SMART STREET

Cost Benefit Assessment Study

10 April 2018

VERSION HISTORY

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First draft	6 April 2018	Geraldine Paterson	0.1	
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CONTENTS

1 INTRODUCTION

1.1 Purpose of document

The purpose of this document is to achieve the associated deliverable related to the Smart Street **SDRC 9.4.3 – Publish a final Cost Benefit Assessment Study on the Smart Street website by April 2018.**

This document describes the methodology used to develop a techno-economic model, a business case model and a cost benefit analysis (CBA) framework. The tools and models developed were used in conjunction with the trial data to produce a cost benefit assessment of the Smart Street method.

1.2 What is Smart Street?

Smart Street used advanced real time optimisation software to simultaneously manage high voltage (HV) and low voltage (LV) network assets to respond to customers' changing demands. Voltage management on HV networks reduced network losses while conservation voltage reduction (CVR) on the LV networks reduced energy demand. Capacitor banks on the HV network were used to help manage network losses by adjusting the network's power factor. On the LV network, a mix of capacitor banks and controlled meshing of circuits were integrated to flatten the voltage profile and improve energy efficiency. The meshing of LV networks also released additional network capacity.

1.3 Conservation voltage reduction (CVR)

Electrical equipment made for the European market, including household appliances and lighting, is designed to operate most efficiently in the region of 220 to 230V. This equipment, however, operates most efficiently at voltages in the region of 200V. If power is delivered at voltages higher than these optimum levels, the excess energy is wasted. This can also shorten the useful life of electrical equipment, since the excess energy is dissipated as heat. Therefore optimising network voltages reduces overall energy consumption, improves power quality and extends the life of customers' equipment.

Smart Street optimised network voltages by using CVR on the LV trial networks.

CVR on a distribution network is defined as a reduction of energy consumption resulting from a decrease in feeder voltage. Smart Street optimised the voltage by using on-load tap changing (OLTC) transformers. These transformers regulated the voltage along the feeder while maintaining statutory limits. This allowed for the peak load to be reduced, hence reducing the annual energy consumption.

Additionally Smart Street used shunt capacitors on the LV feeders to provide a voltage boost at the end of the circuit to reduce voltage drop. This flattened the voltage profile, allowing for the OLTC to tap closer to the lower limit.

1.4 LV network meshing

In addition to the proposed CVR techniques, Smart Street assessed the benefits of meshing LV networks to balance load while releasing network capacity at times of high demand.

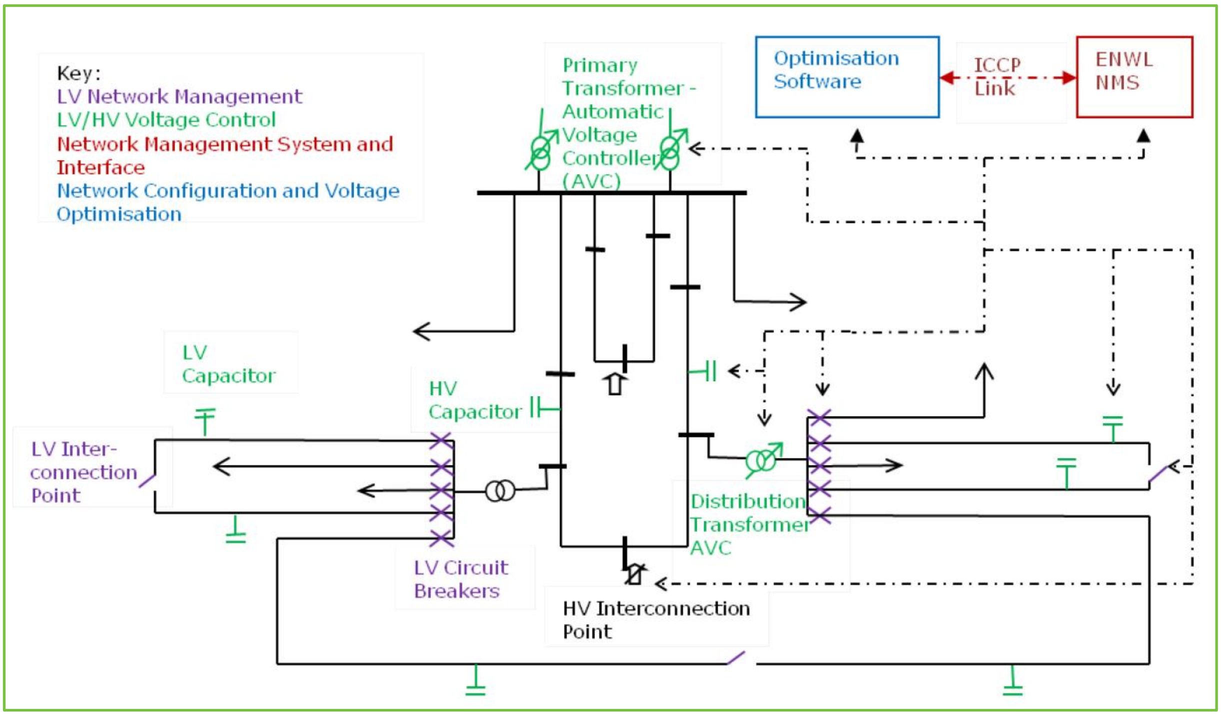
Our project partner, Kelvatek, developed new controllable retrofit vacuum switching devices specifically for this project. These devices were used at existing distribution boards and in link boxes across the LV trial circuits. The devices were remotely controlled allowing both sensing of feeder flows and reconfiguration of the LV network.

1.5 Control systems

Figure 1.1 shows an example of how the various Smart Street technologies were installed across the trial networks. The software included the ability to optimise for violations, losses and to minimise load as a single Volt Var Compensation (VVC) function. The opportunity to mesh the trial networks was also included in this function, but radial configurations were the preferred running arrangement. This was specified to minimise customer outages during electrical faults. Therefore the switching equipment was closed (create loop or mesh networks) when the objective-function resulted in positive changes to the network above a set threshold.

The software calculated the best solution to reach the optimisation objectives, which may be different for HV and LV depending on the chosen function. The user selected whether switching equipment should be included or inhibited in the optimisation scheme.

Figure 1.1: Smart Street network management



2 OVERVIEW

Smart Street equipment is fast to deploy and can increase firm capacity to defer traditional reinforcement. Traditional solutions can be costly and emission intensive. Smart Street offers the potential to enhance traditional network planning practices by considering new optimisation techniques alongside traditional asset-based interventions. Based on this premise, it is reasonable to assume that attractive financial and carbon benefits could be accrued if Smart Street is appropriately deployed as an enhancement to traditional network planning practices, based on a suitable CBA framework.

This analysis identified and quantified the benefits from enhancing traditional distribution network reinforcement practices with Smart Street in the light of potentially significant penetration of low carbon technologies (LCTs). The analysis tested the following two hypotheses:

- Smart Street supports accelerated LCT connections and reduced distribution network reinforcement costs by facilitating energy and losses savings and increasing firm capacity
- Smart Street will deliver a portfolio of distribution network upgrade strategies to accommodate uncertain demand and LCT uptake based on a CBA framework.

However, evaluating these hypotheses is a difficult challenge that requires:

- Proper understanding and modelling of the techno-economic characteristics of all the Smart Street options and their combinations, particularly their contribution to energy and losses savings and firm capacity
- Business cases from the perspective of distribution network operators (DNOs), in light of existing regulation
- The perspectives of customers and other stakeholders across the value chain whose interests may be directly or indirectly affected by the deployment of Smart Street
- Carbon impacts attributed to Smart Street.

Existing distribution network operation and investment optimisation models do not provide sufficient means to model the Smart Street method with the level of detail required. Furthermore, using these models would require the use of dedicated optimisation software which may not be used by DNOs. Based on this, a techno-economic distribution network reinforcement planning framework which combines a bespoke simulation tool and optimisation engine was used.

3 TECHNO-ECONOMIC ASSESSMENT

The techno-economic framework was developed with the aim of seamlessly applying the relevant models and knowledge developed as part of the academic technical analysis. This uses the same input files, which included the HV and LV network data, and load profiles. It also used the interface between the Matlab models and the OpenDSS software.

By sharing key models and data, the simulation engine could be validated through replication of the technical studies presented. For example, the simulation engine was adjusted based on relevant assumptions (eg tap position, load profiles, etc.) to replicate the energy savings and losses savings attributed to optimisation at the LV level.

When the same underlying assumptions were used, the simulation engine provided results that were consistent with those produced in the technical analysis, ie CVR factors of approximately 1 were expected throughout the trial LV networks.

The techno-economic simulation engine allowed customisation of the case study based on the following settings:

- *Type of network:* The simulation engine allowed the consideration of specific LV networks, HV networks and integrated HV/LV networks. The LV network model included the secondary transformers, lines and services, independent customer profiles and other relevant elements (eg switches and fuses).The HV network model included the primary substation, lines, secondary transformers, aggregated loads at the transformer level, and other relevant infrastructure (eg breakers and switches). The integrated HV/LV model combined HV and LV models by replacing the aggregated loads at the secondary transformer level with the relevant LV network models.
- *Time resolution:* The simulation engine allowed the use of different resolutions for the study, and was pre-loaded with half hour and one-minute resolution data for typical days. The half-hour data was used when assessing thermal limits and energy, losses

or other parameters required for economic assessment. The one-minute data was used for the assessment of voltage violations.

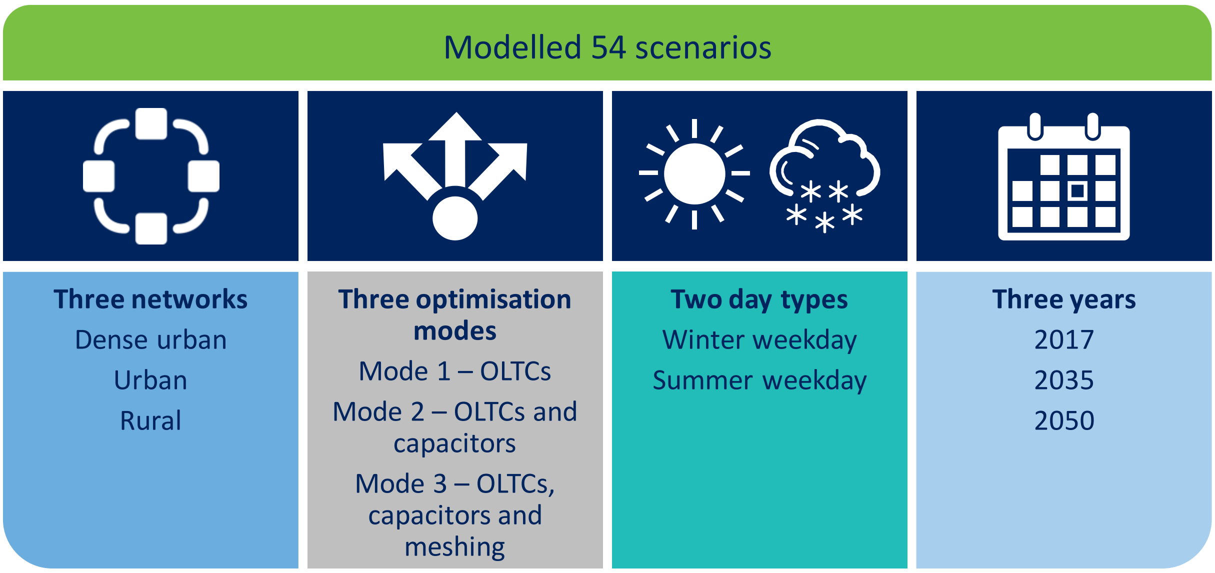
- *Transformer settings:* The tap position of the transformers could be fixed, predefined at the beginning of each simulation, or actively managed based on the optimisation strategies.
- *Scenarios:* The engine combined different daily simulations (eg weekdays and weekends) to create seasonal profiles. The combination of different daily simulations was then used to create yearly profiles. Finally, different yearly profiles, which may consider different levels of demand growth (eg from adoption of electric vehicles (EVs), heat pumps (HPs) and other technologies) and photo voltaic (PV) integration were then combined to create a scenario.
- *Reinforcement:* The simulation engine allowed replacement or addition of most elements, including primary and secondary transformers, lines, services and capacitors. In addition, based on network issues or security considerations, the engine could also recommend reinforcement based on a predefined list of options.
- *Smart Street:* In addition to optimising the transformer settings when OLTCs were available, the simulation engine also allowed the active use of capacitors and meshing. As in the case of transformers, the use of capacitors and meshing could be fixed, predefined for each simulation, or optimised.

3.1 Modelling scenarios

As well as assessing the impact Smart Street has on today's network it was important to understand the benefits for future networks with different levels of demand and generation as well as the impact it has for different types of networks.

The benefits of Smart Street were assessed across a range of scenarios developed to ensure all network types and demand variations were covered.

Figure 3.1: Models and scenarios



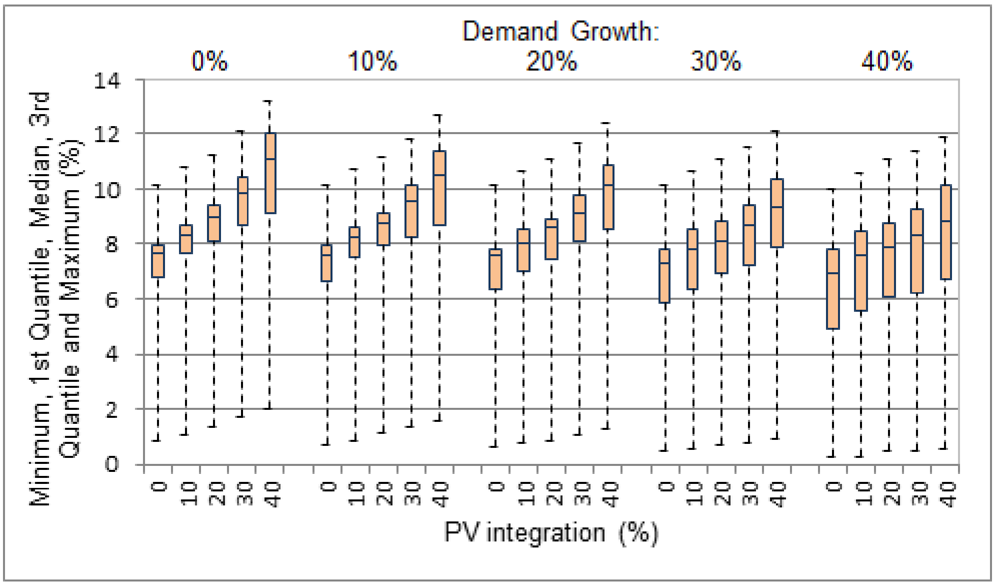
The combinations of all the above criteria resulted in 54 scenarios modelled and analysed.

In order to project the demand and generation growth for years 2035 and 2050 an average was taken of the four National Grid future energy scenarios which resulted in 20% and 40% PV penetration and multiplication factors of 1.0535 and 1.1859 for demand.

3.2 Energy savings

Smart Street reduced energy consumption; the energy savings attributed to the full application of Smart Street are shown in Figure 3.2.

Figure 3.2: Energy savings (%) throughout the 38 Smart Street LV networks



Net annual energy savings (kWh) at LV and HV levels increase with higher demand growth and decreased with higher PV integration. This is due to the higher energy consumption in those cases, which provides more potential for savings.

The trend is the opposite when energy savings are assessed in terms of percentages compared with the baseline. A greater percentage of energy savings is achieved when demand growth is low and PV integration is high. The reason for this trend is the operation of the networks further from the lower voltage limit, under low demand and relatively high PV integration levels, which provides additional footroom for deploying optimisation techniques.

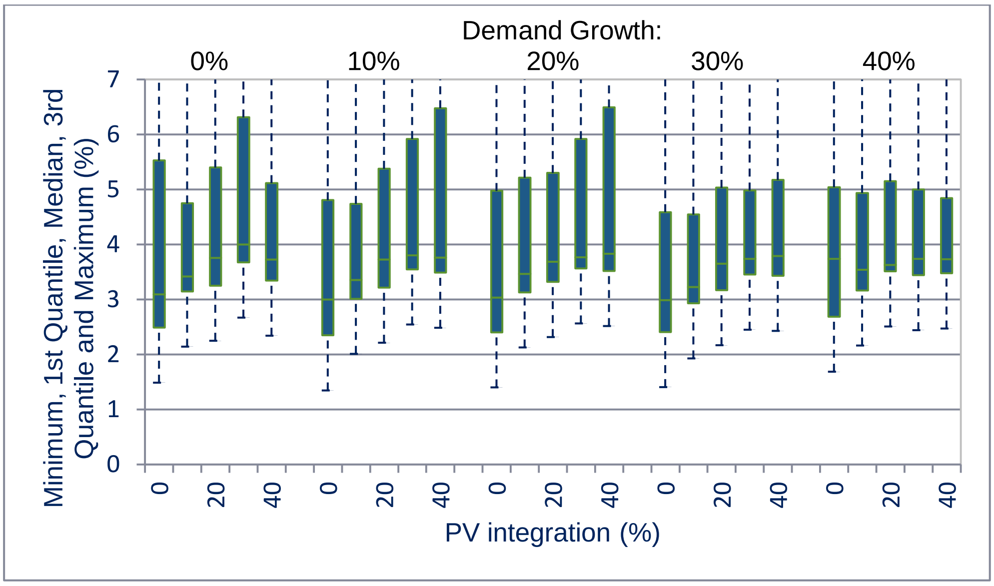
In most cases under consideration, the intelligent use of OLTCs was the option that provided the highest energy savings

3.3 Losses savings

The annual energy losses in the baseline demonstrated that energy losses increase with higher demand growth levels. Low levels of PV integration lead to reduced power losses, while higher integration levels result in increased losses. This is due to the potential of PV energy to mitigate (reducing losses) and ultimately reverse (increasing losses again) power flows.

The potential of Smart Street to reduce power losses is in line with the overall net losses throughout the network. Greater losses savings can be achieved under conditions where losses in the baseline are the highest. The trends are roughly reversed when losses savings are calculated as a percentage, as shown in Figure 3.3. This is due to voltage constraints that generally limit the applicability of optimisation, particularly under high demand growth or high PV integration conditions.

Figure 3.3: Losses reduction (%) at the LV level



OLTCs played an important role in facilitating losses savings. However, meshing also demonstrated a prominent role in reducing power losses by redistributing power flows and, potentially, changing the overall trend of losses savings.

3.4 Firm capacity

In addition to the reduction of energy consumption and losses, Smart Street can also increase the firm capacity of the distribution network. The OLTCs and capacitors can be used to alleviate voltage issues, also potentially reducing network stress due to the voltage dependence of loads. In addition, network meshing can redistribute power flows, potentially alleviating voltage and thermal issues.

The analysis of firm capacity is based on assumptions used in the rest of the studies and Engineering Recommendation P2/6 requirements. The firm capacity of the LV network was modelled based on normal conditions (N-0). However, for the HV networks, emergency conditions were considered when different contingencies arose. For this purpose, 'valid' emergency conditions were defined as conditions where customers that are disconnected from the network due to a randomly located contingency can be reconnected to a different section of the network by closing a switch.

To understand the contribution of the various Smart Street solutions in increasing firm capacity, the potential of the different combinations of solutions to alleviate voltage and thermal issues was explored. The following conclusions were drawn from the outputs of the study:

- The studies showed that the intelligent use of OLTCs provides attractive means to manage voltage problems as long as strong thermal issues do not arise. This usually occurs under low demand growth levels.
- The fixed capacity of the capacitors considered in the studies meant that the devices were only applicable under very specific conditions. Other assumptions that allow capacitors to be more flexible (eg operation at partial capacity) could improve their performance.
- Meshing proved to be a particularly attractive option to increase firm capacity at the LV level, particularly under high demand growth conditions. This is due to the potential of meshing to alleviate thermal as well as voltage issues.

- At the HV level, it was challenging to identify conditions where Smart Street would increase firm capacity. Meshing may not be a viable option to increase firm capacity at this level due to the consideration of contingencies which break the loops created through meshing. OLTCs and capacitors proved to alleviate problems under some conditions, yet no solution was effective based on the different locations for contingencies considered in this work.

4 BUSINESS CASE ASSESSMENT

In order to investigate the business case for DNOs adopting Smart Street, the business case assessment framework (BCAF) coupled with the techno-economic framework were used to assess the economic value. The studies focused on the economic value that Smart Street can bring to DNOs based on the current forecast for LCT adoption provided by National Grid. These studies also considered several economic factors such as changes in investment timing, network fees, Smart Street costs, reinforcement costs and uncertainty.

The BCAF allows the comparison of different investment decisions based on the well-known Net Present Cost (NPC) and Net Present Value (NPV) economic criteria. The criteria is calculated based on the existing UK regulatory framework by taking relevant economic assumptions from the CBA framework developed by Ofgem for the regulation of distribution network asset investment.

An optimisation engine was used to formulate investment strategies, ie the engine identifies which reinforcement options to deploy through time. These reinforcement options are predefined whereas reinforcement timing is dictated by the conditions of the network throughout a scenario and an objective function (eg the BCAF). The optimisation engine was built on a bespoke recursion-theory based distribution network reinforcement planning model. By using recursion-theory, the model identified optimal solutions, even for complex (and uncertain) mixed integer nonlinear problems as the ones considered in this project.

The expected costs (NPC) per network associated with planning asset reinforcement at the LV level based on the different strategies is presented in Figure 4.1, whereas the expected benefits compared with the baseline (NPV) on a per network basis out to 2060 are presented in Figure 4.2.

Figure 4.1: NPC for LV networks and different strategies

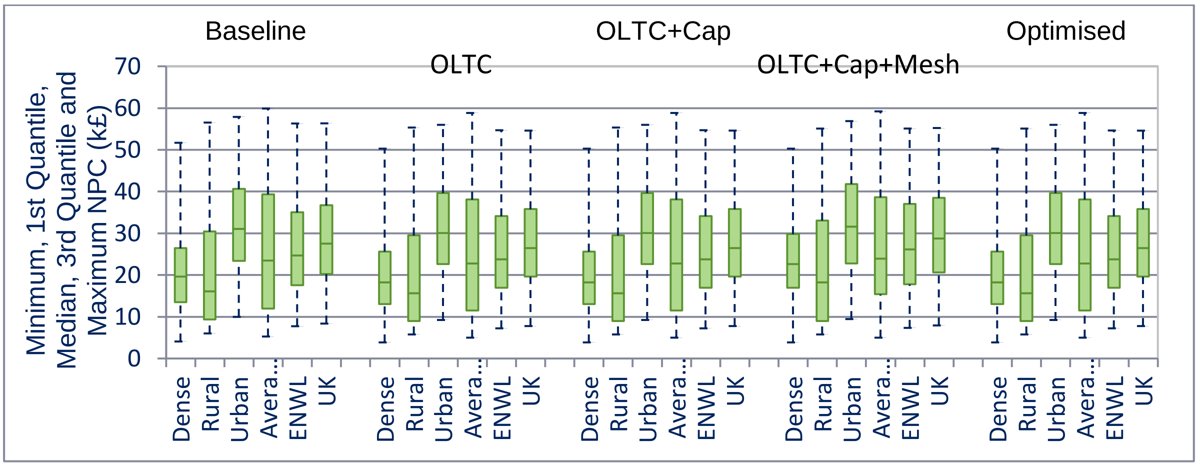
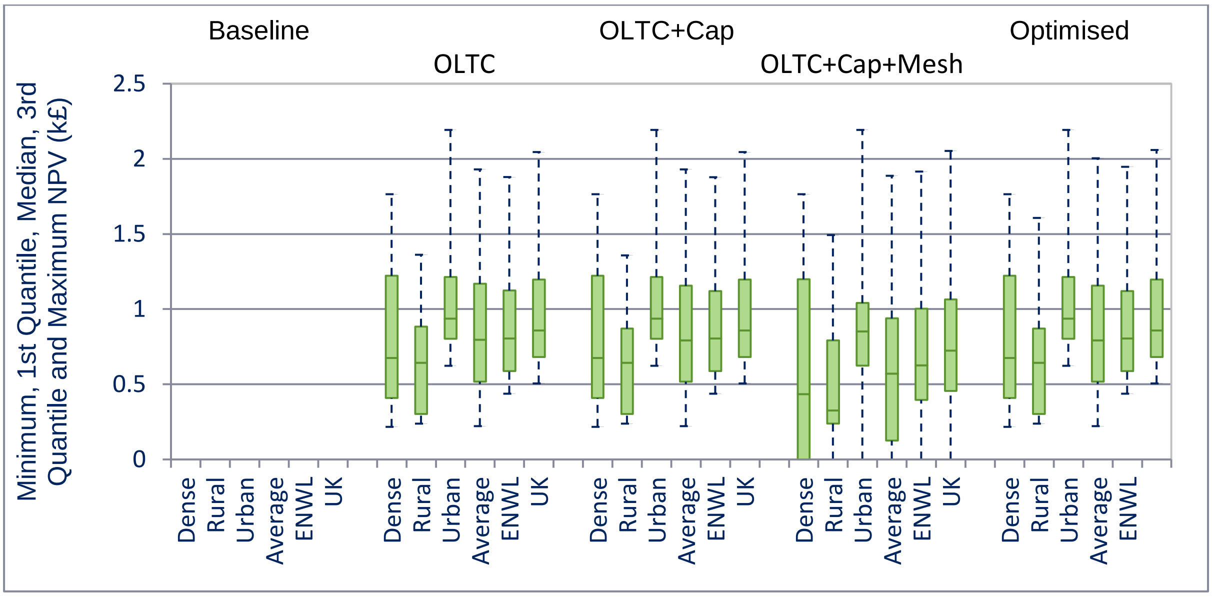


Figure 4.2: NPV for LV networks and different strategies



The results suggest that the median NPV per network is in the order of £800. In the final submission Electricity North West stated that Smart Street is likely to be applicable to 64% of its network and 72% of GB networks.

Using this benefit per network, and scaling to 64% and 72% for Electricity North West and GB respectively, results in savings of £44m and £518m out to 2060 in deferred reinforcement. The Ofgem CBA is based on deferment of reinforcement only and not avoidance. If using Smart Street completely avoided the need for reinforcement, the benefits would be greater than those discussed here.

4.1 Impacts of Smart Street costs

It should be noted that the financial benefits have been calculated based on the current cost to purchase the individual assets. Equipment such as distribution transformers with on-load tap changers are relatively new to the market and are currently expensive; however as this type of equipment is more widely adopted, it is expected that the cost will reduce and consequently, increase the financial benefits of Smart Street.

4.2 Impacts of network fees

The capability to reduce energy consumption is undoubtedly an attractive feature for customers. However, it can affect the business of DNOs or other stakeholders who rely on energy related charges (eg network fees such as DUoS, TUoS, etc). If future efficiencies were to impact on DUoS it could ultimately influence network investments if it were a consideration when assessing available reinforcement strategies.

4.3 Business case conclusions

The potential to reduce network losses can be valuable for DNOs, particularly if demand grows rapidly and minimal investment in enabling infrastructure is required to meet the increase.

The loss of revenue for DNOs from the reduction of network fees could significantly decrease the attractiveness of Smart Street.

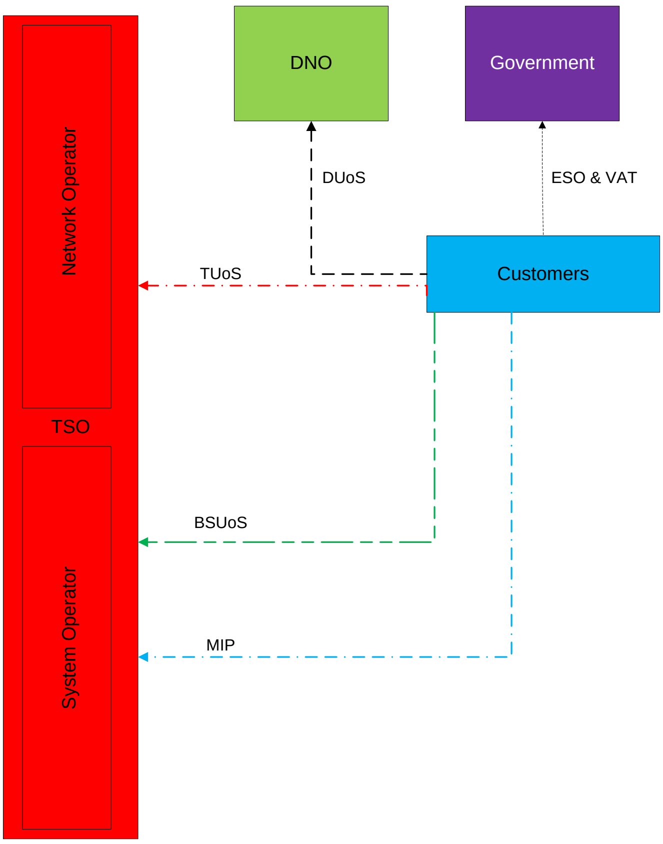
One of the key features of Smart Street is its potential to defer or avoid traditional network reinforcement. This is particularly attractive when reinforcement costs are high or demand growth is uncertain. In the latter case, Smart Street could potentially avoid investment in stranded assets.

5 COST BENEFIT ANALYSIS

The proposed CBA framework comprises two main components, namely a tool that provides economic studies (including optimisations) in light of existing regulations and a value flow mapping approach. The former is provided by the techno-economic framework and BCAF described above. The latter was built using the graphic interfaces provided by the e3-Value approach to map energy, information and cash flows between different stakeholders throughout the electricity system.

The value flow mapping approach used in this work is presented in Figure 5.1. The map highlights key exchanges between stakeholders which, in this case, correspond to the Market Index Price (MIP), Distribution Use of System (DUoS) charges, Transmission Use of System (TUoS) charges, Balancing Services Use of System (BSUoS) charges and Value Added Tax (VAT).

Figure 5.1: Simplified value flow map of considered in this work



The stakeholders considered in this work were DNOs, customers, a transmission network operator (TNO), an electricity system operator (ESO) and the Government. There were two reasons to consider a TNO and an ESO instead of a transmission system operator (TSO):

- Firstly, NG is currently being divided into a TNO and an ESO
- Secondly, in the interest of simplicity, generators, energy service companies and the other entities can be aggregated as an ESO.

This work resulted in an understanding of the impacts that adoption of Smart Street can have on different stakeholders. The study centred on selected dense urban, urban, and rural HV and LV networks, the current regulatory framework, and existing forecasts for future PV uptake and demand growth (including adoption of EVs and HPs). In addition, the studies considered different combinations of solutions.

The following conclusions can be made after analysing the results:

- Customers benefit from energy savings; the results showed annual economic savings of up to £70 per customer
- For DNOs the results showed an annual economic loss of up to £7 per customer
- The TNO incurs losses due to a reduction in revenue from transmission network charges. The results showed an annual economic loss of up to £7 per customer
- The ESO incurs losses from lower trade of energy and energy-related services. The results showed an annual economic loss of up to £39 per customer
- The government is expected to receive less revenue from taxes. The results showed an annual economic loss of up to £15 per customer.

6 CONCLUSIONS

Net annual energy savings (kWh) at LV and HV levels increase with higher demand growth and decreased with higher PV integration. This is due to the higher energy consumption in those cases, which provides more potential for savings through CVR under those conditions.

The optimised use of OLTCs provided the highest energy savings. These energy savings result in economic savings of up to £70 per customer.

Losses decrease with low levels of PV integration (eg, ≤40%). However, losses rise again for higher levels of PV integration as power flows are more likely to shift and increase in an opposite direction. The potential to reduce network losses can be valuable for DNOs, particularly if demand grows rapidly and minimal investment in enabling infrastructure is required to accommodate the increase.

Meshing plays a prominent role in reducing power losses by redistributing power flows and, potentially, changing the overall trend of losses savings.

In addition to reducing energy consumption and losses, Smart Street can also increase the firm capacity of the distribution network. The OLTCs and capacitors can be used to alleviate voltage issues while network meshing can redistribute power flows, potentially alleviating voltage and thermal issues.

The analysis shows savings of £44m to Electricity North West and £518m to GB out to 2060 in deferred reinforcement. This is particularly attractive when reinforcement costs are high or demand growth is uncertain. In the latter case, Smart Street could potentially avoid investment in stranded assets. Part of this benefit will be offset by the loss of DUoS. If it is assumed that customers are split evenly across the LV network, the benefit of Smart Street reduces to £34m and £378m for Electricity North West and GB respectively (based on the percentage figures of 64% and 72% used in the business case.

The loss of revenue for DNOs from the reduction of network fees could decrease the attractiveness of Smart Street.