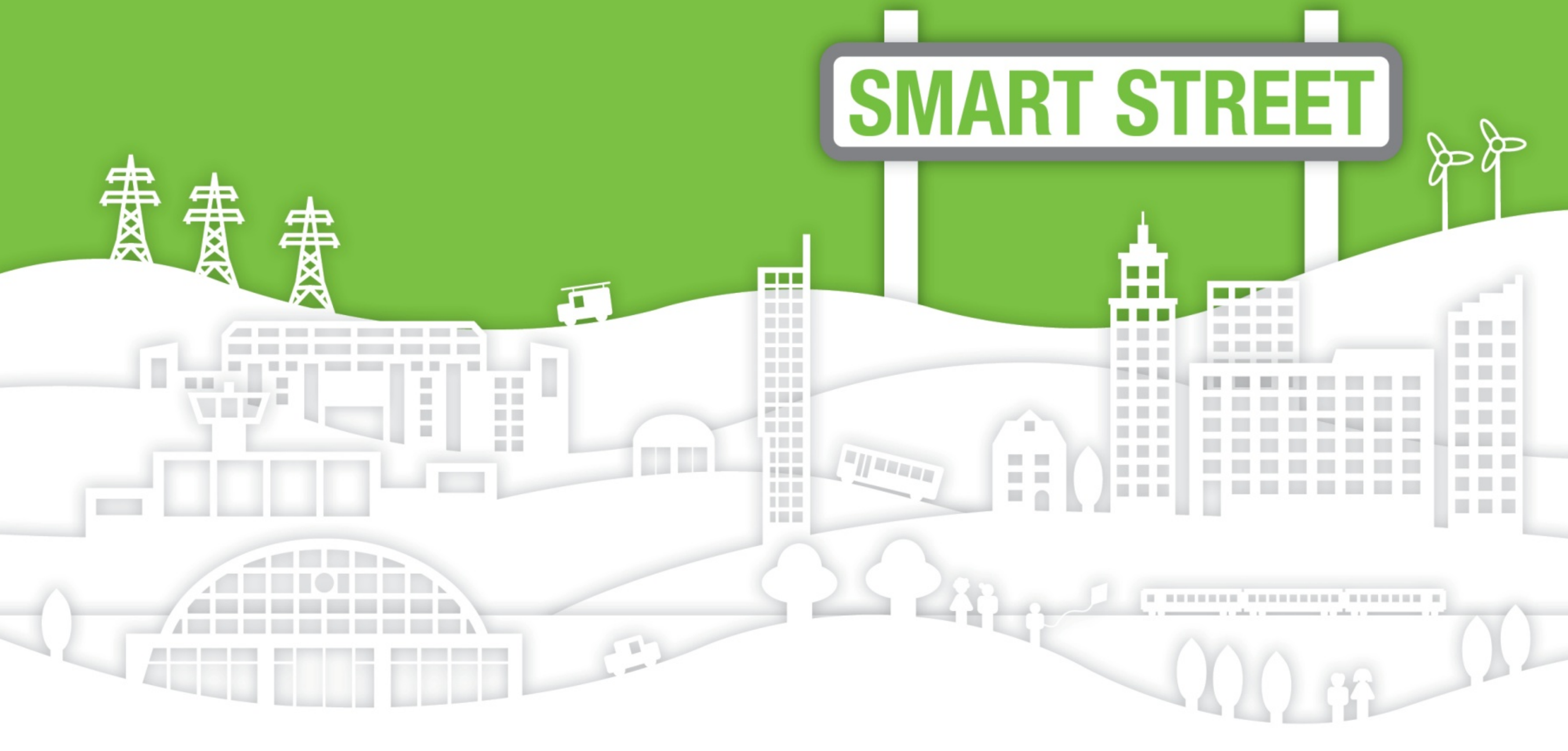
Smart Street
Cost Benefit Assessment Study

20 February 2017



VERSION HISTORY

Version	Date	Author	Status	Comments
Version 1.0	20/02/17	Geraldine Bryson	1.0	

LIST OF ACRONYMS

Abbreviation	Term
CRMS	Control room management system
CVR	Conservation voltage reduction
DG	Distributed generation
HV	High voltage (11kV / 6.6kV)
LCT	Low carbon technology
LCNF	Low Carbon Networks Fund
LV	Low Voltage (400V / 230V)
NMS	Network management system
NPC	Net present cost
NPV	Net present value
OLTC	On load tap changer
SP5	Spectrum Power 5 (Siemens optimisation software)
THD	Total harmonic distortion
VVC	Volt/Var control

CONTENTS

1 INTRODUCTION

1.1 Purpose of document

The purpose of this document is to achieve the associated deliverable related to the following Smart Street **SDRC 9.4.3 – Publish an interim Cost Benefit Assessment Study on the Smart Street website by February 2017.**

This document describes the methodology used to develop a techno-economic model, a business case model and a CBA framework. The tools and models developed will be 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 aims to utilise advanced real time optimisation software to simultaneously manage HV and LV network assets to respond to customers' changing demands. Voltage management on HV networks will look to reduce network losses while Conservation Voltage Reduction (CVR) on the LV networks will look to reduce energy demand. Capacitor banks on the HV network are being utilised to help manage network losses by adjusting the networks power factor. On the LV network, a mix of capacitor banks and controlled meshing of networks will be integrated to flatten the voltage profile and improve energy efficiency. The meshing of LV networks will also aim to release 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 230 to 220volts. This equipment can, however, operate adequately at voltages in the region of 200volts. If power is delivered at voltages higher than these optimum levels, then energy will be consequently wasted. Excess voltage can 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 the customer's equipment. Smart Street proposes to optimise 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 proposes to optimise the voltage by utilising on-load tap changing (OLTC) transformers. These transformers will be able to regulate the voltage along the feeder while maintaining statutory limits. This will allow for the peak load to be reduced, hence reducing the annual energy consumption.

Additionally Smart Street will utilise shunt capacitors on the LV feeders to allow for a voltage boost at the end of the circuit to reduce voltage drop. This will allow for a flatter 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 will assess the benefits of meshing LV networks to balance load while releasing network capacity at times of high demand.

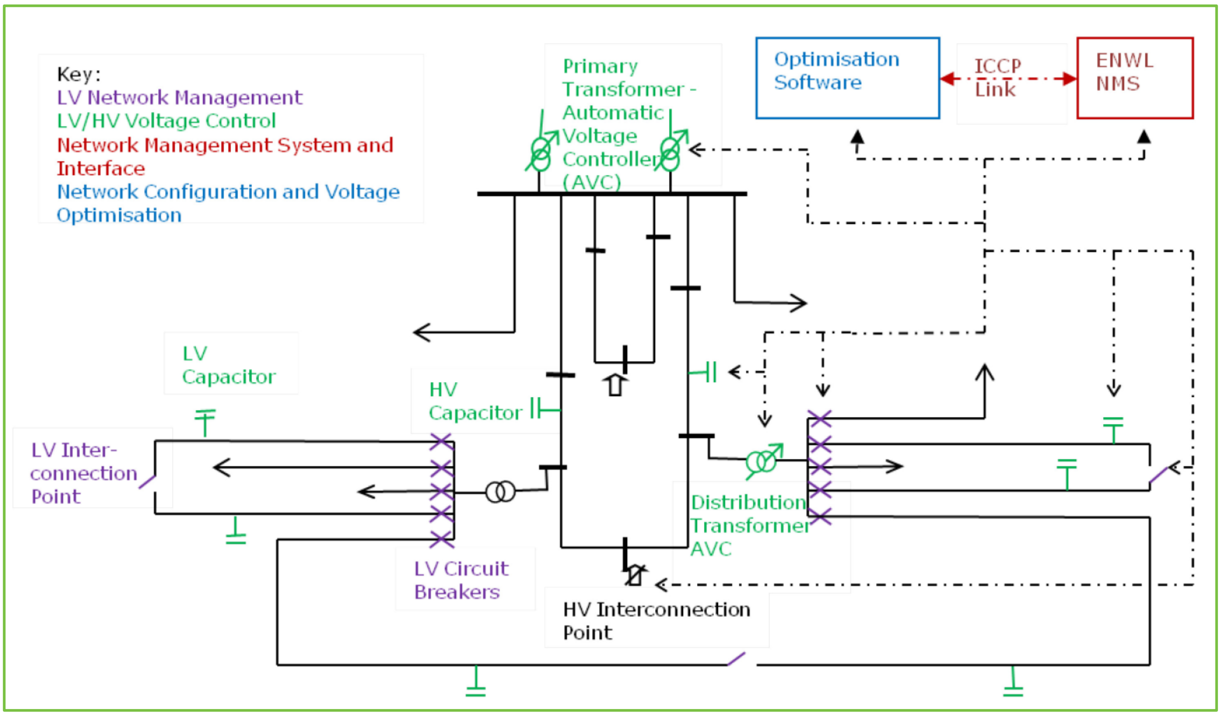
Our project partner, Kelvatek, has developed new controllable retrofit vacuum switching devices especially for this project. These devices are to be utilised at the existing distribution boards and in link boxes across the LV trial circuits. The devices will have the capability to be remotely controlled allowing both sensing of feeder flows and reconfiguration of the LV network.

1.5 Control systems

Figure 1 shows an example of how the various Smart Street technologies will be installed across the trial networks. The optimisation will include the ability to optimise for violations, losses and to minimise load as a single VVC function. The opportunity to mesh the trial networks will also be included in this function, but radial configurations will be the preferred running arrangement. This is specified to minimise customer outages during electrical faults. Therefore the switching equipment shall be closed (create loop or mesh networks) if the objective-function results in positive changes to the network above a set threshold.

The optimisation application calculates the optimal procedures to reach the optimisation objectives, which may be different for HV and LV depending on the chosen function. The user can select if the switching equipment shall be included or inhibited in the optimisation scheme and only specified remote controlled switches will be included in the optimisation.

Figure 1: Smart Street network management



1.6 Overview of the Smart Street test regimes

A summary of the Smart Street trials is shown in Table 1 below.

Table 1: List of Smart Street trials

Smart Street Trial	Test Regime
Trial 1: LV voltage control	T1.1 On-load tap changing distribution transformer only
	T1.2 On-load tap changing distribution transformer and capacitor(s) on LV circuits
	T1.3 Capacitors at distribution substation only
	T1.4 Capacitors at distribution substation and on LV circuits
	T1.5 Capacitor(s) on LV circuits only
Trial 2: LV network management & interconnection	T2.1 LV radial circuits
	T2.2 LV interconnected circuits
Trial 3: HV voltage control	T3.1 Voltage controllers at primary substation only
	T3.2 Voltage controllers at primary substation and capacitors on HV circuits
Trial 4: HV network management & interconnection	T4.1 HV radial circuits
	T4.2 HV interconnected circuits
Trial 5: Network configuration & voltage optimisation	T5.1 Losses reduction
	T5.2 Energy consumption reduction.

The Smart Street trials will take place over a two year period using an off/on test regime which will result in one year's worth of data for both network normal running configurations and for Smart Street operation. This will allow for the two scenarios to be compared and analysed enabling the overall benefits of Smart Street to be calculated.

2 TECHNO-ECONOMIC MODELS

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 has been proposed.

2.1 Simulation tool

The simulation tool is a general framework developed in Matlab that provides an interface between the information produced throughout the Smart Street project and most models developed for the business case and carbon analyses. In addition, besides collecting relevant data, it also provides the key network studies that are required by these models.

Interfaces were created to seamlessly collect inputs. The interfaces facilitate the collection of relevant network and demand profile information from relevant files. This includes the HV and LV network data, and load profiles, as well as the use of an interface between the proposed Matlab models and the OpenDSS software.

Once the data has been loaded into Matlab, it can be modified to reflect a particular operation strategy, as well as a demand growth and LCT uptake scenario. The operation strategies will be defined based on recommendations and information from the project team. Once the conditions of the simulation have been defined and the relevant variables have been updated, relevant OpenDSS compatible script is produced and the engine is called to perform the simulation.

The main network studies provided by the simulation framework are network headroom, power losses and network reinforcement. These studies take the network models of the Smart Street trial networks and scenarios for demand growth and LCT penetration as inputs to produce relevant results as equivalent time series.

2.2 Optimisation engine

UoM proposed a bespoke recursion based optimisation engine to address the complex problems associated with network planning. This approach rather than simplifying the complexity of the problem, exploits the specifics of network planning to reduce the size of the search space where the solutions may lie. As a result, the approach can capture the full complexity of the problem and does not compromise the reliability of the solution. This is a key feature of the proposed approach, as it allows exploiting available information, which could be taken from:

- The network studies produced by the simulation tool, which can be pre-calculated off-line to improve computational complexity;
- Studies from other research areas within the Smart Street project, which is critical to evaluate different operation strategies proposed within this project; and/or
- Other results that DNOs may have at hand, which enable the tool to be used for applications beyond the Smart Street project.

2.3 Uncertainty modelling

Uncertainty is modelled using long term scenarios and short term forecast errors.

Long-term uncertainty on demand growth and LCT uptake for the next 45 years is currently modelled based on a number of scenarios. These scenarios show conditions where due to combinations of demand/distributed generation growth (or potentially reduction), net peak system demand that determines network headroom can increase, decrease or remain static.

Short-term uncertainty represents the fact that, even if the general trend of the scenario is known, there is still uncertainty from committing network reinforcements ahead of time based on imperfect forecast due to construction lead time. This uncertainty is modelled using robust optimisation constraints for up to three years in the future, which corresponds to the longest considered construction lead time (ie, for substation upgrades).

The proposed simulation and optimisation methodology is a flexible approach that facilitates the planning of distribution network upgrades in light of complexity from the technical characteristics of the network and reinforcement options, uncertainty, planning strategies and so forth.

3 BUSINESS CASE MODELS

Under current regulation, DNO costs relevant to their business model should include capital expenditure from direct network costs, as well as from network upgrades meant to mitigate social costs. This is in line with a CBA framework introduced by Ofgem as part of RIIO-ED1. The framework is used by UK DNOs to justify network upgrade decisions to Ofgem. This facilitates regulation of the current business of DNOs by providing consistent and comparable metrics of the social and direct costs associated with investments made by every DNO.

Even though Ofgem's CBA provides consistent means to evaluate network reinforcement options in light of the business model of DNOs and relevant regulation, under its current form, it has major drawbacks that make it unstuitable for the purposes of the Smart Street project. Several improvements are required before the CBA framework can be used for the evaluation of the business case of the Smart Street method.

The mathematical model and key assumptions extracted from the Excel-based Ofgem's CBA framework were used to develop a more flexible Matlab version of the CBA framework. This version can be easily embedded in the other tools (eg, the simulation tool and optimisation engine) and extended to provide additional calculations by coupling to a value flow mapping approach. This approach allows mapping and quantifying of the impacts that distribution network solutions, such as use of CVR techniques, can have on customers, DNOs and other actors throughout the value chain.

Ofgem's CBA has been extended to classify cash flows as capital expenditure and operational expenditure. Data format was maintained consistent with that used by the Excel version of the tool to facilitate compatibility and to allow replication of results in the standard format.

The proposed methodology extends Ofgem's CBA framework to systematically model the characteristics of distribution network solutions under a wide range of considerations. In addition, it allows for consideration of different preferences on trade-offs between social and direct network costs that can be driven by different policies. This approach can be used to demonstrate the value of the different Smart Street options under a wide range of LCT uptake scenarios and different regulatory environments (in terms of social or network cost preferences).

4 CBA FRAMEWORK

This section presents a new methodology developed for the evaluation of impacts from the deployment of distribution network reinforcement options on different actors throughout the value chain. The methodology was developed based on the modelling requirements for properly capturing the impacts that deploying the Smart Street method can have on DNOs, customers and other actors. More specifically, the methodology was formulated by interfacing bespoke versions of Ofgem's CBA framework and the e^3-value mapping approach.

4.1 Ofgem CBA

The CBA framework provides a set of mathematical models (including evaluation criteria) and assumptions to assess investment decision in terms of relevant costs and benefits. CBA frameworks comprise a family of financial tools used to consistently assess the value of decisions (eg, deploying the Smart Street method or other alternatives) in terms of relevant criteria and associated costs and benefits. The specific costs and benefits and preferred criteria can substantially vary for different types of decisions, regulatory frameworks, perspectives and so forth. Accordingly, bespoke CBA frameworks are typically developed for the assessment of specific types of decisions.

A mathematical model extracted from the Excel-based CBA framework for the assessment of distribution network reinforcement options proposed by Ofgem was developed. This mathematical model can be classified as the equations that estimate direct DNO costs, calculate social costs, and denote the objective function.

Direct DNO costs according to existing regulation comprise expensed investments, depreciation and costs of capital

The term social cost is used to define costs associated with the distribution network, which impact different actors and society as a whole. In the context of Ofgem's CBA, social costs are associated with power losses and relevant carbon emissions and the reliability of the network in terms of customer interruptions and customer minutes lost.

The objective function used by Ofgem's CBA framework is the NPV criterion which is estimated as the combination of two NPC calculations.

By taking this approach, Ofgem's CBA framework identifies if a proposed network upgrade option is more attractive than baseline options, which are generally based on reinforcing feeders and substations whenever firm capacity is reached. Thus, this approach inherently identifies (with a positive NPV) whether or not the proposed approach is an improvement to current practices.

However, this criterion may unnecessarily add complexity to relevant Smart Street studies, which will consider multiple scenarios of LCT penetration where combinations of different network reinforcement options may be required at different times based on the conditions assumed in particular scenarios. In such cases, it is vital to capture how the economic performances of the baseline and Smart Street options under consideration vary per scenario, which is better represented by the independent NPC criteria.

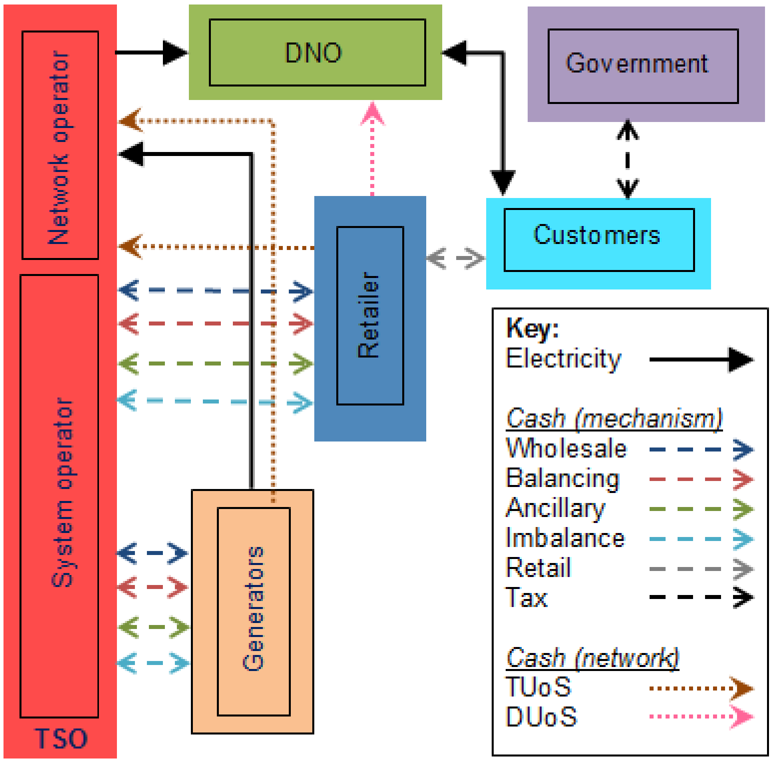
Based on this, the CBA framework used in this work is based on the NPC criterion, while the baseline is presented in all analyses to guarantee that the general findings are consistent with the preferences of the regulator as hinted by Ofgem's CBA.

4.2 Value mapping

In order to develop the mapping approach required for this work, it is first critical to identify the actors to be considered, as well as the relevant regulatory framework that allows them to interact. The latter in the context of this work corresponds to the electricity markets. Once the actors and their interactions are defined, the graphical components of the flow mapping approach are selected and used to map key exchanges between actors, which are finally modelled with interaction matrices.

At this stage, the actors that are being considered in this work include DNOs, customers, the Transmission System Operators (TSO), Retailers and Generators. In addition, the government is also considered as an actor responsible for implementing policies and collecting taxes. The proposed simplified value flow map of the UK electricity sector is presented in Figure 2.

Figure 2: Value flow map



The value flow mapping methodology is applied by inputting cash flows (captured by the CBA) from the model of the relevant actor (eg, DNO and customer) to the different exchange arrows. For example, the impacts on changes on DUoS fees from improved network reinforcement practices or reductions in customer consumption facilitated by CVR techniques can be mapped with this approach.

Even though the value flow mapping approach is a comprehensive visual technique, it has its limitations. Particularly for the direct extraction of information and communication of the results in systems with a large amount of interconnections which have to be assessed under a wide range of assumptions (eg, different LCT penetration levels). In such cases, it is more practical to map all interactions using matrices informed by the flow mapping, named interaction matrices. Two interaction matrices are used in this work, namely, an exchange-to-role interaction matrix and role-to-actor interaction matrix.

The proposed methodology that combines the CBA framework and mapping approach (using the interaction matrices) can readily be used to process impacts to different actors throughout the value chain. More specifically, this approach facilitates the formulation of clear and valuable cost and benefits charts showing the potential effects that deployment the Smart Street method can have on different actors (compared with a business-as-usual baseline).

The proposed methodology combines a CBA framework that captures the UK regulatory framework from the perspective of DNOs with a bespoke value flow mapping technique that captures relevant energy and cash flow exchanges throughout the value chain. The illustrative examples highlight the potential of the tool to evaluate the impact of DNO decision on different actors and under different considerations.

5 CONCLUSIONS

The formulation of the simulation and optimisation methodology and its main components has been concluded. However, the methodology has only been validated for a single and specific set of conditions (eg, those inherently assumed in the input data files). Accordingly, the next steps are to validate the methodology under a wider number of scenarios. Afterwards, the Smart Street method will be assessed under a wide range of scenarios for LCT uptake, also considering the CBA, business case and carbon assessment tools.

The business case assessment tool has been finalised and now efforts will be aimed at coupling the tool with other frameworks eg, the techno-economic models, as well as defining and performing initial business case studies.

The proposed CBA model has been finalised. The next steps, in progress, are to couple the model with other tools developed, particularly the techno-economic tools and identify relevant regulatory and operational scenarios. This will ultimately allow assessing the impact that the Smart Street method can have on customers and other actors under different conditions.