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Carbon footprinting of railway embankments and cuttings: A circular framework

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Abstract

There is now a consensus that global temperatures are rising and that the world is in a climate emergency. Science has proven unequivocally that there is a relationship between anthropogenic carbon emissions and global warming. Reducing anthropogenic carbon emissions to net zero by 2050 is now one of the highest priorities for many governments around the world. Network Rail (NR), as the GB mainline railway infrastructure manager, have a need to align themselves with the legal requirement to meet net zero by 2050. At present the quantities of carbon in railway geotechnical assets, in particular embankments and cuttings, are not well understood or recorded as separate entities. The research described in this paper aims to fill this gap through the accurate measurement of carbon emissions associated with railway embankments and cuttings in a business as usual (BAU) scenario. This data can then be interrogated to identify potential areas of savings. Carbon sequestration measures such as afforestation and enhanced weathering may also be deployed as part of this effort to balance the carbon in a project to net zero. This paper outlines a proposed framework to measure the lifetime carbon associated with earthworks assets and identify areas of carbon intensity ('hot spots'). It then discusses potential solutions to reduce carbon and thus assist NR in meeting its science-based targets via a move from a linear to a resource cycle analysis, taking into account circularity principles.

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Keywords: Carbon account; Railway; Geotechnical solutions; Circularity

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1. Introduction

Global temperatures are rising. The latest IPCC report states that science has now proved unequivocally that there is a relationship between anthropogenic carbon emissions and global warming, with a global surface temperature rise of approximately 1.07 °C being recorded in the period 2010–2019, relative to 1850–1900 (the IPCC approximate pre-industrial comparator and the earliest period which contains sufficient globally complete observations for estimating the global surface temperature) [1]. To counter this, legislation at global, UK and rail industry specific

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levels has been enacted as highlighted in the IPCC special report concerning temperature rise of 1.5 °C [2]. A rise of 1.5 °C represents the level at which significant intervention is required to reduce the risks and impacts of climate change [3]. Holding the global average temperature to well below 1.5 °C was at the heart of the Paris Agreement, and the UK Net Zero Strategy (NZS) [4], which is regarded as one the most extensive national NZS published to date. The UK NZS collates decarbonisation strategies for individual sectors including transport and infrastructure.

In the UK the scale of GHG emissions is known. In 2019 it was 454.8 $MtCO_2e$, with transport accounting for 27% (122.2 $MtCO_2e$) and rail 0.4% (1.7 $MtCO_2e$) [5]. Network Rail (NR) aims to achieve a stepped reduction in their carbon emissions via their own Environmental Sustainability Strategy [6] and the science based targets they have set, for both themselves and their suppliers [7]. The aim is for rapid implementation of decarbonisation up to 2030, normalisation of decarbonisation by 2040, and a final push to net zero by 2050 [8]. These ambitious targets have been set to align with NR's financial Control Periods (CP) as they progress towards their 2050 target, shown in Fig. 1 [9].

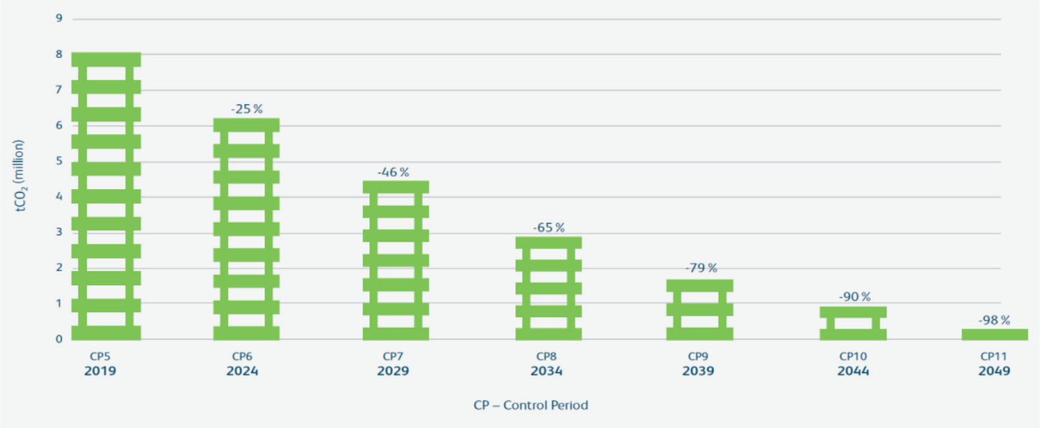


Fig. 1. NR Global Carbon Emissions Pathway to Net Zero, from NR Our ambition for a low-emission railway 2020–2050, 2019 [9].

A number of methods to assess and help reduce carbon emissions are available including life-cycle analysis (LCA) and the use of PAS2080 [10], a global standard for carbon management in infrastructure which includes guidance on the various life-cycle stages of a project, to reduce carbon emissions in infrastructure via a suite of free to use online and subscription tools, of which the Rail Safety and Standards Board (RSSB) Rail Carbon Tool (RCT) is one. The RSSB RCT draws principally on the databases of the Bath Inventory of Carbon Emissions (ICE), a database of embodied energy and carbon in building materials, and the Department for Business, Energy & Industrial Strategy (BEIS) [11] conversion factors for company reporting, which include carbon emission factors for vehicle fuels. These methodologies and tools need to become embedded as 'business as usual' (BAU), that is, the day-to-day 'carbon' accounting of a business, to enable the rail industry to meet its science-based targets on the journey to net zero. Quantification of emissions using tools such as the RSSB RCT also needs to include not only the embodied carbon, but also the lifetime carbon. Methodologies exist to assist with this journey to net zero, as well as tools for the assessment of carbon. In this research, the methodology set out in PAS2080 is utilised along with the RSSB RCT to measure ex-post construction carbon emissions in case studies of railway embankments and cuttings.

2. Life cycle analysis

To assist in meeting its ambitious targets, NR is in the process of implementing PAS2080 aligned templates in the RSSB RCT. Projects on low carbon steel are well underway [8], along with research into carbon reduction in earthworks and other assets [12]. The scope of this study is limited to specific rail infrastructure geotechnical intervention types and lifespans, which fall under the earthworks section of NR's Costs & Volumes handbook, illustrated in Fig. 2 [13]. As indicated in Fig. 2, the scope of the earthworks considered for this study comprises embankments and cuttings, and is bounded by temporal limits of 2, 20 and 120 years for maintenance, refurbishment,

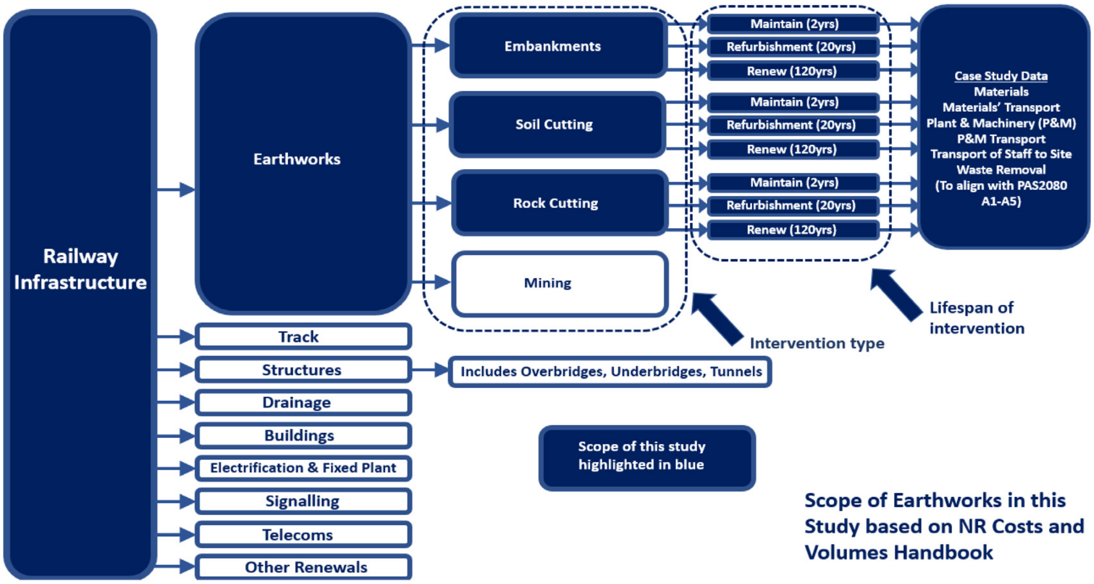


Fig. 2. Scope of Earthworks in this Study, figure adapted from tables in NR Costs and Volumes Handbook, 2021 [13].

and renewal respectively; these being the projected lifetimes of these interventions. Mining is excluded from this study, and structures such as bridges and tunnels are also excluded as they lie outside of the NR earthworks domain. It is proposed to use the PAS2080 methodology [10], as illustrated in Fig. 3, and the corresponding RSSB RCT PAS2080 aligned templates, to carry out the inventory analysis for each case study. Use of the PAS2080 template allows the carbon footprint to be found in BAU scenarios; the proposed extensions summarised in Section 3 can then be used to move towards circularity and whole life-cycle analysis.

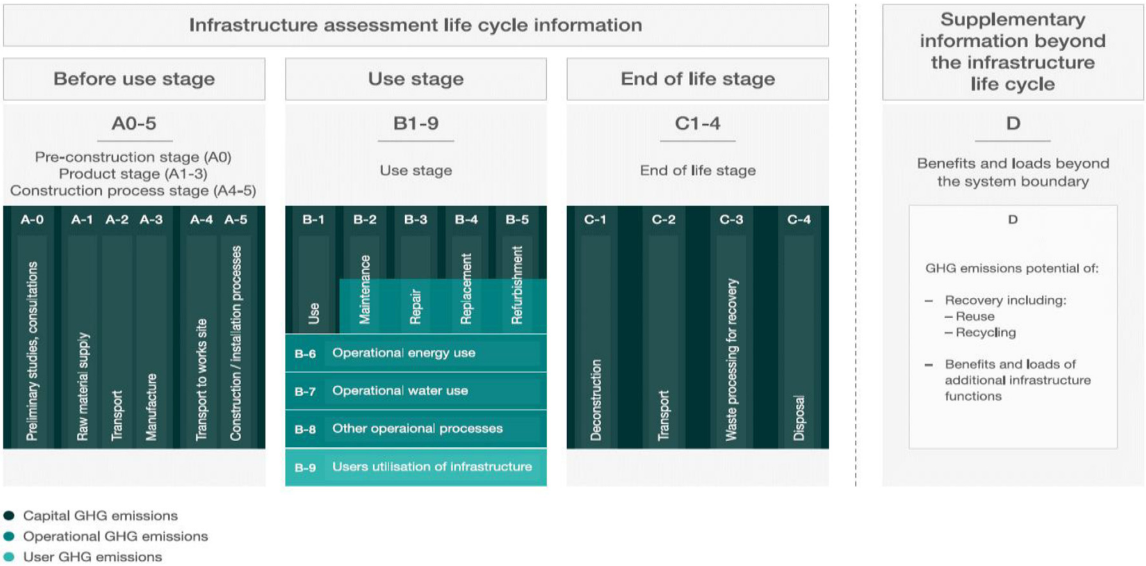


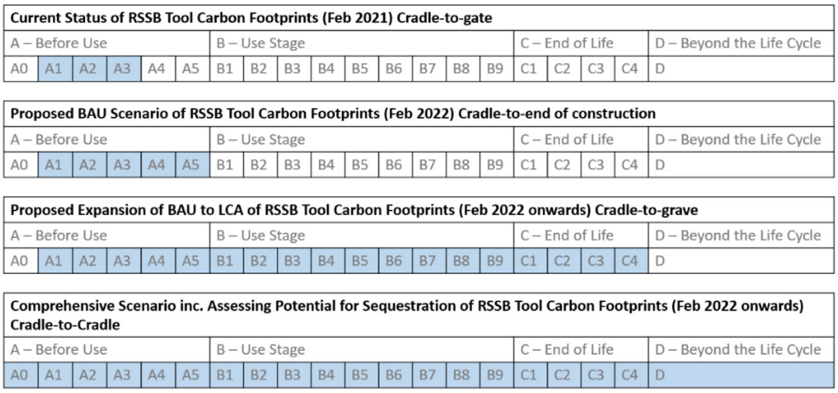
Fig. 3. PAS2080 Life Cycle Stages, from PAS 2080:2016 Carbon Management in Infrastructure, 2016 [10].

The case studies from this research will provide data on carbon footprints for railway embankments and cuttings not available in the literature and current databases. They will facilitate inter-regional comparison and the creation of a NR-GB average for typical earthwork interventions. It is expected that three examples will be procured for each intervention type and time span, giving a total of 27 case studies for each NR region (Eastern, Northwest and Central, South East, Wales and Western, and Scotland). Once data is received for each intervention, comparisons will be made in terms of where zones of carbon intensity are located for these particular geotechnical interventions, and the effect of time, in the form of the three intervention timespans, will be taken into account. For example, one comparison that could be made is, whether an intervention with a 20-year life-span, which at first glance looks to have a lower carbon footprint than a 120-year intervention, actually had a lower footprint when the lifetime analysis of 100 years is applied to both and annualised for comparison? This is a key question to be explored by this research, as carbon saved now is worth materially more than carbon used in the future, as once spent it is locked into the infrastructure for its lifespan, whatever this may be. This material worth is different to the fiscal cost of carbon, which is a measure to assign a social cost for the impact of carbon and is excluded from this study. It is proposed to use CO_2e as the measure of climate-impacting emissions, as this measure includes the Kyoto basket of gases [1] in which CO_2 constitutes the majority of anthropogenic GHG emissions and as such is the largest contributor towards positive radiative forcing of the climate, which tends to warm the climate system, as observed between 1750 and 2005 [14]. By using this measure all Kyoto gases will be accounted for in a temporal way. CO_2e has a global warming potential factor of 100 (GWP100), introduced by the IPCC and reiterated in the Sixth Carbon Budget [15], meaning that via its use GHG gases' differing radiative effects and lifetimes can be taken into account over this 100 years timespan, which aligns with the 100-year lifespan being investigated. Other climate change indicators, such as temperature change and sea level rises, were excluded from this study due to several reasons, including that they are reactions to the anthropogenic actions of the global population, and as the net zero by 2050 goal has a narrow focus on CO_2e only. It is also worth noting that the RSSB RCT being used for creating carbon footprints is a tool for collating CO_2e emission factors.

3. Methodology: Proposed framework

Primary data will initially be collected for the PAS2080 life cycle Stages A1-A5 via the carbon data capture form issued to NR. This form was created as an innovative original contribution to capture the carbon data for each case study in a format congruent with PAS2080 life cycle stages and in line with the RSSB RCT PAS2080 template. This form was an essential tool in the data collection portion of this research, as no such form was available from NR for data collection of this type. The form covers basic project details and classifies information into intervention type and lifetime, materials data, plant and machinery data, staff transport data, and waste removal data. For all sections full inventory data is required including material, weight and/or dimensions, travel distance to site, hours running and engine type (for plant and machinery), type of transport including fuel type, if known, for staff transport. Once accurate BAU data are available for Stages A1-A5, estimates for Stages B1-B9 and C1-4 can be made based on the A1-5 calculations. For life cycle stage D, the input data will be based on a literature review. Once all life cycle stages have been entered into the form, a life cycle carbon footprint for each asset type and an intervention life span will be produced. This corresponds to the proposed extension to cradle-to-grave, from the current status of cradle-to-gate, illustrated in Fig. 4.

This research will encourage a move from current linear thinking of cradle-to-grave (including before use, use, and end of life stages) to a more circular method encompassing cradle-to-cradle. The proposed circular framework will also introduce the time intervention aspects for different geotechnical solutions as an integral part of the new BAU moving forward, as circularity is an important principle that can potentially aid NR in reducing its carbon footprint via reuse and recycling or products where possible. As it is proposed to use CO_2e as the measure, all lifetime data will be aligned to 100 years for consistency with the GWP100 timescale, to enable comparison of gases with differing life spans in the atmosphere, as in the framework diagram shown in Fig. 5 and to allow for comparison between interventions with differing lifespans. Fig. 5 illustrates the circularity of PAS2080 life cycle CO_2e footprints. It has been created to draw together what is currently a very linear and discrete footprint for each intervention type and timespan into a methodology for comparing these different time spans, taking into account the GWP100 boundaries of CO_2e. Circularity and alignment with a 100-year boundary will allow for a functional unit for comparison to be produced to allow rail infrastructure managers to make decision on intervention types. These decisions could then be based not only on the total carbon account for a 20-year or 120-year intervention, but also on an annual basis over the asset's lifetime. Lifetime footprints may show that a longer time scale intervention has a lower annual carbon footprint over its whole lifecycle; however, accounting for this on an annual basis will



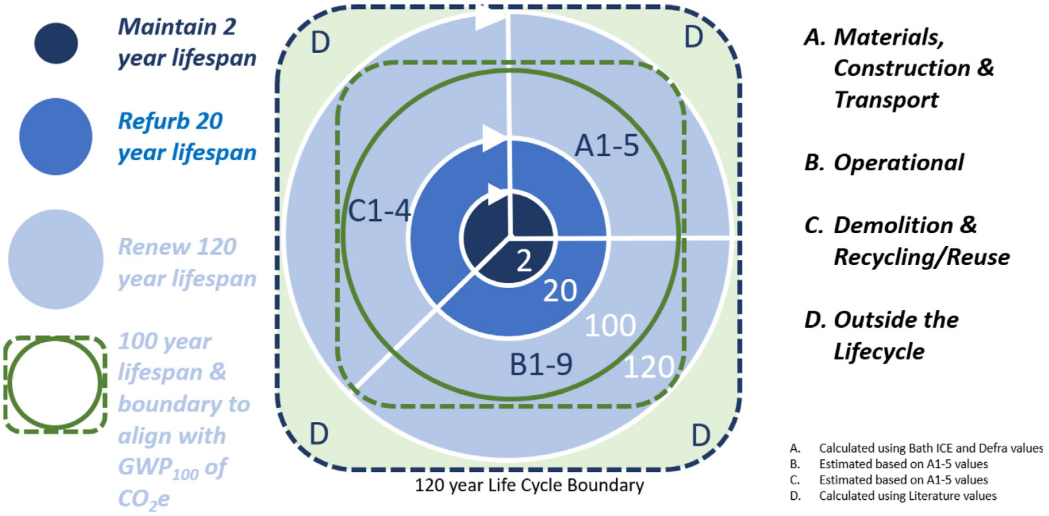
Current Status of RSSB Tool Carbon Footprints (Feb 2021) Cradle-to-gate																			
A – Before Use						B – Use Stage									C – End of Life				D – Beyond the Life Cycle
A0	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	B8	B9	C1	C2	C3	C4	D

Proposed BAU Scenario of RSSB Tool Carbon Footprints (Feb 2022) Cradle-to-end of construction																			
A – Before Use						B – Use Stage									C – End of Life				D – Beyond the Life Cycle
A0	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	B8	B9	C1	C2	C3	C4	D

Proposed Expansion of BAU to LCA of RSSB Tool Carbon Footprints (Feb 2022 onwards) Cradle-to-grave																			
A – Before Use						B – Use Stage									C – End of Life				D – Beyond the Life Cycle
A0	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	B8	B9	C1	C2	C3	C4	D

Comprehensive Scenario inc. Assessing Potential for Sequestration of RSSB Tool Carbon Footprints (Feb 2022 onwards) Cradle-to-Cradle																			
A – Before Use						B – Use Stage									C – End of Life				D – Beyond the Life Cycle
A0	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	B8	B9	C1	C2	C3	C4	D

Fig. 4. Linearity of Current and Proposed Footprints.



A. Calculated using Bath ICE and Defra values
B. Estimated based on A1-5 values
C. Estimated based on A1-5 values
D. Calculated using Literature values

Fig. 5. Circularity of PAS2080 Life Cycle CO$_2$e Footprints.

enable the importance of avoiding immediate and short-term carbon emissions to be taken into account, thereby potentially providing a case for expending less carbon each year via longer term, and in terms of installation, larger, carbon footprint interventions.

4. Results

Analysis of the case study investigated so far, on a soil cutting renewal with 120-year lifetime, has indicated that early carbon savings can be made by movement to electric vehicles (EVs) for staff transport and materials transportation [16]. However, it is too early in the data analysis process to begin drawing parallels between case study types and across temporal boundaries. Once all case studies have been entered into the RSSB RCT, an in-depth analysis can begin, the results of which will be discussed in a later paper. Areas of high carbon intensity ('hot spots') can be identified, and, on a life-cycle basis, different intervention types and temporal scales can be compared to provide a catalogue of lower carbon materials and processes to reduce the embodied carbon of a particular intervention. Offsetting may then be introduced to reduce the carbon footprint on any particular project to net zero.

5. Conclusion

Investigating whole life cycle CO_2e emissions and analysing differing life cycle boundaries will encourage rail infrastructure managers to move from linear to circular thinking. It is also envisaged that the results of this research will provide NR with an insight into not only the carbon embodied in embankments and cuttings, but also over which temporal scales the least carbon can be expended; that is whether it would be more carbon efficient to have one 120-year intervention than six 20-year interventions. These temporal data could then be used for forward carbon planning in the next Control Period, assisting NR in meeting their CO_2e reduction targets as set out in Fig. 1. It is also hoped that carbon savings can be made in products and processes used in the construction of embankments and cuttings, and that by applying whole life principles and circularity, attention will be drawn to the reuse of materials and recycling via implementation of the principles shown in the circular economy 'butterfly' diagram produced by the Ellen MacArthur Foundation, 2019 [17]. Making increased use of the inner arms of the right hand side of this diagram which include loops for maintenance, reuse, refurbishment and recycling, will encourage the prolonged use of assets via maintenance and reuse and redistribution of materials at end of life, to move rail infrastructure managers from linear 'take-make-waste' organisations, into 'use and reuse' organisations [18], and [19], to help them meet their net zero by 2050 targets.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Tracey Najafpour Navaei reports financial support was provided by Network Rail Ltd.

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