.36	£ 456,266.66	£ -	
	Flexibility Max	£ 56,283.81	£ 263,100.90	£ 456,266.66	£ -	
	Minimum	£ 41,092.28	£ 247,391.36	£ 456,266.66	£ -	
	Maximum	£ 56,283.81	£ 345,985.78	£ 640,040.13	£ -	
	Regret					Worst Regret
	All Knowing	£ -	£ 98,594.42	£ 183,773.48	£ -	£ 183,773.48
	Flexibility Min	£ 15,191.52	£ -	£ -	£ -	£ 15,191.52
	Flexibility Max	£ 15,191.52	£ 15,709.54	£ -	£ -	£ 15,709.54

		Low Growth	Mid Growth	High Growth	Very High Growth	
Assessment Year 4	Strategy	Outcome	Outcome	Outcome	Outcome	
		Scenario1	Scenario2	Scenario3	Scenario4	
2040	All Knowing	£ 41,092.28	£ 345,985.78	£ 640,040.13	£ -	
	Flexibility Min	£ 56,283.81	£ 256,518.69	£ 484,051.74	£ -	
	Flexibility Max	£ 56,283.81	£ 272,228.22	£ 484,051.74	£ -	
	Minimum	£ 41,092.28	£ 256,518.69	£ 484,051.74	£ -	
	Maximum	£ 56,283.81	£ 345,985.78	£ 640,040.13	£ -	
	Regret					Worst Regret
	All Knowing	£ -	£ 89,467.09	£ 155,988.39	£ -	£ 155,988.39
	Flexibility Min	£ 15,191.52	£ -	£ -	£ -	£ 15,191.52
	Flexibility Max	£ 15,191.52	£ 15,709.54	£ -	£ -	£ 15,709.54

8.1.5 Case Study 5: Heritage Centre

Note that the table below starts at assessment year 2035 as no intervention is required before that time.

Table 8.7 Regret table for CS5

		Low Growth	Mid Growth	High Growth	Very High Growth	
Assessment Year 3	Strategy	Outcome	Outcome	Outcome	Outcome	
		Scenario1	Scenario2	Scenario3	Scenario4	
2035	All Knowing	£ -	£ -	£ -	£ 60,261.68	
	Flexibility Min	£ -	£ -	£ -	£ 62,059.03	
	Flexibility Max	£ -	£ -	£ -	£ 62,059.03	
	Minimum	£ -	£ -	£ -	£ 60,261.68	
	Maximum	£ -	£ -	£ -	£ 62,059.03	
	Regret					Worst Regret
	All Knowing	£ -	£ -	£ -	£ -	£ -
	Flexibility Min	£ -	£ -	£ -	£ 1,797.36	£ 1,797.36
	Flexibility Max	£ -	£ -	£ -	£ 1,797.36	£ 1,797.36
					Least Worst Regret	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth	
Assessment Year 4	Strategy	Outcome	Outcome	Outcome	Outcome	
		Scenario1	Scenario2	Scenario3	Scenario4	
2040	All Knowing	£ -	£ -	£ -	£ 60,261.68	
	Flexibility Min	£ -	£ -	£ -	£ 62,059.03	
	Flexibility Max	£ -	£ -	£ -	£ 62,059.03	
	Minimum	£ -	£ -	£ -	£ 60,261.68	
	Maximum	£ -	£ -	£ -	£ 62,059.03	
	Regret					Worst Regret
	All Knowing	£ -	£ -	£ -	£ -	£ -
	Flexibility Min	£ -	£ -	£ -	£ 1,797.36	£ 1,797.36
	Flexibility Max	£ -	£ -	£ -	£ 1,797.36	£ 1,797.36
					Least Worst Regret	£ -

8.1.6 Case Study 6: Christchurch Gardens

Table 8.8 Regret tables for CS6.1

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 2	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2030	All Knowing	£ -	£ 72,824.44	£ 137,368.84	£ -
	Flexibility Min	£ -	£ 23,974.19	£ 26,431.54	£ -
	Flexibility Max	£ -	£ 23,974.19	£ 25,740.99	£ -
	Minimum	£ -	£ 23,974.19	£ 25,740.99	£ -
	Maximum	£ -	£ 72,824.44	£ 137,368.84	£ -

Regret					Worst Regret
All Knowing	£ -	£ 48,850.25	£ 111,627.85	£ -	£ 111,627.85
Flexibility Min	£ -	£ -	£ 690.55	£ -	£ 690.55
Flexibility Max	£ -	£ -	£ -	£ -	£ -
				Least Worst Regret	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 3	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2035	All Knowing	£ 37,709.09	£ 144,977.00	£ 272,867.01	£ -
	Flexibility Min	£ 36,115.86	£ 144,885.97	£ 235,838.55	£ -
	Flexibility Max	£ 36,115.86	£ 144,885.97	£ 235,838.55	£ -
	Minimum	£ 36,115.86	£ 144,885.97	£ 235,838.55	£ -
	Maximum	£ 37,709.09	£ 144,977.00	£ 272,867.01	£ -

Regret					Worst Regret
All Knowing	£ 1,593.23	£ 91.03	£ 37,028.46	£ -	£ 37,028.46
Flexibility Min	£ -	£ -	£ -	£ -	£ -
Flexibility Max	£ -	£ -	£ -	£ -	£ -
				Least Worst Regret	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 4	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2040	All Knowing	£ 37,709.09	£ 144,977.00	£ 298,508.17	£ -
	Flexibility Min	£ 36,115.86	£ 144,885.97	£ 314,323.79	£ -
	Flexibility Max	£ 36,115.86	£ 144,885.97	£ 314,323.79	£ -
	Minimum	£ 36,115.86	£ 144,885.97	£ 298,508.17	£ -
	Maximum	£ 37,709.09	£ 144,977.00	£ 314,323.79	£ -

Regret					Worst Regret
All Knowing	£ 1,593.23	£ 91.03	£ -	£ -	£ 1,593.23
Flexibility Min	£ -	£ -	£ 15,815.62	£ -	£ 15,815.62
Flexibility Max	£ -	£ -	£ 15,815.62	£ -	£ 15,815.62
				Least Worst Regret	£ 1,593.23

Table 8.9 Regret tables for CS6.2

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 2	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2030	All Knowing	£ -	£ 72,824.44	£ 19,260.91	£ 20,792.51
	Flexibility Min	£ -	£ 23,974.19	£ 19,260.91	£ 20,223.96
	Flexibility Max	£ -	£ 23,974.19	£ 19,260.91	£ 20,223.96
	Minimum	£ -	£ 23,974.19	£ 19,260.91	£ 20,223.96
	Maximum	£ -	£ 72,824.44	£ 19,260.91	£ 20,792.51

Regret					Worst Regret
All Knowing	£ -	£ 48,850.25	£ -	£ 568.55	£ 48,850.25
Flexibility Min	£ -	£ -	£ -	£ -	£ -
Flexibility Max	£ -	£ -	£ -	£ -	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 3	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2035	All Knowing	£ 37,709.09	£ 144,977.00	£ 229,463.76	£ 20,792.51
	Flexibility Min	£ 36,115.86	£ 144,885.97	£ 235,838.55	£ 20,223.96
	Flexibility Max	£ 36,115.86	£ 144,885.97	£ 225,258.57	£ 20,223.96
	Minimum	£ 36,115.86	£ 144,885.97	£ 225,258.57	£ 20,223.96
	Maximum	£ 37,709.09	£ 144,977.00	£ 235,838.55	£ 20,792.51

Regret					Worst Regret
All Knowing	£ 1,593.23	£ 91.03	£ 4,205.19	£ 568.55	£ 4,205.19
Flexibility Min	£ -	£ -	£ 10,579.99	£ -	£ 10,579.99
Flexibility Max	£ -	£ -	£ -	£ -	£ -

		Low Growth	Mid Growth	High Growth	Very High Growth
Assessment Year 4	Strategy	Outcome	Outcome	Outcome	Outcome
		Scenario1	Scenario2	Scenario3	Scenario4
2040	All Knowing	£ 37,709.09	£ 144,977.00	£ 235,785.70	£ -
	Flexibility Min	£ 36,115.86	£ 144,885.97	£ 314,323.79	£ -
	Flexibility Max	£ 36,115.86	£ 144,885.97	£ 303,743.80	£ -
	Minimum	£ 36,115.86	£ 144,885.97	£ 235,785.70	£ -
	Maximum	£ 37,709.09	£ 144,977.00	£ 314,323.79	£ -

Regret					Worst Regret
All Knowing	£ 1,593.23	£ 91.03	£ -	£ -	£ 1,593.23
Flexibility Max	£ -	£ -	£ 78,538.09	£ -	£ 78,538.09
Flexibility Min	£ -	£ -	£ 67,958.10	£ -	£ 67,958.10

8.2 References

Castro, M., et.al. 2014. Customer-Led Network Revolution: Review of the distribution network planning and design standards for the future low carbon electricity system. http://www.networkrevolution.co.uk/wp-content/uploads/2014/12/ACE49-Report-1.1.pdf

Corporate Finance Institute. What is Net Present Value (NPV)? https://corporatefinanceinstitute.com/resources/knowledge/valuation/net-present-value-npv/

DNV GL. 2014. SDRC 1: Lessons Learnt on Energy Efficiency and Behaviour Change. https://save-project.co.uk/reports-and-presentations/

DNV GL. SAVE Regulatory Report. 2018. https://save-project.co.uk/reports-and-presentations/

EA Technology. 2019. SDRC 7.3: Network Model. https://save-project.co.uk/reports-and-presentations/

HM Treasury. 2018. The Green Book: appraisal and evaluation in central government. https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

Ofgem. 2012. Assessing the Impacts of Low Carbon Technologies on Great Britain Distribution Networks www.ofgem.gov.uk/publications-and-updates/assessing-impact-low-carbon-technologies-great-britains-power-distribution-networks

SSEN. 2019. SDRC 8.1: Project Closedown Report. https://save-project.co.uk/reports-and-presentations/

SSEN. 2019. SDRC 8.5 and 8.6: Pricing model, customer model and network model. https://save-project.co.uk/reports-and-presentations/

University of Southampton. 2017. SDRC 2.2: SAVE Updated Customer Model. https://save-project.co.uk/reports-and-presentations/

University of Southampton. 2019. SDRC 2.3: SAVE Customer Model Final Report. https://save-project.co.uk/reports-and-presentations/

Zachary, S. 2016. Least worst regret analysis for decision making under uncertainty, with applications to future energy scenarios. https://arxiv.org/pdf/1608.00891.pdf