Capacity to Customers (C_2C) Carbon Impact Assessment *Whitepaper*

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Assessing the Carbon Impact of Distribution Network Projects

1 Introduction

Capacity to Customers (C_2C) is one of the projects supported by the OfGEM Low Carbon Networks Fund to explore new ways of delivering a secure and affordable low carbon electricity system. Extending the use of electricity in our energy system, to heating and transport for instance, is judged to be an effective and low cost way of reducing its climate change impact. The majority of research to date has focussed on reducing the carbon intensity of electricity supply with a diverse range of technologies from renewables, to nuclear power and fossil fuels with carbon capture and storage. However, it is just as important to understand the delivery and final consumption of larger quantities of electricity.

The C_2C project explores one way of providing greater capacity from existing distribution assets. The intention is to enable the connection of new low carbon technologies (LCTs) such as heat pumps, electric vehicles and distributed renewable generation at lower financial and environmental cost. The C_2C solution has multiple consequences in terms of assets, operation of the network and facilitation of new connections that are different to the existing practices of Electricity North West. The Tyndall Centre for Climate Change Research, at the University of Manchester, is participating in the project to assess its carbon impact, identifying and quantifying the major sources of emissions and areas where C_2C can provide savings and where it may increase emissions.

Electricity North West pilot studies suggest that C_2C will realise a net reduction in carbon emissions over the lifetime of the assets compared to traditional reinforcement methods. It is also proposed that by releasing capacity with less requirement for administration, groundworks and disruption, that the C_2C solution will facilitate emissions savings from other low carbon technologies such as heat pumps and renewable electricity generation by allowing more rapid connection. This whitepaper introduces the techniques that will be used and reviews the research to date that has considered the carbon impact of electricity networks.

2 Approaches to Carbon Accounting

Climate change is the result of the accumulation of greenhouse gases, most significantly carbon dioxide (CO_2) from the combustion of fossil fuels, and the imbalance this causes in heat transfer. The carbon dioxide concentration in the atmosphere is currently at a level that has not been seen for at least 800,000 years and is rising at exponential rates due to human activity (IPCC 2013).

It is clear that the UK needs to substantially reduce its greenhouse gas emissions to make a fair contribution to avoiding dangerous climate change. The Climate Change Act (2008) sets an end point target of an 80% reduction in the net UK carbon account from 1990 levels by 2050. However, the pathway to this point is much more significant as it is the cumulative quantity of greenhouse gas emissions that correlates best with the ultimate extent of climate change. It is for this reason that the UK has carbon budgets set by the Department of Energy and Climate Change (DECC) in five year periods. Whilst these carbon budgets are set at a national level, forming a framework for other policies and investments, it is important that there is a similar quantification of emissions at lower levels.

As with financial accounting there are a number of approaches to quantifying and documenting the greenhouse gas performance of a nation, a company, a product or a project. Organisation level carbon accounts are the most commonly encountered, either as part of a corporate responsibility activities or to fulfil legal requirements. They are typically prepared annually focussing on direct emissions from combustion of fossil fuels or releases of other greenhouse gases, with some going further to report indirect measures associated with an organisation's activities such as the emissions from the manufacture of bought-in goods and services.

2.1 Life Cycle Assessment

Life cycle assessments (LCA) are widely applied within both the research and commercial community to aid decision making. As a technique, LCA is focussed on products and services not organisations. It recognises that many environmental impacts are not directly located in time and space with the use or operation of a product, nor do they all occur within an organisation's boundaries. In an LCA resource flows and emissions of pollutants are calculated across the whole supply chain of a product or service, from the raw materials sourced for manufacture, through use phase, to ultimate disposal. These flows are then allocated to a defined *functional unit* of the product; for instance, a litre of orange juice or a kilometre travelled by a vehicle passenger. In the case of energy sources, this is typically either a unit of thermal energy (e.g. joules, J) or electrical energy (e.g. kilowatt hours, kWh) provided by the source upon use.

Consistent study boundaries and careful choice of functional unit allow a meaningful comparison between different means of delivering equivalent goods or services. Multiple types of environmental impact such as eutrophication, acidification potential, and quantity of finite fuel or mineral resources consumed are measured and normalised in a full LCA. A life cycle greenhouse gas assessment, is formulated on the same principles but considers climate change as the sole impact category. Carbon impact or carbon footprint are terms used loosely to describe the contribution of all greenhouse gas emissions (see box 1).

LCA studies typically consider a static system which may not be appropriate where substantial changes are anticipated in significant elements of the system within the lifespan of the assets involved. In considering the C_2C solution, the UK grid emissions intensity is expected to reduce substantially, with the effect of changing the climate change impact of losses of electricity on the distribution network. Furthermore, the lifecycle approach is focuses on complete systems rather than alterations to existing systems. An alternative approach is therefore required for the C_2C trial.

Box 1: Comparing Different Greenhouse Gas Emissions

There are multiple greenhouse gases (GHGs) and their effects must be summed and compared within carbon accounting frameworks. The Intergovernmental Panel on Climate Change identifies four long-lived well-mixed GHGs as responsible for the bulk of the anthropogenic radiative forcing that is driving climate change. These are carbon dioxide (CO_2), nitrous oxide (N_2O), halocarbons (CFCs and HCFCs) and methane (CH_4). Fossil fuel production and consumption causes the release of a number of these gases but most significantly carbon dioxide and methane, whilst electrical switch gear and transformers may also contain the high impact GHG sulphur hexafluoride (SF_6) as an insulator.

Different GHGs have different heat trapping properties, lifespans in the atmosphere, and interactions with other atmospheric components. A number of metrics are available for the comparison of the warming effect of different GHGs. Global Warming Potential (GWP) is the most commonly used metric for policy appraisal, LCA and project carbon accounting. It integrates the warming effect of an instantaneous release of gas relative to carbon dioxide as a reference, over a chosen time period, typically 100 years but also 20 years or 500 years. The use of different time periods and different sources for GWP estimates can be a significant factor affecting the quantitative and qualitative conclusions of comparative emissions accounting studies. However, 100 years is the most justifiable to energy policy appraisal, considering the timescale of the effect of changes in the climate system and impacts on human activity and infrastructure.

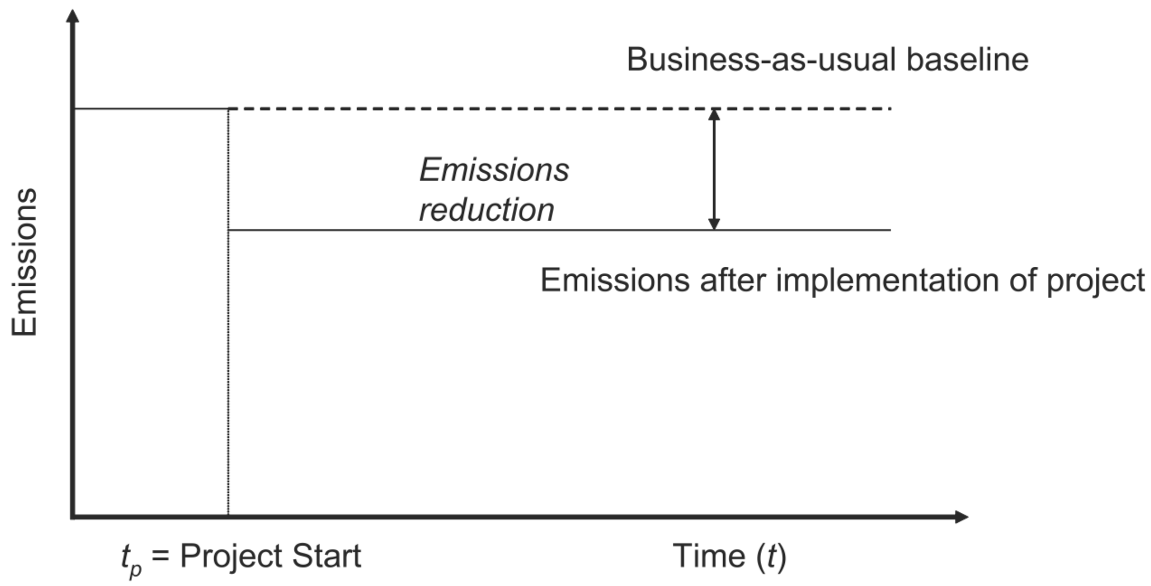
2.2 Project Based Carbon Accounting

Assessing the impact of the C_2C solution will require estimates of absolute quantities of emissions from operation of the network in alternative configurations. No direct precedent for such calculations has been identified in the academic literature. However, the GHG Protocol (2005), developed by business focussed NGOs the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI), provides a framework for project emissions accounting. This sets out principles in general for accounting for the impact of defined activities, rather than businesses and organisations as a whole, which will guide development of the methodology.

Numerous examples of project based calculations of this type are found in the projects submitted to the UN Clean Development Mechanism (CDM). The CDM is a carbon trading framework within the legally binding international climate change regime, the UNFCCC Kyoto Protocol.[1] Government and industry led projects that support renewable power generation and direct mitigation of industrial GHG sources in “non-Annex 1 countries” (developing countries without emissions caps) can earn credits on the basis of project accounting. These credits represent emissions reductions and can be sold to organisations and governments in “Annex 1 countries” (OECD, developed economies with emissions targets) to allow them to increase their permitted emissions. This exchange is informally known as carbon offsetting.

[1] http://cdm.unfccc.int/

Whilst Electricity North West is not seeking to trade the reductions associated with the C_2C trial or future deployment, the calculation framework established by the GHG Protocol and the CDM is a useful model to follow. This structure of emissions reduction calculations, quantifying the difference between the project and an alternative "business-as-usual" baseline, can be illustrated diagrammatically:



The carbon impact from the C_2C trial will be considered in a similar way. As for CDM projects, a quantification methodology is established specifying the relevant measurements and calculations to be performed. This also details the counterfactual alternative future emissions profile under "business as usual" circumstances, the baseline, and the monitoring and auditing procedures to be used during project delivery. That is the purpose of this document.

The framework can readily accommodate what have been termed asset and operational carbon impacts in the C_2C proposal documents. Facilitated reductions may be calculated in a similar way but over much shorter timescales and with additional caveats.

The GHG Protocol suggests that the lifecycle consequences of installation and decommissioning of project assets be considered as secondary effects. The definition of significance for secondary effects is not clear specified, but determined by the analyst's judgement of their estimated scale in relation to primary effects. Surveying the CDM database[2] identified five methodologies that are of some relevance to the C_2C project (box 2). None of these explicitly considers the carbon impact of the assets installed. Given that one of the key aims of the C_2C project is the reduction in assets required to provide an equivalent service, this source of carbon impact ought to be considered regardless of scale.

Methodology Code	Title	Current Version	Number of projects	Location of projects	Methodology Summary
AM0035	SF_6 emission reductions in electrical grids	2.0.0	2	China, Korea	Recycling and/or leak-reduction of SF_6 during repair and maintenance of electricity transmission and distribution

[2] http://cdm.unfccc.int/DOE/scopes.html

					systems.
AM0067	Installation of energy efficient transformers in a power distribution grid	2.0	0		Replacement of existing less-efficient transformers with more-efficient transformers in an existing distribution grid or the installation of new high-efficient transformers in new areas that are currently not connected to a distribution grid.
AM0097	Installation of high voltage direct current power transmission line	1.0.0	0		Installation of Greenfield High Voltage Direct Current (HVDC) power transmission line/s or replacement of existing AC power transmission line by a new HVDC power transmission line.
ACM0002	Grid-connected electricity generation from renewable sources	15.0	3303 (+44 PoAs)	Diverse nations	Displacement of electricity provided to the grid by more GHG intensive means by installation of a new renewable power plant or the retrofit, replacement or capacity addition of an existing renewable power plant.
AMS-II.A	Supply side energy efficiency improvements – transmission and distribution	10.0	2 (+3 PoAs)	India, China, Yemen	Energy losses are reduced through energy efficiency measures such as upgrading the voltage on a transmission/distribution system, replacing existing transformers with more efficient transformers.
AMS-III.C	Emission reductions by electric and hybrid vehicles	13.0	6 (+1 PoA)	India	Operation of less GHG emitting vehicles with electric/hybrid engines for transportation services.

3 LCA of Electricity Networks

Whilst there is limited research on low voltage and distribution networks, a review of the academic literature identified a number of relevant findings in previous studies of the life cycle impacts of electricity networks. These findings have contributed to the development of the C_2C carbon impact methodology.

1. When a national system is considered and impacts normalised per kWh over a 40 year period (Denmark), distribution networks are responsible for the larger part of losses and material consumption (Turconi et al 2014).
2. Losses constituted the main cause of carbon impacts of transmission and distribution (>85%) in multiple studies (Harrison et al 2010, Jones & McManus 2010). However, an LCA of power transmission in Norway found the balance of embodied emissions to emissions from losses to be approximately 50:50. This is due to the very low emissions intensity of the hydro dominated Norwegian power sector (2.2 gCO2e/kWh). A similar balance may be expected should the recommendations of the Committee on Climate Change for substantial grid decarbonisation by 2030 be realised.
3. Losses are a significant contributor to the *total* environmental impact of electricity provision, not just of the network life cycle. Transmission was found to contribute 2% of the total carbon impact of providing electricity in Denmark, with distribution responsible for 8% (CIGRE 2004). On average, approximately 5% to 6% of total units delivered are lost and this may account for up to 1.5% of annual GB greenhouse gas emissions (OfGEM 2008). OfGEM notes that losses on distribution networks vary substantially between DNO area, from 3.8% to 7.8% in the most recent year with reliable data (2008-09), due to different physical and geographic characteristics (OfGEM 2011).
4. Multiple studies find that specifying high capacity cables is environmentally and economically optimal over their lifespan with the ‘payback’ in terms of their additional embodied carbon less than 6.5 years which is short in comparison to their 70+ year

lifespan (Jones and McManus 2010). This applies equally to optimal design of whole networks; economic and environmental optimisation suggests a network comprising greater material investment, quite different to a strategy of minimum assets to handle peak load (Mancarella et al 2010a, 2010b).

5. Release of sulphur hexafluoride (SF_6) may cause a significant impact (~40% of embodied carbon), and may increase with the deployment of smart grid assets in future. Releases from transmission and distribution assets are poorly quantified in LCA studies, and during the past decade measured atmospheric concentrations do not tally with those reported in national emissions budgets.

4 Methodology for C_2C Carbon Impact Assessment

This methodology sets the general framework for the carbon impact assessment (CIA) of the application of the C_2C solution to trial circuits and wider elements of the Electricity North West network. The full CIA will develop multiple scenarios of future load growth, reinforcement and deployment of C_2C to estimate its likely impact on multiple networks. These scenarios form the basis of future work and are not described here, however the calculations are framed in a consistent and universal format such that they are transferable across scales.

4.1 Assessment Boundary

4.1.1 Direct Emissions – Primary Effects

Direct emissions are those greenhouse gas emissions arising from the intentional activities of the project. This is analogous to an organisation's Scope 1 emissions.[3] No direct sources of carbon dioxide from fossil fuel combustion have been identified within the C_2C project trial or future networks. Where SF_6 is used within network assets that are altered by the C_2C solution or required under the business as usual baseline it will be monitored and accounted for. No other direct sources of greenhouse gas are included in calculations.

4.1.2 Indirect Emissions – Secondary Effects

Indirect emissions are those that arise outside of the C_2C solution's intentional activity but are associated with it. They are analogous to an organisation's Scope 2 and 3 emissions attributed to the consumption of electricity and other goods and services.

4.1.2.1 Assets

C_2C requires different combinations of conductors, switchgear, transformers and civil works to traditional reinforcement. The emissions of all GHGs associated with the manufacture of assets deployed in the C_2C solution and the baseline will be accounted for using life cycle inventories. Wherever possible, the geographic origin and fate of the assets used by Electricity North West will be specified to enable more accurate characterisation of impacts. This category of impact is termed embodied emissions.

4.1.2.2 Losses

The emission of all GHGs arising from the generation of electricity that is subsequently lost in transmission through the network will be accounted for. Energetic losses will be calculated using power flow models, developed in the University of Manchester Cost Benefit Analysis work package, for both baseline and C_2C network configurations. Given the long life of assets and current changes to UK grid supply driven by energy and climate policy DECC's dynamic marginal emissions factor will be used.

4.1.2.3 Other secondary effects

When a circuit suffers a fault, the C_2C solution will disconnect demand differently to a traditional network configuration, enabling quicker restoration of the majority of customers who are not on a managed demand response contract. However, faults are rare and short lived occurrences and so any reduction in consumption is deemed to be negligible.

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[3] See the GHG Protocol http://www.ghgprotocol.org/

It is assumed that the C_2C solution, in its trial or wider deployment, does not have other economic impacts or wider effects that alter GHG emissions. CO_2 emissions arising from the EU power sector are capped by the operation of the EU Emissions Trading Scheme (ETS) up to 2020. Whilst changes in energy consumption are material, the effect on emissions may not be. The GB Grid is supplied almost entirely by installations regulated under EU ETS caps and so any savings of electricity do not affect the final volume of emissions from the sector as a whole; the same quantity of permits persists and may be surrendered elsewhere rather than being used by GB generators. Nonetheless, the period covered by the EU ETS is short relative to the lifespan of the assets involved and estimating implicit emissions savings is valuable for comparing different technical interventions.

4.1.3 Time Period

Emissions will be considered over the maximum 45 year lifespan of assets defined by the OfGEM RIIO ED1 Cost Benefit Analysis (CBA) framework. All episodic and continuous sources of emissions will be summed over this period. The starting point is taken as the time when a network constraint is reached. It is assumed that all assets complete their life cycle (manufacture, deployment, disposal/recycling) during this period. Many assets, for instance cables, have a longer anticipated useful life so, although consistent with other network assessments, this constraint may not fully reflect the benefit of new investment.

4.2 Baseline definition

Where load growth or new connections require increasing network capacity, i.e. a thermal overload or statutory voltage constraint is reached, business as usual has been to reinforce the distribution network, typically with additional cable sections to mitigate the constraint and provide additional capacity. The C_2C solution is deployed by Electricity North West on approximately 10% of its HV network only as part of the LCNF project trial, so its impact is discerned against a baseline of traditional reinforcement as per current design standards.

In the case of the C_2C trial, new customers on trial networks will be offered quotations for connection using both traditional reinforcement methods and the C_2C solution with quantified assets for each.

To understand future impacts, a network capacity and reinforcement model has been developed within the scenario based Cost Benefit Analysis (CBA) work package. This model determines the location of thermal and voltage constraints on the network under predetermined load growth scenarios. It implements OFGEM’s RIIO-ED1 framework and determines the least cost sequence of reinforcement required to alleviate the constraint under business as usual design standards and the C_2C solution. A catalogue of assets and the sum of losses through time are recorded by the model for input to the carbon impact calculation.

4.3 Carbon Impact Calculation

C_2C solution carbon impact, *CI*, is calculated as:

$$CI = \sum_{y=0}^{45} BE_y - C2CE_y$$

Where:

BE_y = Emissions from baseline network configuration in year y, tCO_2e

$C2CE_y$ = Emissions from C_2C network configuration in year y, tCO_2e

Baseline Emissions, BE_y, are calculated as:

$$BE_y = DE_{SF_6,y} \times GWP_{SF_6} + \sum (A_{i,y} \times EE_{A_i}) + L_{BL,y} \times EF_y$$

Where:

$DE_{SF6,y}$ = Direct emissions of SF_6 in year y from assets installed or altered to increase network capacity, tonnes

GWP_{SF6} = Global Warming Potential of SF_6 over 100 year time period

$A_{i,y}$ = Individual assets installed in year y to increase network capacity

EE_{Ai} = Embodied life cycle greenhouse gas emissions of asset A_i, tCO_2e/asset

$L_{BL,y}$ = Energy consumed as losses in year y in baseline network configuration, MWh

EF_y = Grid electricity emissions factor in year y, tCO2e/MWh

Emissions from C_2C solution, $C2CE_y$, are calculated as:

$$C2CE_y = DE_{SF_6,y} \times GWP_{SF_6} + \sum (A_{i,y} \times EE_{A_i}) + L_{C2C,y} \times EF_y$$

Where:

$DE_{SF6,y}$ = Direct emissions of SF_6 in year y from assets installed or altered to increase network capacity, tonnes

GWP_{SF6} = Global Warming Potential of SF_6 over 100 year time period

$A_{i,y}$ = Individual assets installed in year y to increase network capacity

EE_{Ai} = Embodied life cycle greenhouse gas emissions of asset A_i, tCO_2e/asset

$L_{C2C,y}$ = Energy consumed as losses in year y in C_2C network configuration, MWh

EF_y = Grid electricity emissions factor in year y, tCO2e/MWh

The calculation is framed so as to describe the emissions reductions due to C_2C deployment so a negative carbon impact output would suggest a net increase in emissions.

4.4 Data Sources

Parameter	Source(s) of data	Value (if constant)
DE_{SF6}	Manufacturers' data sheets and Electricity North West records.	
GWP_{SF6}	IPCC Working Group 1 (2013) Appendix 8.A	23,500

A_i	UoM and Electricity North West power flow models in guided by existing engineering codes CoP 203 Issue 5 (2014) CoP 204 Issue 3 (2010)	
EE_{Ai}	EcoInvent Database v2.2 Electricity North West Carbon Footprint Report (2008)	
L_y	Output of UoM CBA work package network power flow model in baseline and C_2C configurations	
EF_y	DECC Appraisal Guidance, Toolkit Tables, Sep 2013. Domestic consumption long-run marginal emissions factor.	

4.5 Facilitated Emissions Reductions

Rapid delivery of capacity via the C_2C solution suggests that there may be additional indirect emissions reductions over and above those accounted for in section 4.3. For this to be the case it needs to be shown that the delivery of low carbon technologies (LCT) such as renewable generation, electric vehicles (EVs) and heat pumps (HPs) is delayed by constraints on the network. This is not the case at present but may be so in particular future circumstances.

These LCTs are expected to have comparatively lower emissions than traditional “baseline” means of providing electricity, personal transport and home heating. It was recognised in the pilot study that these putative reductions should be accounted for distinctly due to their short time horizon, substantial uncertainty, and risk of double counting.[4]

In effect, separate methodologies are required for each low carbon technology. A simplified approach is therefore taken for facilitation of electric vehicles and renewable generation. Emissions are only considered from the energy consumption in providing the respective service in each case.

4.5.1 Capacity release through time

The starting point is to calculate network constraints and capacity released by C_2C under load growth scenarios specified by Electricity North West using the Cost Benefit Analysis work package network model. Estimates are summed over a five year period, 2018 to 2022, consistent with the UK’s third carbon budget and over 30 years for comparison. C_2C is conservatively assumed to provide capacity four months earlier than traditional reinforcement methods with emissions reductions summed over that period.

4.5.2 Electric vehicles connections

Baseline emissions are taken to be the purchase and use of new internal combustion engine cars meeting the EU fleet average emissions standard of 95 grams of CO_2 per km by 2021

[4] “Double counting” refers to circumstances where two or more parties claim an emissions reduction from a single project or activity. In this case, both the installer and ENW may have a claim to the reduction due to swift connection.

(April 2013). The C_2C case is assumed to be an electric vehicle of equivalent efficiency to the current Nissan Leaf (0.21 kWh/km). It is assumed that to encourage uptake of electric vehicles 32 amp (7.4 kW) fast chargers are incentivised and that peak load is achieved when 50% of vehicles charge simultaneously.

The emissions factor for the electric vehicle is calculated at 2020 as a static mid-point, taking a grid marginal emission of 0.285 kgCO2e/kWh (DECC 2013). A correction for power factor (80%) and 3% losses between HV and LV networks is also accounted for in the electric vehicle emissions factor.

The DfT Road Transport Forecasts predict annual car mileage per person returning to its 2002 peak by 2020, this implies a mean annual vehicle mileage of 14,720 km (9,200 miles) per annum (National Travel Survey, 2013, Table NTS0901).

Facilitated Emissions Reductions from electric vehicles, FER_{EV}, are calculated as:

$$FER_{EV} = \sum \frac{CR_i}{P_{EV} \times SC} \times (EF_{IC} - EF_{EV}) \times \frac{d}{3}$$

Where:

CR_i = Capacity Released on network *i* by C_2C solution when network constraint encountered

P_{EV} = Charging load of each electric vehicle

SC = Proportion of vehicles simultaneously charging

EF_{ICV} = Emissions factor for new internal combustion vehicle displaced

EF_{EV} = Emissions factor for new electric vehicle facilitated

d = Mean annual vehicle mileage

4.5.3 Renewable generation connections

Additional HV capacity may enable the connection of additional onshore wind turbines, assuming that sites are available in network constrained areas in the relevant period, displacing existing fossil generators. Baseline emissions are taken to be continued emissions at the grid long-run margin. Generating capacity is connected at the same rate as network capacity assuming all turbines attached to a ring will generate simultaneously. Load factor is taken as the five year average 2008-2012 of 26% (DUKES 2013). The emissions factor for displaced electricity is 2020 as a static mid-point, taking a grid marginal emission of 0.285 kgCO2e/kWh (DECC 2013).

Facilitated Emissions Reductions from renewable generation, FER_{RG}, are calculated as:

$$FER_{RG} = \sum CR_i \times LF_{RG} \times t \times EF_y$$

Where:

CR_i = Capacity Released on network *i* by C_2C solution when network constraint encountered

LF_{RG} = Load factor of UK onshore wind turbines

t = Hours of operation

EF_y = Grid electricity emissions factor

4.6 Summary

A carbon impact assessment framework applicable to the deployment of the C_2C solution at trial scale and in future scenarios at a range of scales has been designed. Boundaries have been clarified, baselines established and data sources identified.

Emissions reductions from direct and indirect sources are combined together to provide a net carbon impact for the C_2C solution. A means of calculating short term facilitated emissions reductions, a novel impact category without precedent in the GHG accounting to the author's knowledge, is also documented separately with a simplified methodology.

5 Further Information

For the full report on the carbon impact assessment work please see www.enwl.co.uk/c2c/keydocs