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Embodied carbon dioxide of network assets in a decarbonised electricity grid

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HIGHLIGHTS

- Hybrid functional units for electricity networks are formulated.
- Embodied carbon of network assets is compared to operational grid carbon annually.
- Regional proxies are applied to the GB network as a case study.
- Historic and predicted carbon intensity and demand data are used.
- By 2035 some DNO regions will have lower operational emissions than embodied.

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ABSTRACT

Calculating carbon dioxide (CO_2) emissions associated with electricity is a key component in the field of Life Cycle Assessment (LCA), but is often cited as challenging due to the complex nature of electricity systems despite its importance to the outcome. While calculating the operational CO_2 emissions associated with electricity generation is an active research field, the embodied CO_2 emissions, typically referred to as embodied carbon, of network assets has far less representation in the literature. This paper focuses on the CO_2 emissions aspect of LCA to calculate the embodied CO_2 of network assets in relation to the operational grid CO_2 over time. Several functional units are defined: CO_2 per operational year, CO_2 per asset cost, CO_2 per functional unit of electricity (kW h) and the relationship between embodied emissions and operational emissions in an electricity system over time. Hybrid functional units are then applied in order to better attribute the embodied carbon to the network functions. The hybrid functional units involve network asset lifetime and the issue of temporal horizons. Several suitable horizons are suggested and the comparison of results highlight the importance of the timeframe on results. The relationship between temporal horizons and environmental discounting is discussed and recommendations are made on the appropriate level of discounting depending on the temporal horizon and the purpose of the LCA. The paper uses data from the Great Britain electricity system where planned investment in network assets is £12bn at distribution level (Dx) and £16.4bn at transmission level (Tx) over the next eight years. By using GB network data for embodied carbon, demand and asset data, as well as data from the decarbonisation of electricity generation, indicative results are provided into the way in which embodied carbon impacts could change over time, showing that by 2035, the embodied carbon of the transmission network could contribute almost 25% of total emissions associated with electricity. On a regional basis, DNO level network assets could reach anywhere between 40% and 130%. This network data is also used to show that new network investment could account for up to 6.5% of DNO level network embodied carbon when front loaded during the RIIO-ED1 period.

1. Introduction

The electricity sector is instrumental in the move to a low carbon economy. Calculating the carbon dioxide (CO_2) emissions associated with electricity generation and transmission is an essential

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Nomenclature

D_y	demand in a given in the DNO region (kW h)
DG	distributed generation
DNO	distribution network operator
DSM	demand side management
Dx	distribution network
EC_{Demand}	embodied CO_2 – capacity metric (kg/MW)
EC_{DNO}	DNO embodied emissions (kg)
EC_{PF}	embodied CO_2 during planning framework (kg)
EC_{SO}	transmission level network assets embodied CO_2 (kg)
ECI_{TH}	embodied carbon intensity for a given temporal horizon (kg/kW h)
EF_y	grid emissions factor for a given year (kg/kW h)
L_{OHLDx}	length of distribution level overhead line (km)
L_{UGCDx}	length of distribution level underground cable (km)
LCA	life cycle assessment
OHL_{CO_2}	embodied carbon intensity for overhead lines (kg/km)
PD_{Dx}	DNO peak demand (MW)
REO_{DNO}	ratio of embodied to operational CO_2 (%)
REO_{SO}	transmission level ratio of embodied to operational carbon (%)
SG	standby generator
SO	system operator
T_{DNO}	average estimated lifetime of distribution level network assets (yrs)
T_{PF}	planning framework time period (yrs)
TH_{LCA}	temporal horizon of the LCA (yrs)
Tx	transmission network
UGC	underground cables
UGC_{CO_2}	embodied carbon intensity for underground cables (kg/km)

component of designing policy to meet global emissions reduction targets. The calculation of the CO_2 emissions associated with the operation of the generation-side of electricity networks (operational carbon) is an active research area. Life Cycle Assessments (LCA) of the operational and embodied emissions of different generation technologies are well established e.g. [1,2] and used by policy makers to compare options for the future low carbon electricity supply.

Electricity consumption is noted as a difficult component in many product LCAs e.g. [3,4] despite its importance to the outcome. Due to the complex nature of electricity systems, whose operations are time dependent - both on a daily and annual scale, it is difficult to associate the direct impact of electricity consumption at a particular site. In this area of LCA methodology, it is important that the whole electricity network is considered, not just the operational aspect of electricity generation, but also the embodied emissions associated with the electricity network assets.

This impact of the embodied CO_2 emissions (embodied carbon) is absent from much of the literature, which focuses on the operational CO_2 of electricity generation technologies. The embodied CO_2 impacts associated with the electricity network are due to the materials and the construction and ongoing maintenance activities associated with network assets such as pylons, transformers and cables. The embodied CO_2 of network assets are discussed in a wider set of smart grid literature as a consequence of network investment deferral due to the increase of DG and DSM. While several studies suggest that embodied CO_2 savings due to reduced or deferred network investment is likely e.g. [5–7], none attempt to quantify this saving. This paper builds on work from an initial LCA of the GB transmission network [8] and previous studies by the authors [9,10] which introduced the concept of proxies to calculate embodied CO_2 of network assets. Now, these proxies are applied and the embodied CO_2 of network assets is placed in the context of its proportion of total grid CO_2 over time, considering changing demand and carbon intensity.

As the electricity supply is decarbonised, the operational grid emissions are reduced thus increasing the importance of embodied CO_2 of the electricity network. This growing importance highlights the need for methods to evaluate the embodied CO_2 of electricity networks. Accounting for this complex measurement depends on the assumptions that are made about what the electricity system may look like in the future. Predictions about electricity systems can extend to 50 years but some network assets may have expected lifetimes of 80 years [11], making it difficult to account for the embodied CO_2 associated with the asset across its whole lifetime. In addition to this disparity in time considerations, the electricity network is a constantly changing and evolving system - both from and operational and asset perspective. The transition to a low carbon electricity supply will not just see changes in generation assets but also large changes in the electricity network. In the GB network, this network change could require 16.4bn GBP of investment in the transmission network alone [12]. This level of investment will see major changes in the assets - with old assets being retired and new assets, with embodied CO_2 impacts, being built.

In order to account for these complexities and to discuss how electricity network assets should be most effectively accounted for in LCA, this paper focuses on the CO_2 emissions aspect of LCA calculations. While LCAs often include a range of other greenhouse gas emissions, the paper uses CO_2 due to a lack of data for the electricity network for other gases, particularly the network assets. The paper calculates the changing ratio of operational generation grid CO_2 to embodied network grid CO_2 over time. The paper considers generation, transmission and distribution and how the composition of each of these aspects may change over time. Using the GB network investment and demand data at both transmission and distribution level as a case study, the paper highlights the importance of this relationship between embodied and operational CO_2 emissions and how this relationship may change during the transition to a low carbon electricity supply. By using real data from the GB network for asset lifetimes and predicted demand data in place of static assumptions, results from a previous study are improved upon [8]. This paper shows the growing importance of considering embodied CO_2 of network assets in policy decisions. The distinct lack of focus on the embodied CO_2 impact of electricity networks must change in order for full understanding of the environmental impacts of electricity network changes in the coming years.

2. Life cycle assessment for electricity networks

The importance of fully understanding and assessing the impacts of future electricity systems is clear. The increase in the use of LCA and the importance placed on embodied CO_2 at policy level shows the importance in understanding total impact of a wide range of products and services. As global electricity systems are decarbonised, it will be increasingly important to take account of the embodied CO_2 of electricity network assets when assessing