Title:

Deliverable 3.4.1 "Interim Report on Carbon Accounting"

Synopsis:

This brief Interim Report provides the first progress update of carbon accounting task in WP3 to Jan 2017. During this time and according to schedule, The University of Manchester has developed a methodology for consequential life cycle assessment appropriate for the carbon impact needs of the Smart Street project. This method is based on the most up-to-date methodology for assessing the carbon impact of energy systems. It provides a robust framework for evaluating the potential carbon saving benefits of the Smart Street method in light of complex system dynamics and temporal issues. In addition, the method can be easily integrated with other models developed within the Work Package, and utilises relevant data produced within the project for a comprehensive assessment. Goal and scope stages of the method have been completed, as have generic system boundaries and the approach to temporal allocation of carbon emissions. Initial work on inventory gathering has begun.

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Executive Summary

This document is the first Interim Report on carbon accounting for the Smart Street (SS) project and corresponds to Deliverable D3.4.1 of Work Package (WP) 3 “Cost Benefit Analysis and Business Case” of the SS project run by Electricity North West Limited (ENWL).

The objective of this task is to evaluate the potential carbon savings of the SS method relative to a business as usual counterfactual of traditional network reinforcement in response to the uptake of distribution network connected low carbon technologies (LCTs). This evaluation is a key component in WP3, and compliments the techno-economic evaluation of the SS method.

This deliverable sets out the consequential life cycle assessment (LCA) approach to carbon accounting that has been developed to integrate technical and economic modelling of SS, and therefore provide a comprehensive assessment of the asset and operational carbon saving potential of the SS method. This report provides an outline of the key considerations and requirements for the consequential LCA approach in relation to evaluating change on an electricity distribution network over time. It provides an outline of the key stages of LCA and how consequential aspects will be incorporated. This document will function as a reference for the LCA goal and scope, establishing key system boundary and functional unit principles. Issues particular to consequential analysis, specifically temporal allocation, are discussed and a solution for accounting for these challenges is proposed. The report also presents some initial inventory data and emission factors. It sets out the programme of work for subsequent stages of the method.

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Abbreviations

Acronym	**Full Name**
BAU	Business as Usual
CO_2	Carbon Dioxide
CVR	Conservative Voltage Reduction
DNO	Distribution Network Operator
ENWL	Electricity North West Limited
GHG	Greenhouse Gas
LCT	Low Carbon Technology
OLTC	On Load Tap Changer
LCA	Life Cycle Assessment
SS	Smart Street
WP	Work Package

1 Introduction

Climate change presents a substantial challenge for the electricity sector. The need to reduce global greenhouse gas (GHG) emissions, most notably carbon dioxide (CO_2) is driving changes in energy generation and demand towards greater electrification of heating and transport services, and distributed renewable electricity generation. The uptake of these low carbon technologies (LCT) through market mechanisms such as feed in tariffs lead not only to greater distribution network utilisation, but uncertainty about when and where network operators (DNOs) will have to solve network issues. Resolving emergent issues of voltage management through business as usual, (BAU) traditional network reinforcement options (e.g. cable and transformer replacement) is not only financially costly for DNOs, but has a GHG impact that runs counter to the overall goal of LCT uptake. Smart Street (SS) offers new tools for active voltage management which can postpone or ultimately avoid BAU reinforcement. By reducing energy consumption, demand and generation peaks, and by providing active operation of On Load Tap Changers (OLTCs), switching capacitors and switching tie lines, as well as Conservation Voltage Reduction (CVR) techniques, SS enables the same network provision as the BAU case but with potentially lower carbon impacts.

This report provides a first update on the progress of the carbon accounting work for SS (Task 3.4). As part of Work Package (WP) 3, Task 3.4 will quantify the carbon impact from enhancing traditional distribution network reinforcement practices with the SS method in the light of potentially significant penetration of LCTs. As such it will evaluate the extent to which the SS method achieves carbon benefits compared with BAU tradition reinforcement and operational practices, and will test the hypothesis that SS reduces overall network CO_2 emissions.

The report includes details of the consequential life cycle assessment (LCA) approach that has been developed to enable full comparison of carbon impacts for the electricity distribution network as a whole. The SS method entails a different set of network assets deployed at different points in time, compared to the BAU case which will results in different carbon impact profiles for the physical network. Additionally the SS method for network management will reduce energy consumption and have different network energy loses in comparison with the BAU case. This too is influential on the overall operational carbon impact of the distribution network. The consequential LCA approach to carbon accounting set out in this document enables a holistic comparison of the various carbon impacts of SS method and BAU reinforcement to determine the net impact.

The report is structured as follows:

Section 2 provides a review of carbon accounting and the role of LCA methods. It also provides an overview of relevant LCA literature on electricity distribution networks. It sets out the core principles of the consequential LCA approach as they apply to SS.

Section 3 presents the first stage of the LCA; goal and scope. It also gives an overview of the approach to subsequent stages

Section 4 summarises the key conclusions from methodology development and outlines next steps.

2 Carbon Accounting

The UNFCCC Paris Agreement includes pledges from developed countries such as the UK to reduce GHG emissions from their energy sectors at increasingly rapid rates to comply with an agreed global warming threshold of below 2°C global mean temperature rise. This is the latest in over twenty years of international climate change negotiations that have shaped energy policy at European Union and UK national level. For electricity distribution it is likely to mean a significant change in electricity demand and the incorporation of more small scale renewables and energy storage into networks. This is likely to prompt a requirement to expand network capacity to facilitate LCT uptake. Traditional, passive control approaches to solving network capacity issues involve reinforcing network assets such as transformers and cables. Such business as usual (BAU) network solutions have climate change impacts themselves, in the GHG emissions associated with raw material extraction, component manufacture and installation of the assets deployed. A key aim of SS is to enable LCT uptake, but with significant GHG reduction benefits compared to traditional methods of network reinforcement and operational practices.

Carbon accounting is a process of quantifying GHG emissions so that projects, products, nations and organisations can compare, manage and reduce their contribution to climate change. There are multiple GHGs responsible for anthropogenic global warming including; carbon dioxide (CO_2), nitrous oxide (N_2O), halocarbons (CFCs and HCFCs), methane (CH_4) and sulphur hexafluoride (SF_6). These gases have different heat trapping properties, lifespans in the atmosphere, and interactions with other atmospheric components. Of the GHGs CO_2 is the dominant anthropogenic driver of climate change [1] to which the effects of other gases are compared and quantified as CO_2 equivalent within carbon accounting frameworks. While electrical switch gear and transformers may contain the high warming impact SF_6 as an insulator, leakage of this is increasingly well managed through EU F-gas directives. Consequently, for the remit of SS, CO_2 is the primary GHG for accounting purposes, as significant emissions of other GHGs are not anticipated within the scope of the analysis. Therefore carbon accounting through the rest of SS applies exclusively to CO_2.

The carbon accounting for SS covers three carbon impacts on the electricity distribution network arising from network solutions; the embodied CO_2 in network assets (including cables, transformers etc) from their manufacture through to deployment, essential operation and maintenance requirements; changes in operational energy loses from the network; changes in network energy demand. The network assets and operational processes that form SS are expected to reduce the need for traditional reinforcement assets with higher embodied CO_2 for equivalent service provision. A reduction in operational energy loses from the distribution network due to traditional network reinforcement as well as SS interventions results in lower system emissions through avoided electricity generation, relative to CO_2 emissions associated with that electricity. Reducing network energy demand also provides a saving in electricity system CO_2 through avoided power generation, and this is a further benefit of the SS approach. For carbon accounting in the SS project an LCA methodology-based approach will be applied that incorporates the embodied CO_2 of assets and CO_2 values for reduced electricity generation in comparable SS and BAU scenarios.

2.1 Life Cycle Assessment

This section presents the core elements of the life cycle assessment (LCA) method that will be applied to the SS project carbon accounting. It sets out how the SS carbon accounting method will comply with formal LCA processes in relation to the specific project goal of quantifying CO_2 savings from SS electricity network solutions. It will also discuss the consequential system analysis that is required by the scope of SS and how this will be incorporated into the carbon accounting method.

LCA is a widely used method for determining the environmental impact of a product or process. The method was developed to quantify the totality of environmental burdens and benefits of a given unit of analysis, accounting for transactions to and from the environment associated with the provision of the unit, from the extraction of raw material inputs, through manufacture, operational usage to final disposal (cradle to grave life cycle). As such it is a valuable tool for comparing the environmental performance of products or processes and identifying particular 'hot spots' in the life cycle with particularly high costs that can be targeted for improvement.

LCA methods have been formalised in the International Organisation of Standardization ISO14040 [2] and ISO14044[3] guidelines and principles which are set up to ensure proper standards in LCA practice. These guidelines set out the four stages of LCA which will also be applied to SS:

- Goal and scope definition
- Life cycle inventory (LCI) analysis
- Life cycle impact assessment (LCIA)
- Interpretation of results

Figure 1 graphically illustrates the standard stages of LCA and their relation to useable outputs:

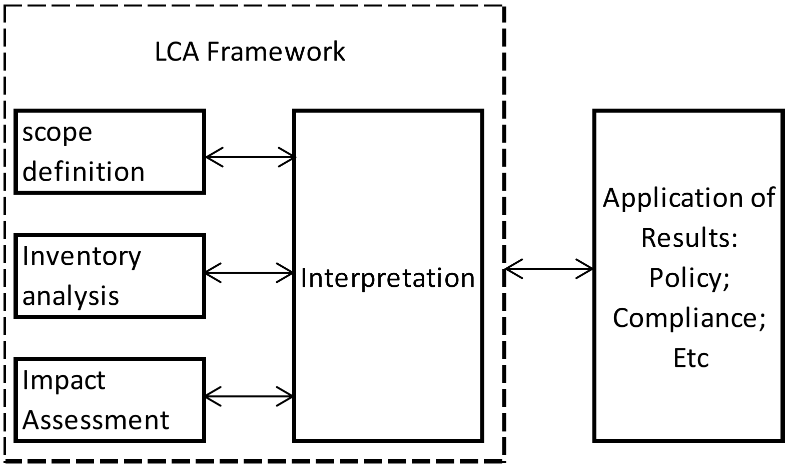

Figure 1: LCA framework adapted from Frischknecht et al. [4]

A full LCA accounts for a range of environmental impacts including eutrophication, acidification, human toxicity and resource depletion. Global warming potential (GWP) is another impact vector used in LCA modelling that weights the CO_2 equivalence of the various GHG emissions associated with the project. The final impact assessment for a traditional LCA weights the importance of these different impacts to provide a final quantification of the environmental impact. For the purposes of SS a full LCA is not being undertaken as it is not with the project requirements, and it is not fully compatible with the consequential approach that includes network operational impacts given the static nature of the weightings used.

2.1.1 Consequential LCA

In addition to the standard LCA approach described above, SS requires a consideration of consequential system aspects, specifically changes to network distribution losses and demand. These factors fall outside of the typical 'attributional' form of LCA, which limit the boundary of analysis to direct impacts from the product [4]. Consequential LCA incorporates the significant direct and indirect changes in adjacent products or process arising from the addition of a new product or function. It was primarily developed for the bioenergy sector to provide a more comprehensive assessment for the wider sustainability of bioenergy products, and has been increasingly used as a valuable tool for informing policy makers about the net system impacts of a low carbon intervention [5], including the electricity sector [6].

Consequential LCA approaches differ from the standard attributional LCA approach in that;

I. It requires assumptions about the ongoing operational framework of the system (e.g. electricity network) over the timeframe of analysis (referred to as prospective analysis, such as the future uptake of LCTs);

II. An equivalent baseline counterfactual of the system operation is needed for comparison;

III. It allows the comparison of scenario outcomes rather than products;

IV. It requires dynamic modelling of system operation, rather than the static, steady state operation of attributional LCA, so that the relationship between objects in the system boundary are well characterized and resultant changes are quantified;

V. Requires the equal temporal allocation of benefits and burdens relating the system being analysed rather than standard allocation based on economic function or utility.

Consequential LCA is an emergent methodology increasingly used in policy making, however it necessitates clear methodological practices to be a robust tool for carbon accounting. Specifically the method of consequential LCA must be clearly specified and key contingent assumptions conveyed to end users of the analysis for the outputs to be of robust value to policy makers [7]. The SS method for carbon accounting will achieve this by:

I. Aligning scenarios for decarbonisation of electricity generation and the uptake of LCT with the UK Government and National Grid assumptions used in WP1-3 of SS.

II. A BAU case for network adaptation will be used as the counterfactual based on a detailed carbon impact assessment of standard network reinforcement under the same decarbonisation and LCT uptake scenarios as the SS method outputs.

III. Comparable LCA processes carried out for all relevant SS scenarios and the BAU counterfactual.

IV. Carbon accounting will be based on detailed dynamic system modelling outputs from WP1-3 of SS detailing network changes overtime.

As discussed above, the consequential approach requires dynamic system modelling to determine the consequences of change within a system for a given intervention. In the case of SS the carbon accounting in this task will be closely aligned with network model outcomes used in the rest of WP3, and informed by the other SS WPs. The results of the carbon accounting are therefore in part contingent upon the implicit and explicit assumptions in the modelling process. The outputs from this task will clearly communicate that the consequential analysis results are for the purposes of comparison between future options as opposed to an accounting process for reporting absolute values. Absolute values comparing the embodied CO_2 in the physical network assets for SS method and BAU will however be presented.

3 LCA Based Carbon Accounting Methodology

The following section will outline the consequential LCA approach for SS carbon accounting in detail. It will serve as the goal, scope and system boundary for inventory analysis stages of the work. An outline of the inventory, impact assessment and interpretation stages, with initial inventory data outputs is presented.

3.1 Goal and Scope

The goal of the Smart Street LCA is facilitate comprehensive carbon accounting of the SS method for adapting to uncertain yet potentially rapid LCT uptake. The scope includes;

1) Life cycle CO_2 associated with network assets. These include;
    a. BAU reinforcement assets – underground/over ground electricity cable, transformers
    b. Smart Street assets – on-load tap changers (OLTC), switches (WEEZAP, LYNX)
2) Operational CO_2 emissions associated with energy loses from distribution network
3) Operational CO_2 emissions associated with energy demand reduction on network

The current functional unit considered for the consequential LCA study is tCO_2/electricity network over the time frame of analysis. This unit may be revised in the interpretation stage of the analysis; however this unit aligns with the SS project aims of comparing network carbon impacts.

The initial scale is the SS trail networks as modelled in other WPs, however the scope will expand to scale up the finding from the carbon accounting to ENWL DNO area and then provide outputs on potential carbon savings at a national scale.

3.1.1 System Boundary

The system boundary for the LCA has two discrete elements. Firstly, for the attributional assessment of the CO_2 assets there will be an assessment of upstream emissions (raw material extraction through to installation) and any ongoing inputs during standard operation (e.g. replacement of oil, cooling load) as required. The disposal phase of a product's life cycle is not always included in LCA projects, and it is discretionary as to whether doing so adds value to the analysis [8]. For products with high metal content such as transformers and cables there is potentially a net environmental benefit if materials are recycled as this often has lower impacts than virgin materials. Such an assumption is more problematic for long lived products such as those in electricity networks, requiring further assumptions about metal production and manufacturing in coming decades. Therefore the disposal phase is not currently included in system boundary of this study. The same boundary is being applied to both the traditional reinforcement and the SS intervention cases to ensure consistency.

The second system element is electricity from electricity grid. The boundary for CO_2 emissions is applied to UK territorial emissions associated with electricity generation. Average annual emissions intensity of electricity supplied by the grid will be used. Figure 2 presents a conceptual outline of the system boundary for network CO_2 emissions in the LCA

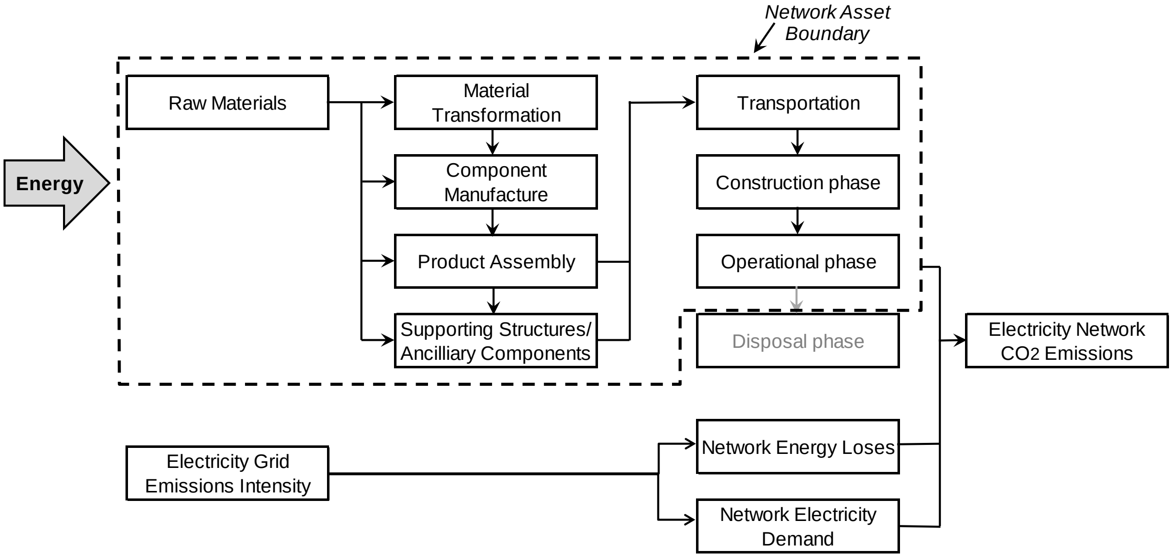

Figure 2: Representation of Smart Street LCA System Boundary

3.2 Inventory Analysis

LCA requires detailed accounting of the material and energy flows into the system boundary, and the quantification of flows to the environment from the system boundary. The second stage of LCA is therefore to obtain an inventory of the material and energy inputs into the SS and BAU network assets. Inventory data gathered for previous Tyndall Manchester projects, including with ENWL (CLASS and C2C), will be built upon to develop detailed accounting. Initial inventory results for material inputs associated with traditional reinforcement and OLTC are shown in Figures 3-5:

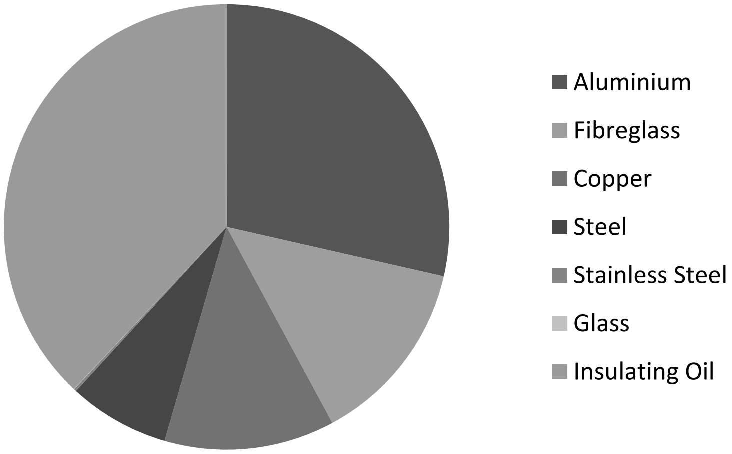

Figure 3: Material Composition of OLTC

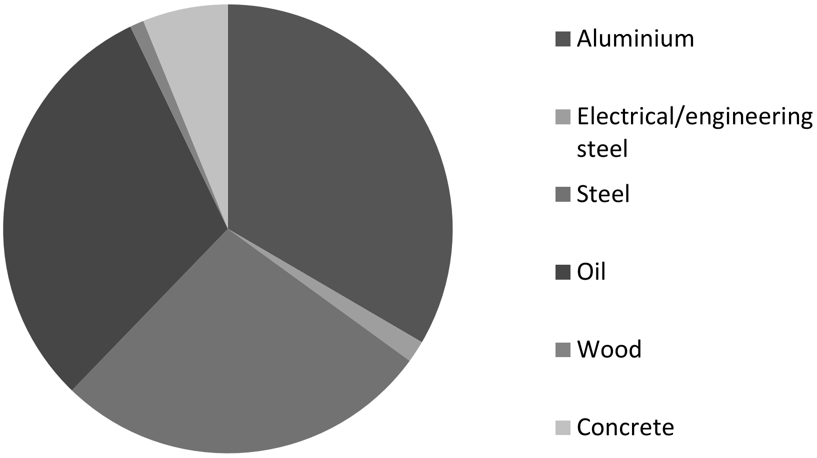

Figure 4: Material Composition of 335kVA Transformer, Concrete Base Mount

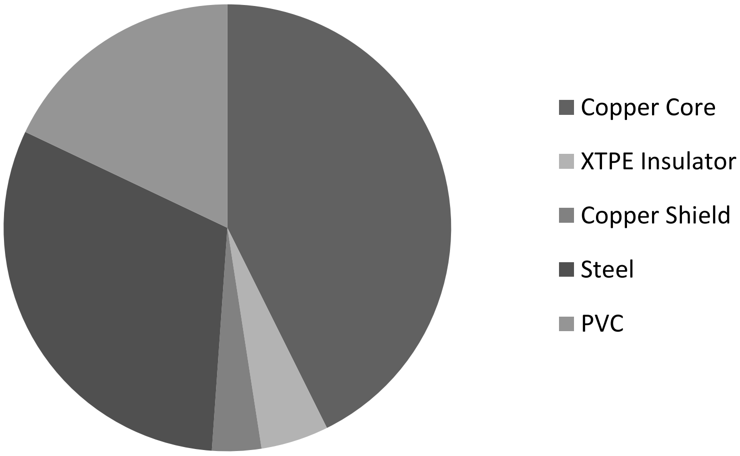

Figure 5: Material Composition of Three Core Copper Cable

Inventory data also includes material and energy input for excavation, cable laying, backfilling and restoring road/pavement for underground cables and the resources for pole affixed overhead cables. Existing literature from [9] and [10] as well as ENWL in house data will support these assumptions.

Inventory data will used in conjunction with country specific CO_2 emission factors compiled by Tyndall Manchester. As part of the scoping in project's next steps countries of origin for assets manufacture and raw materials will be determined. Initial results of relevant CO_2 emission factors for China (2015 baseline year) are presented in Table 1:

Material	Notes (process)	kgCO2/kg	Source
Nickel	Flash furnace	11.4	[11]
Copper	Smelting	3.3	[11]
Lead	Blast furnace	2.1	[11]
Zinc	Electrolytic	4.6	[11]
Aluminium	Bayer, Hall-heroult	22.4	[11]
Titanium	Becher and knoll	35.7	[11]
Steel	Blast furnace	2.3	[11]

Stainless Steel	Elect Furnace	6.8	[11]
Solar Grade Silicon	Modified Siemens process/Chinese grid	118.55	Derived from [12]
Silicon Carbide	Chinese grid emissions	8.9	Derived from [12]
Glass	Chinese grid emissions	0.82	Derived from [12]
Ammonia		1.4	[13]
Ethylene		1.65	[13]
Graphite	Standard mining value used	0.29	[14]
Lithium		7.1	[15]
Cobalt		8.3	[15]
Iron		1.5	[15]
Poly Propylene		2.14	[16]
Nitric Acid		2.31	[13]
Energy		**kgCO2/kWh**	
Electricity (Chinese Grid)		0.76	[17]
Diesel		0.279	[18]
Natural Gas		0.184	[18]
Coal		0.333	[18]

Table 1: 2015 Baseline Year CO2 Emissions Intensity China Specific

Emission factors relevant to other countries including Germany, Poland and the USA may be required depending upon the country of origin for SS and BAU network assets.

The transport of materials to manufacturing sites and completed components to point of installation are quantified as a tonne kilometer (tkm) value. Transport distances are calculated using commercial cargo distance estimation tool SeaRates (https://www.searates.com/). Standardised CO_2 emission factors for transportation (Table 2) are applied based on reported values in other LCA studies.

Transport	**kgCO2/tkm**	**Source**
Large Container Ship	0.003	[19]
Fleet average lorry	0.08	[20]
Rail	0.02	[20]

Table 2: CO2 Emission Factors for Modes of Goods Transport

3.2.1 Electricity Grid Emissions:

Consequential analysis of the carbon impact SS relative to traditional reinforcement requires quantification of the CO_2 value of electricity lost at distribution network level and electricity inputs saved by SS method demand reduction. The comparable levels of operational network loses and demand are determined by network modelling of SS and BAU under different scenarios. These outputs will then be combined with a projection of annual average electricity grid CO_2 emissions. The projection of average grid emissions are based on National Grid Gone Green Scenarios [21] which are aligned to UK carbon budgets set out by the Committee on Climate Change (Figure 6).

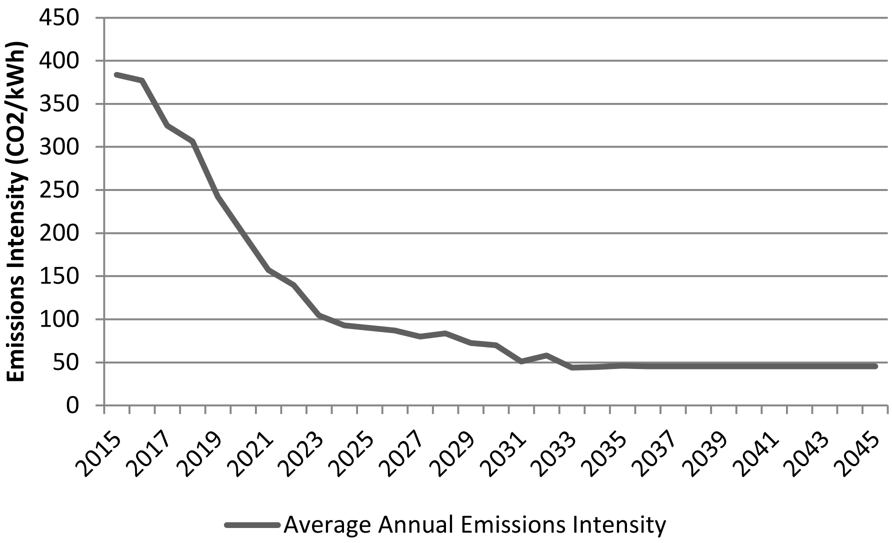

Figure 6: Projections for Grid Electricity CO2/kWh Value

3.2.2 Impact Assessment

The impact assessment stage in this LCA approach will allocate the appropriate net CO_2 impact of each network scenario. As there are not multiple environmental indicators to comparatively weight, the primary objective for this stage will be appropriate allocation of fixed asset (emissions associated physical network assets manufacture, installation and O&M etc) and operational network emissions.

Temporal allocation is an important step in consequential LCA approaches to carbon accounting, particularly for long lived assets. It is often the case that asset lifetimes exceed the timeframe of the system model, or that the investment occurs midway through or to the end of the timeframe (Figure 7). To align carbon accounting with the period of modelling, while fairly accounting for different asset lives and investment dates, temporal allocation is used to determine how burdens and benefits of the change in the system. Two forms of temporal allocation discussed in the LCA literature; dynamic and static [22]. Dynamic temporal allocation counts only emissions within the timeframe of the analysis[7]. Static allocation averages the fixed (non-model dependent, in this case the network assets) emissions for their full assumed lifetime, then proportionally allocates these emissions relative to the period within the timeframe of analysis[7]. For example a hypothetical transformer with a 60year lifespan installed six years prior to the end of the network modelling period, would have 10% of its total lifetime fixed emissions allocated to reflect the period for which it provides a network service within the analysis timeframe. This method of temporal allocation prevents potentially endless recursive time horizon on network change as each asset lifetime overlaps with the next.

The static allocation method is most appropriate for SS because the comparison between BAU and SS solutions is for the provision of network services within a particular timeframe. It therefore fits with the tCO_2/network functional unit.

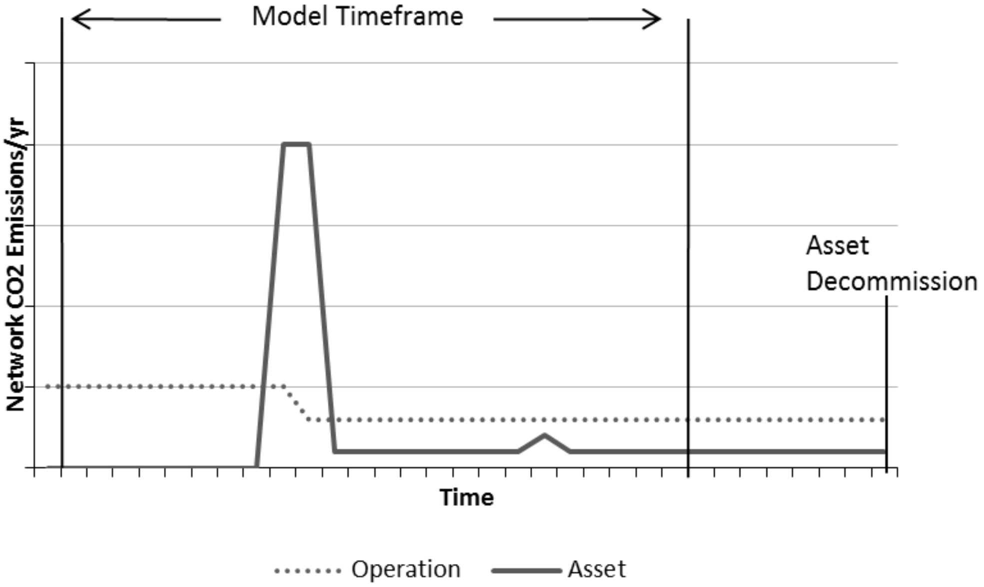

Figure 7: Graphical Display of Temporal CO2 Allocation: For static allocation, asset CO_2 emission are averaged over the typical lifespan for the unit then proportionately. Based on[7]

3.3 Interpretation

As highlighted in Section 2.1.1 consequential LCA requires a specific form of articulation to end users. The contingency of the output values on explicit and implicit LCT uptake scenarios and network modelling means that the interpretation stage needs careful development. For clear policy articulation the carbon accounting will be presented in two forms; dynamic consequential comparison of system level impacts and static comparison between network assets. The consequential outputs have value to end users in providing comprehensive evaluation of the different carbon impacts of SS method and BAU approaches to LCT uptake integration in distribution networks. The static attributional carbon accounting will also provide end users with absolute values for carbon reporting purposes on installed network assets. This stage of the work will also undertake to scale the results from the trial network scale to the ENWL DNO area and then nationally applicable findings as appropriate.

4 Conclusions and next steps

This report has defined the methodological approach that will be taken for carbon accounting in the SS project. The life cycle CO_2 emissions arising from network solutions are considered so as to comply with ISO14040 and ISO14044 standards of environmental impact assessment and the international policy regime around carbon accounting framed by the UNFCCC Paris Agreement. A consequential LCA will be employed to compare the SS network solutions with BAU network reinforcement for increased LCT uptake. The consequential approach accounts for changes in network loses and network energy demand precipitated by the network solutions, which are derived from SS project modelling work in WP1-3. Comparing the consequential carbon impact of SS with the BAU counterfactual will provide a comprehensive assessment of the carbon benefits of SS at a system level.

This document serves as method framework for SS carbon accounting and comprises the goal and scope stage of the LCA process. The next steps, as outlined in Section 3, are to complete the inventory gathering, impact assessment and interpretation stages. Inventory gathering will build upon existing Tyndall Manchester data sources and add new network assets as required. For the impact assessment stage, the carbon accounting work will integrate model outputs from other SS WPs to quantify the CO_2 impacts for the network asset deployment, network loses and network demand determined by the modelling. The subsequent interpretation phase will scale these results to DNO and national level as appropriate for SS project end users.

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