**Carbon Accounting in Mainline Railway Geotechnical Solutions:  
Reducing Embodied Carbon in Conjunction with Offsetting to Reach Net Zero**

Tracey NAVAEI1,2, Simon BLAINEY1, William POWRIE1, John PRESTON1

1University of Southampton, Southampton, United Kingdom

2Network Rail Sponsored Student, Southampton, United Kingdom

Corresponding Author: Tracey Navaei (T.A.Najafpour-Navaei@soton.ac.uk)

**Abstract**

The government has enacted into law the requirement to meet net zero carbon emissions by 2050 [1]. Network Rail (NR) has risen to the challenge and embedded this into its own Environmental Sustainability Strategy [2]. NR has also set markers along the way on the journey to net zero via ambitious Science Based Targets (SBTs) for both itself and its supply chain [3]. Having these SBTs embedded in the supply chain is vital as NR’s scope 3 emissions account for over 97% of its Green House Gas (GHG) emissions [4]. This paper addresses potential solutions to the climate change and carbon reduction problem through a UK rail focused lens. It also outlines some of the challenges in reducing carbon in specific railway geotechnical solutions, namely earthworks. The focus of the research is on accurate measurement of current carbon accounts in Business As Usual (BAU) scenarios for railway embankments and soil and rock cuttings. The current situation will be accurately recorded via analysis of a variety of case studies to identify carbon hot spots within these specific earthworks, which are hypothesised to be in the cements and steel used. A suite of alternative lower carbon products and/or processes will be discussed and analysed, which, when coupled with a taxonomy of negative carbon technology solutions, such as sequestration via afforestation and enhanced weathering, could enable NR to move closer towards its goal of achieving net zero carbon.

Keywords: Carbon Account; Railway; Geotechnical Solutions

**1. Introduction**

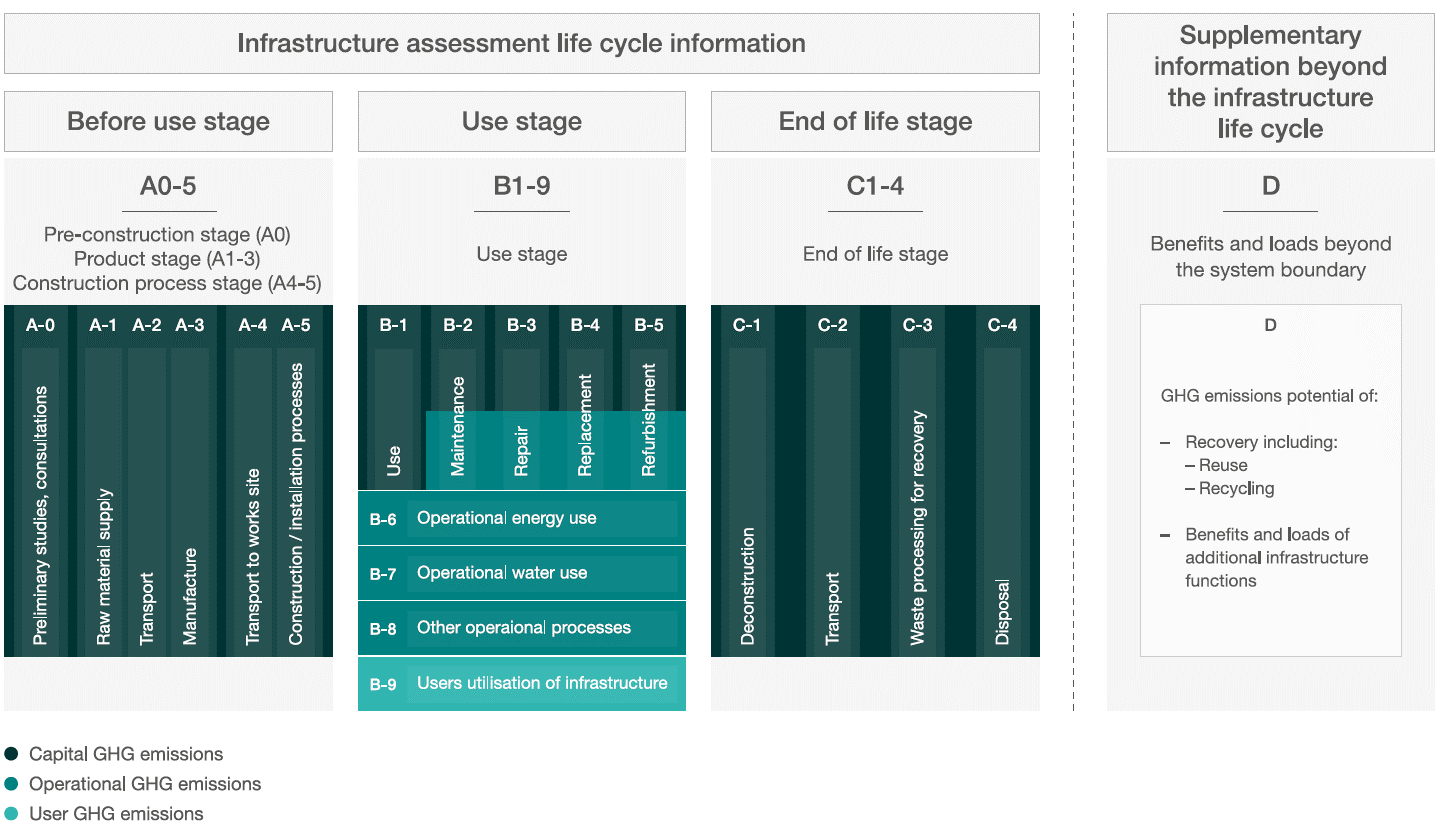
Increasing evidence is being presented that global temperatures are rising and that the world is in the grips of a climate emergency [5]. Global surface temperatures have risen by around 1.07°C in the period 2010-2019, relative to 1850 and 1900 (pre industrial comparator), and it is now unequivocal that this is attributable to human-induced warming [5]. Reducing anthropogenic carbon emissions and reaching net zero by 2050 is paramount to reducing the risk of the potential impacts of global warming as highlighted in the IPCC special report concerning temperature rise of 1.5°C [6]. The legislative landscape of global warming is vast, encompassing both global and UK legislation, including specific rail legislation. For the purposes of this research, the most pertinent policies and acts are noted here as the Paris Agreement signed by over 197 parties to date and the UK Net Zero Strategy (NZS) [7]. The aim of the Paris Agreement is to “strengthen the global response to the threat of climate change” [8] by holding global surface temperatures to well below 2°C and to pursue efforts to limit this increase to 1.5°C above pre-industrial levels, as this is widely recognised as the action required to significantly reduce future risks and impacts of climate change [8]. The NZS published in November 2021 is one the most extensive national strategies for net zero published to date, collating decarbonisation strategies for individual sectors including the Transport Decarbonisation Plan [9], which builds on the National Infrastructure Strategy [10], into one all-encompassing policy. This policy, and those that preceded it, has fed into rail specific policies such as the Rail Environment Policy Statement [11], which follows on from the Williams-Shapps’ review [12], and will feed into the recently published (November 2021) Integrated Rail Plan [13].

The scale of the problem is known; the UK territorial GHG emissions in 2019 stood at 454.8 MtCO2e, with transport accounting for 27% at 122.2 MtCO2e, and rail accounting for 0.4% at 1.7 MtCO2e [14]. Some of the solutions are available now, and via life-cycle analysis and use of PAS2080 carbon can be measured, identified, and then reduced in infrastructure via a plethora of tools, including the RSSB Rail Carbon Tool (RCT), National Highways Carbon Calculator, and EcoInvent. What is less well established is which reduction measures should be implemented in specific context on the rail network, and which offsetting methods should be utilised in conjunction with these to reach net zero. What is required now is the impetus and the framework to implement these actions as BAU procedures for all of the rail industry to set the industry on the path to net zero. Use of SBTs is crucial to chart the progress and adjust the course as necessary in the intervening years as NR work through the essential stages of rapid decarbonisation to bring us to 2030, and then normalising decarbonisation by 2040, followed by the final push to net zero by 2050 [4].

**2. The Problem**

**2.1 Research Outline**

At present the quantities of CO2e in railway geotechnical solutions are not well documented, particularly in specific earthworks such as embankments and cuttings. This research is concerned with accurate carbon accounting of embankments and cuttings, both soil and rock, for specific intervention types, for given life spans of maintenance at 2 years, refurbishment at 20 years and renewal at 120 years, over the whole lifetime of the intervention via use of PAS2080 life cycle stages as illustrated below in Figure 1 [15].



**Figure 1:** PAS2080 Life Cycle Stages

The initial focus of this research is developing an accurate A1-A5 life cycle. As the research progresses the A0, B1-9, C1-4 and D stages will also be included with estimations to achieve a full BAU life cycle. Once this BAU scenario is known attention can then be drawn to the carbon hotspots, and solutions for emissions reduction can be proposed. Once this option is exhausted, emissions offsetting options can be considered to balance the remaining carbon in a project to reach net zero.

**2.2 Methodology**

This research is focused on the BAU situation for 2 large case studies, and a suite of micro case studies covering 100m or 5 chain length, embankments and cuttings over the 2, 20 and 120-year lifetimes as described earlier. The focus of this paper will be the emerging results from the micro-case studies and the resultant carbon savings that could be made by tackling the resultant carbon hotspots. One particular hotspot has been identified in each of the major project segments of A1-A3, A4 and A5 and these are explored in greater depth below.

The data for the case studies is being collected via means of a Carbon Accounting Data Collection Form, which closely follows the PAS2080 life-cycle stages. For the case study footprinted to date the following assumptions, were made: A1-3 materials use carbon emission factors from Bath ICE V2.0, V3.0, UK, Europe and US region or Plastics EPD; A4 transport items use Fuel Unknown or diesel carbon emission factors from Defra 2018 for UK region; A5 construction processes use a mixture of emission factors from Defra 2018 UK region and EMEP/EEA Europe region.

Over the whole footprint, the following were excluded: Construction-phase consumable products (excluding fuel & water), proportional embodied carbon for construction plant & equipment manufacture, fossil fuel use for fixed/static plant & equipment for site operations and welfare, grid electricity use by plant / equipment / services for site operations and welfare and mains water use for site operations and welfare.

Assumptions will be made consistently across all future case studies to allow for comparison and averaging within the data set (once at least three examples of each type and intervention are footprinted), and with the literature. Carbon accounting will follow the PAS2080 structure and cover modules A-D, as illustrated in Figure 1 above. Initially life cycle stages A1-5 will be assessed in the BAU scenario as this is where the primary data collection will fall. Life cycle stages B-D will be based on academic judgement and all assumptions again clearly identified. Prior to full life cycle analysis, the carbon hotspots within A1-5 have been investigated further to ascertain if any ‘quick-wins’ could be achieved by NR by material and or process changes using currently available materials and/or processes.

**2.3 Boundaries and Scope**

To capture the whole life cycle, accurate material, and transport data (A1-A5) will be obtained from NR via the data collection form. To complete Stage B multiples of relevant A1-A5 stages will be applied. For C1-C4 the quantities of materials are known from the relevant A1-5 stages and these will be applied here with liaison with the relevant project manager to find the routes for recovery/disposal of materials as relevant. For life cycle Stage D, to expand the life cycle and possibly obtain negative carbon emissions, sequestration and mineralization will be explored further and these weightings balanced against the carbon footprint once it has been reduced to its lowest practicable level.

**3. Results**

Data collected has been aligned with products and processes in the RSSB RCT within each life cycle stage and full details of materials and assumptions are available in the form of supplementary data tables. The first result of the micro-case studies concerns a 120-year renewal of a soil cutting, illustrated in Chart 1 below.

**Chart 1:** Bar chart showing KgCO2e Per Sub Life Cycle Stage for Soil Cutting Renewal 120 years

The results of this case study indicate that the majority of the emissions are located in life cycle stage A5, construction processes, at 12,483 KgCO2e followed by A1-3 materials at 5,425 KgCO2e and then A4 worker travel to site at 3,184 KgCO2e. These are therefore the starting points for further investigation into the carbon hotspots of this particular geotechnical solution which will be discussed in further detail in Section 4.

**4. Discussion**

When looking down into the next level of the A5 life cycle stage it is found that fossil fuel use for mobile plant and equipment is the dominant sub-stage within A5. The two main construction processes contributing to this carbon hotspot are the use of the Liebherr A924 Rail Litronic and the 130 cfm Compressor with CVSA. These two items alone result in 9,348 and 3,135 kgCO2e respectively. Digging down deeper into this life cycle stage it is clear that the petrol being used to power these items of machinery is responsible for the high carbon values. Alternatives to fossil fuel powered vehicles must be sought and implemented where practicable to lower these emissions. To this end research is being carried out in the rail sector by HS2 in the use of greener construction machinery including machinery which uses biofuels and electric powered vehicles [16]. This is an area that will be explored further as this research progresses as the potential for early adoption of this next generation construction machinery could bear great fruit.

The second carbon hotspot identified is found in the A4 life cycle stage of transportation. For this case study, worker travel to and from site in the A4 life-cycle stage accounted for nearly 60% of the total. For this particular transport stage, the majority of vehicles used are cars and vans which are assumed to be fossil fuel powered. As fuel type is not indicated on all vehicles, all vehicles have been assumed as “fuel unknown” within the RSSB RCT and the corresponding averaged weighting from the RSSB RCT tool used, being 0.25654 kgCO2e/km for vans and 0.22658 kgCO2e/km for cars. If all vehicles used were changed to EV a CO2e saving could be made, with the carbon factor for an EV car being 0.07469 KgCO2eVkm and an EV van 0.06924 KgCO2eVkm. Even if cars could only be changed to plug in hybrid EV versions a 6.5% carbon saving could be realised across the worker transport sub section of the project. Table 1 below illustrates the BAU scenario for worker travel to and from site using the fuel unknown factor which lies around the diesel and petrol current factors and demonstrates the fuel savings that could have been made on this project if CNG, LPG or EV battery vehicles were used instead.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Fuel Type Unknown** | **Diesel** | **Petrol** | **CNG** | **LPG** | **Plug in HybridEV** | **EV - Battery** |
| Van Average Size <3.5t (KgCO2e VKm) | 0.25654 | 0.2568 | 0.24917 | 0.24986 | 0.27457 | 0.25654 BAU | 0.06924 |
| Van (km) | 10,139 | 10,139 | 10,139 | 10,139 | 10,139 | 10,139 BAU | 10,139 |
| Van Total (KgCO2e) | 2,601.06 | 2,603.70 | 2,526.33 | 2,533.33 | 2,783.87 | 2,601.06  BAU | 702.02 |
| Car Average Size (KgCO2e VKm) | 0.22658 | 0.21949 | 0.23353 | 0.21489 | 0.22536 | 0.14663 | 0.07469 |
| Car (km) | 2,575 | 2,575 | 2,575 | 2,575 | 2,575 | 2,575 | 2,575 |
| Car Total (KgCO2e) | 583 | 565 | 601 | 553 | 580 | 378 | 192 |
| Total Transport to Site (KgCO2e) | 3,184.50 | 3,168.88 | 3,127.67 | 3,086.67 | 3,364.17 | 377.57 | 894.35 |
| Potential KgCO2e Saving from BAU | N/A | 15.62 | 56.83 | 97.83 | - 179.66 | 2,806.93 Van BAU | 2,290.15 |
| Percentage CO2e Saving from BAU | - | 0.49% | 1.78% | 3.07% | -5.64% | 6.50% | 71.92% |

**Table 1:** Comparison of Differing Fuels’ Embodied Carbon Factors

Table 1 demonstrates that savings of over 71.92% of the BAU scenario can be achieved by implementing EV cars and vans across all worker transport. This table also highlights the powerful impact that changing all vehicles to EV would have on projects of this type as these savings would be scaled up across the whole of the transportation life cycle and savings would be realised within products and materials transport, plant and equipment transport and waste transport. Implementation of this change to EV cars and vans would realise a saving of more than 70% in GHG emissions across all cars and vans used in life cycle stage A4, compared to BAU. Note: The EV figures used in this table are based on those available in the RSSB RCT, which are based on DEFRA 2018 values and the zero carbon electricity generation percentage behind these figures is not detailed in this database.

The carbon hotspots within A1-A3, as hypothesised earlier, are, in descending order; steel (including stainless steel), limestone, and cement, at 46%, 41% and 10% of the A1-A3 total, with steel and limestone accounting for 12% and 10% of the project total and therefore any carbon reduction here being of great value to the overall project footprint. These results give the initial areas to concentrate on with regards to carbon reduction measure implementation. Following on from the above a brief review of cements currently available in the market was made and from Mineral Products Association factsheet 18 [17] a lower CO2e cement of the same composition used here, CEMII/A-L, was found to have a carbon factor of 0.690 KgCO2e giving a carbon saving of 81.75 kg if used in place of the RSSB Tool Bath ICE Europe regional average. This succinctly highlights the issue of using average factors, and the need to use EPDs where available for the actual items used in the project when conducting these post installation analyses. However, for the purposes of forward project planning, which is the aim of this research, the Bath ICE figure would suffice if the actual figure of the cement used were not available.

Looking at the alignment of these carbon reductions in line with the route map for net zero for NR [4], shows that by 2030 a 65% reduction of carbon versus 2020 levels is required, this moves to 85% by 2040 with by 2050 the ultimate goal of net zero being reached. Implementation of the swich to EVs for all cars and vans for both worker and material transport could give a 11% reduction over the entire project, making a notable contribution towards the 65% reduction by 2030. Once these carbon hotspots are mitigated other life cycle stages can begin to be interrogated by order of relevance to the overall project carbon footprint and alternative materials and methods proposed to reduce the footprint. Once the above stage is exhausted carbon offsetting methods can then be investigated and implemented where feasible to achieve a net zero carbon balance as illustrated in Figure 2 below.

**Figure 2:** Net Zero Carbon Balanced Scales for Projects

**5. Conclusion**

When discussing carbon savings, the route map for NR to achieve these must be taken into consideration and the ‘low hanging fruit’ principle applied first before moving onto other items which are less easy to decarbonise, with the view being that as time progresses those items which are less easy to decarbonise will become inherently lower carbon as each manufacturer is striving to reduce their embodied carbon in their products and as the UK national grid decarbonises too [11]. For example, when looking at data from the MPA it is clear that their members are taking great strides in reducing their carbon footprints via use of novel technologies such as carbon capture and storage, which will, over time, reduce the embodied carbon values in cements as demonstrated in the example above of a lower carbon value CEMII cement.

It should also be noted that in tandem with this research NR is currently implementing a template in the RCT that aligns with PAS2080 to allow for ease of comparison between differing projects. Research is also ongoing by others into the Greenhouse Gas Reduction – Demonstrator (GGR-D) projects. These projects are assessing the viability of five innovative methods of large-scale GHG removal from the atmosphere; Peatland restoration, enhanced rock weathering, biochar, afforestation, and bioenergy crops, and it is anticipated that the literature emanating from these will provide further direction with regards to real life application of carbon offsetting methods. There is also a new free to use online carbon database, Built Environment Carbon Database (BECD), supported notably by the ICE, RICS, IStructE, and the BRE, which may provide some additional clarity and consistency to the assessment of carbon emissions.

**Acknowledgment**

This research was funded by the EPSRC and sponsored by Network Rail, and thanks are given to all members of Network Rail who contributed towards the data collection for this research project. Thanks are also provided to my supervisory team for their invaluable support and comments on the draft copies of this paper.

**References**

1. HM Government, *The Climate Change Act 2008 (2050 Target Amendment) Order 2019*. 2019.

2. Network Rail, *Network Rail Environmental Sustainability Strategy 2020-2050*. 2020. p. 50.

3. Science Based Targets initiative. *Companies Taking Action: Network Rail*. 2021 23.09.21].

4. Expedition, *Route Map to Low CO2e Steel*. 2020.

5. IPCC, *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, V. Masson-Delmotte, et al., Editors. 2021.

6. IPCC, *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strenthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, V. Masson-Delmotte, et al., Editors. 2018.

7. HM Government, *Net Zero Strategy: Build Back Greener*. 2021.

8. UNFCCC. *United Nations Framework Convention on Climate Change. Convention on climate change. http://www. unfccc. de/resource/conv/index. html UNFCCC*. in *Forest Science*. 1992. Citeseer.

9. Department for Transport, *Decarbonising Transport: A Better, Greener Britian*, D.f. Transport, Editor. 2021. p. 218.

10. HM Treasury, *National Infrastructure Strategy: Fairer, faster, greener*. 2020.

11. Department for Transport, *Rail Environment Policy Statement: On Track for a Cleaner, Greener Railway*, D.f. Transport, Editor. 2021. p. 37.

12. Williams, K., Shapps, G, *Great British Railways The Williams-Shapps Plan for Rail*, D.f. Transport, Editor. 2021.

13. Department for Transport, *Integrated Rail Plan for the North and Midlands*. 2021, HH Assoicates Ltd: London.

14. Department for Business Energy & Industrial Strategy, *Table 8 Supplementary tables: 2019 UK greenhouse gas emissions by Standard Industrial Classification (Excel)*, E.I.S. Department for Business, Editor. 2021.

15. British Standards Institution, *PAS 2080:2016 Carbon Management in Infrastructure*. 2016. p. 60.

16. HS2, *Cleaner Construction Webinar Slides*. 04.11.2021.

17. MPA, *Embodied CO2e of UK cement, additions and cementitious material: Fact Sheet 18*. 2019.