

RSTA Carbon Emissions for Road Surface and Other Maintenance Treatments for Asset Management Purposes



2nd Edition



PYE MANAGEMENT
SUSTAINABILITY CONSULTANTS

**“Decarbonisation of highway maintenance activities is
within reach!” Emma Pye, PYE Management**



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1. Contributors

This report could not have been completed without the following contributors:

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- Archway Products Ltd (1st and 2nd Edition participant)
- ASI Solutions Ltd (1st and 2nd Edition participant)
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2. Introduction

As the world continues to address the growing challenges of climate change, reducing carbon emissions has become a critical priority across all sectors, including infrastructure and transportation. The highway sector contributes to carbon emissions through energy intensive processes, materials, and vehicle traffic.

Most Local Authorities (LAs) in the UK have declared climate emergencies and will be developing climate strategies, supported by carbon reduction targets, to achieve a net zero target by specified dates. This supports the Government's Net Zero target of 2050.

The Department for Transport (DfT) have set out a requirement for local highway authorities (LHAs) to demonstrate 'sustainable asset management', which is linked to decarbonisation of highway maintenance, and adopting whole life, lower carbon, and longer term solutions.

Maintenance treatments and materials can be a significant source of carbon equivalent emissions, but these treatments and alternative materials documented in this report, also offer a solution.

PYE Management, on behalf of the RSTA (Road Surface Treatment Association), have engaged with its member organisations to capture their carbon usage for different highway maintenance treatments, to produce average figures and to show potential carbon emissions for real life project examples for an asset's whole life (60 years).

This 2nd Edition of the RSTA's carbon guidance builds on the 1st Edition's 'cradle to installation' approach. The 2nd Edition takes this a step further to look at where highway maintenance should fit in the carbon lifecycle which is in Section B. This information will enable and inform strategic decisions within LA's and road operators, to support considerations of whole life carbon scenarios associated with maintenance of their roads. This will also enable Association members to accurately document figures to support the marketing of their products.

The RSTA's objective is to create awareness of the options for maintenance, and to provide fair comparisons, which will assist local authorities and road operators decision making, assist them in setting a course for future innovation, ensuring highways contribute to a more sustainable, low-carbon future for generations to come.

3. Road Surface Treatments

Road surface treatments are methods or materials for extending the lifetime of road when they begin to deteriorate, delaying the need for major maintenance or rehabilitation, and known as preventative treatments. They also include permanent solutions to failing or end of life roads, as an alternative to conventional methods and materials.

3.1 Asphalt Surface Preservation Systems

Asphalt preservation includes both penetrative and non-penetrative preservation treatments. Both involve the spray application of a sealant treatment onto bituminous bound road surfaces that consequently restricts water ingress, inhibits binder oxidation and consequently binder ageing. By providing a protective seal, the treatment can significantly extend the resilience and performance life of an asphalt road surface. A penetrative preservation treatment further penetrates the surface course to a depth of approximately 30mm, filling any micro cracks and interconnecting voids.

The techniques can be used as part of an asset management strategy designed to maintain network condition by delaying the need for reactive maintenance.

3.2 Asphalt Surface Rejuvenation Systems

Rejuvenators restore the chemical components of asphalt lost in the aging process and are designed to penetrate, flux and co-mingle with the existing asphalt binder.

An asphalt rejuvenator penetrates the asphalt through the full depth of the surface course to chemically revitalise and protect the asphalt binder, and restore the chemical elements (maltenes) in the bitumen.

3.3 Surface Dressing

Surface Dressing is a long-established proven highway maintenance technique. In simple terms, it involves the even spray application of a bituminous emulsion binder through a purpose built spray tanker onto the existing road surface, followed immediately by the even application of aggregate chippings to 'dress' the binder.

3.4 Encapsulation Systems for Surface Dressing

Encapsulation is a bitumen emulsion sealing spray which is applied to a surface dressing, providing an additional surface coating and waterproofing layer. This treatment locks down the chippings and provides the aesthetics of a newly laid thin asphalt surface.



3.5 Microsurfacing

These materials are cold-applied, thin bituminous surface courses incorporating bitumen emulsion and fine graded aggregate with fillers. Microsurfacing incorporates a polymer modified bitumen emulsion and is often a two-coat application and can be laid mechanically or manually to a maximum dried film thickness of 20mm.

3.6 High Friction Surfacing

High Friction Surfacing (HFS) has a long history of proven use in saving lives by imparting the highest level of skid resistance onto a road surface. High Friction Surfacing is available as hot or cold applied systems. The cold applied technique involves the even application of a tough resin binder onto the road surface followed by the application of calcined bauxite aggregate. The hot applied systems involve the application of a hot, pre-mixed, thermoplastic material consisting of binder and calcined bauxite.

The concept was first investigated in the USA during the 1950's using epoxy resin binders and was first known as "Anti-skid Surfacing".

3.7 Retexturing Techniques

Retexturing is described in the Design Manual for Roads and Bridges (DMRB) as the mechanical reworking of an existing surface to improve its frictional characteristics of the aggregates and hence its skid resistance.

In addition to improving road safety, the re-use of existing road surfacing materials will considerably reduce the attendant energy consumption in quarrying, processing, laying new road surfacing materials and waste removal. By extending the life of existing surfaces and by making best use of what's available, the conservation of substantial quantities of irreplaceable high-quality aggregate is ensured.

3.8 Ironworks

Ironworks Reinstatement Systems are a long-lasting, polymer modified, mastic asphalt system designed to reinstate failing surfaces surrounding manholes, drainage gullies and other public utilities ironworks.

3.9 Patching

Patching is a key preventive maintenance strategy to address road deterioration. Patching techniques, including spray injection, thermal, screed, and conventional methods, are designed to repair and reinforce damaged road surfaces effectively. By sealing defects and preventing water ingress, these methods help extend the lifespan of roadways and reduce the likelihood of further damage. (RSTA, 2025).

3.10 Spray Injection Patching

Spray Injection Patching (SIP) is a unique process that provides a quick and effective solution for pothole repair. The system applies a blended bitumen emulsion and aggregate mix to potholes for a permanent repair solution.

3.11 Thermal Patching

Thermal patching requires heaters that are used to heat the defective area of road surface, making it 'workable', with the addition of a rejuvenation binder or asphalt as required, which is then raked, mixed and then compacted, to produce a seamless joint repair, with zero waste.

3.12 Polymer Modified Mastic Asphalt Patches (PMMA)

PMMA patching involves marking the defined area for repair with tape, then pouring a flowable hot mastic asphalt liquid, which is then spread across the required area manually using mastic floats, with an application of aggregate to provide adequate skidding resistance.

3.13 Geosynthetics and Steel Meshes

Geosynthetics are industry recognised for extending the life of pavements. When placed between bituminous bound layers, these products retard the initiation and propagation of reflective cracking which leads to premature pavement failure (RSTA, no date).

Key products include:

- Steel meshes.
- Polymer grids.
- Non-woven textiles.
- Glass grids.
- Composites.

3.14 In Situ Recycling

In-situ recycling is used to restore a failed road pavement by recycling and reusing the existing construction materials to construct a new pavement. There are three different types:

3.15 Shallow In Situ Cold Recycling (Retread)

Retread is an in-situ recycling process which reconstructs the carriageway. The process involves pulverising the existing material, and regrades, reshapes and reconstitutes a deformed or deteriorated asphalt surface, when mixed with an emulsion binder, to produce a recycled bound layer. This recycled layer is then sealed with a new surface, which is typically a surface dressing.

It is a process that recycles 75mm to 85mm of the existing construction. Extra thickness can be achieved by importing and incorporating additional material up to 125mm. (BSI, 2021).

3.16 Medium In Situ Cold Recycling (Regen)

The purpose of medium depth in-situ recycling is to repair roads suffering from more extensive failures, including potholes, cracking, poor surface profile, and requiring strengthening, through a process of similarly pulverising existing asphalt material, regrading and reshaping, with the addition of a bituminous or hydraulic material as a binder.

It is a process that treats a nominal thickness of 150mm of the existing construction, to form a bound recycled layer, onto which a new surface is laid. This could be a surface dressing, but alternatively could be a conventional asphalt surface course. (BSI, 2021)

3.17 Deep In Situ Cold Recycling

The purpose of deep in-situ recycling, in conjunction with a new asphalt surface, is to strengthen the existing pavement by in-situ recycling, using bitumen or hydraulic material as a binder or as an additive, where appropriate.

It is achieved by pulverising the pavement, which may be asphalt, hydraulic bound mixture or unbound material and binding the pulverised layer together with bitumen emulsion, foamed bitumen or hydraulic material.

The in-situ process shall be carried out using a recycler incorporating a rotating pulverising drum and a means of adding the binder and, if required by the mix design, water and hydraulic material to the pulverised material.

Materials shall be recycled to depths of between 150mm and 450mm and sealed with an appropriate surface. (BSI, 2021)

4. What is a Carbon Footprint?

A carbon footprint measures the total greenhouse gas (GHG) emissions caused directly or indirectly by an individual, organisation, product, or activity. It is expressed in terms of carbon dioxide equivalents (CO₂e), which account for the varying global warming potentials of different GHGs. The primary GHGs contributing to a carbon footprint include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and fluorinated gases such as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). Each of these gases has a different capacity to trap heat in the atmosphere, with methane and nitrous oxide being significantly more potent than carbon dioxide over shorter timeframes. (Springer, 2020).

4.1 What is Embodied Carbon?

Embodied carbon refers to the total GHG emissions associated with the lifecycle of a material, product, or structure, excluding its operational energy use. This encompasses emissions generated during raw material extraction, transportation, manufacturing, construction, maintenance, and eventual disposal or recycling. Embodied carbon is particularly significant in sectors like construction and manufacturing, where materials such as concrete, steel, and glass have high energy demands in their production processes. These emissions are measured in terms of carbon dioxide equivalents (CO₂e) and represent a crucial part of the overall carbon footprint of products or projects. (Hammond and Jones, 2008).

Addressing embodied carbon is essential for achieving sustainability goals, as it accounts for a large proportion of emissions in the built environment, especially in modern infrastructure. Strategies for reducing embodied carbon include using low-carbon materials, optimizing designs to minimize material usage, implementing recycling programs, and adopting local sourcing to reduce transportation impacts. Unlike operational carbon, which can be reduced over time through energy efficiency and renewable energy sources, embodied carbon is released upfront. Therefore, prioritizing low-carbon designs and materials early in projects is critical to minimizing overall emissions and supporting climate action efforts. (Hammond and Jones, 2008).

Figure 1 shows the life cycle stages and identifies which are embodied carbon and which are operational. These are discussed in more detail further in the report.

The fundamental principle of an embodied carbon calculation is typically to multiply the quantity of each material or product by a carbon factor (normally measured in kgCO₂e per kg of material) for each lifecycle module being considered:

$$\text{Embodied carbon} = \text{quantity} \times \text{carbon factor}$$

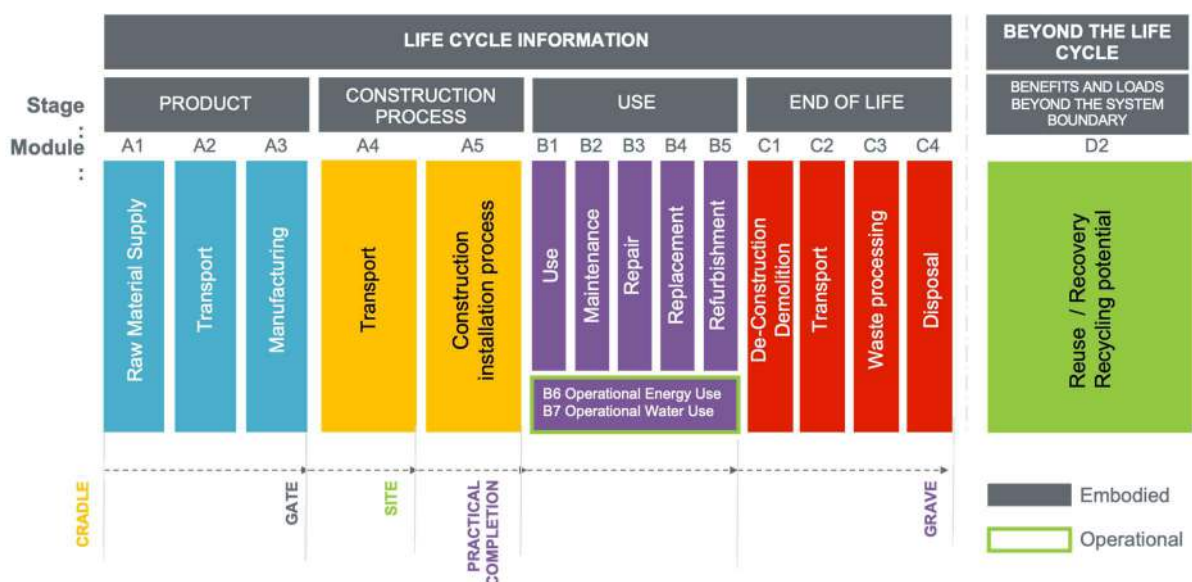


Figure 1: Lifecycle stages and modules



5. Standards

The following are the key standards within the infrastructure sector for calculating carbon life cycle assessments and associated carbon footprints.

5.1 BS EN 17472:2022 - Sustainability of construction works. Sustainability assessment of civil engineering works.

The BS EN 17472:2022 standard is a crucial document in the realm of sustainable construction, focusing on the comprehensive assessment of the environmental, economic, and social impacts of civil engineering projects. One of the pivotal aspects of this standard is its detailed evaluation of the carbon footprint of construction activities. By considering the entire lifecycle of a project from material extraction through to construction, use, and demolition, BS EN 17472:2022 helps identify opportunities to minimize carbon emissions and enhance the overall sustainability of construction endeavours. (BSI, 2022).

The standard provides clear system boundaries for assessments, ensuring that all relevant stages of a project's lifecycle such as material extraction, construction, operation, and end-of-life are consistently considered. By establishing these boundaries, the standard minimises ambiguities and ensures that sustainability evaluations are comprehensive. (BSI, 2022)

5.2 BS EN 15804 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products.

The BS EN 15804 is the Environmental Product Declaration (EPD) standard for the sustainability of construction works and services. The standard makes the Life Cycle Assessment (LCA) information in the construction industry transparent and comparable. The first version was published in 2012, known as EN 15804+A1 "Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products". A second version of the standard called EN 15804 +A2 was published in 2019, with the main goal to align the standard based EPDs with the Product Environmental Footprint (PEF) formats.

The new revision of EN15804 (EN15804+A2) meant that all construction products now must declare modules A1-A3, as well as C1-C4, and module within an EPD. These life stages were previously optional. The revised norm specifically states that only under very specific conditions it would still be possible to do a cradle-to-gate (A1-A3 only) EPD. (BSI, 2021b).

A significant linkage exists between BS EN 17472:2022 and BS EN 15804:2012+A2:2019. While the former provides a holistic framework for sustainability assessments, the latter offers the core rules for creating Environmental Product Declarations (EPDs) for construction products. These EPDs, as defined in BS EN 15804, provide transparent, verified, and comparable information about the environmental performance of products, which can be utilized within the broader sustainability assessments outlined in BS EN 17472:2022. This synergistic relationship ensures that the environmental impacts of individual products are accurately reflected in the overall assessment of a construction project's sustainability. (BSI, 2021b).

5.2.1 BS EN 15804 Sustainability of construction works for Highway Maintenance

BS EN 15804 does not state specifically about linear infrastructure and does not give definitions of where highway maintenance should sit within the standard.

If we aligned the highways maintenance definitions to BS EN 15804, the maintenance activities fit within the B categories as shown in table 1 below.

B1	Use	N/A
B2	Maintenance	Programmed maintenance i.e. surface treatments (preservation, surface dressing).
B3	Repair	Reactive maintenance i.e. pot hole filling
B4	Replacement	Programmed maintenance i.e. resurfacing
B5	Refurbishment	Programmed maintenance i.e. reconstruction

Table 1: Aligning highways maintenance to BS EN 15804

Therefore, using the alignment in table 1 and the boundaries definitions from BS EN 15804, to ensure a highway maintenance carbon footprint meets the requirements of the BS EN 17472 and BS EN 15804 standard the following life cycle stages have to be included in the carbon footprint, as illustrated in figure 2 below:

- Deconstruction – Emissions associated with the deconstruction of current materials i.e. C1 (End of life) of the materials currently in place i.e. any waste asphalt
- Transport to waste processing of previous waste i.e. C2
- Waste processing i.e. C3
- Disposal of waste (if applicable) i.e. C4
- A1-A3 (Product) of the materials required for installation
- A4 (Transport) for the transportation for the material and plant
- A5 (Construction) for the installation

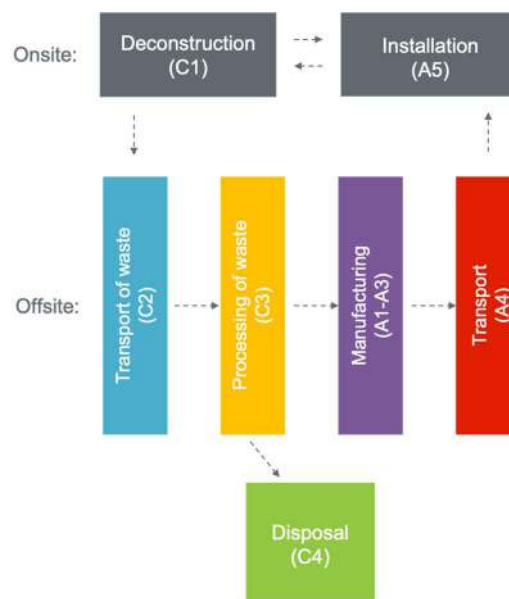


Figure 2: Highways maintenance carbon footprint

6. Scope of project

The scope of this project aimed to build upon the foundation established in the 1st Edition of the RSTA Carbon Emissions for Road Surface and other Maintenance Treatments for Asset Management Purposes issued in 2023. The 2nd Edition looks at advancing the methodology and data analysis to better align with current standards.

The key focus of the report has been transitioning the life cycle assessment (LCA) of highway maintenance treatments from section A (product stage) to section B (use stage). The analysis has also expanded to provide life cycle examples for 60-year periods.

The methodology of the project adheres to the established standards such as BS EN 15804+A2 and BS EN 17472:2022. This projects agreed methodology for calculating the carbon footprint of treatments are listed in section 6.1.

Building on the data from the 1st Edition, the project has expanded to include more participants, growing from 14 to 18 and including a number of new treatments. The report has compiled average carbon footprints for the sectors represented within the Road Surface Treatments Association (RSTA). These averages have been produced from the data provided by treatment companies.

The results are presented in kgCO₂e per square metre, ensuring the data is in a useable format to understand a project's potential carbon impact.

6.1 Methodology

The carbon footprints have been calculated in accordance with BS EN 15804 + A2 with the following assumptions:

- All figures are presented in kgCO₂e/m²
- Tonnage figures were not produced as some products could not be presented in this format.
- On delivery of material, vehicles were classed as 'fully laden'.
- Bituminous deliveries include return trips
- Aggregate deliveries were one-way
- If specific details were not available, then a distance of 110miles was used for delivery of materials to a landing site/satellite depot
- A distance of 20 miles out, and 20 miles back was used for daily site travel
- Return vehicles were either classed as 'average laden' if the whole delivery was not required or 'empty' if full delivery was accepted.
- An assumption of 6 ironworks per 1000m² was used, each ironwork being 0.5m², which equated to 3m² of ironwork per 1000m².
- Road classifications were:
 - A Roads: Major roads that connect cities, towns, and regions. They are primary routes for traffic and are often dual carriageways.

- B Roads: Secondary roads that link smaller towns and villages. They are less busy than A roads and are used for shorter journeys.
- C Roads: Local roads that connect smaller settlements and rural areas. They are managed by local authorities and are not as heavily trafficked.
- Unclassified Roads: Minor roads, often residential or rural, that are not part of the main road network. They are used for local access. (Department for Transport, 2012).
- No Well to Tank (WTT) emissions were included in the fuel figures
- For all pre-sweeps a figure of 0.2 tonne of waste per 1km of road.
- Sweepers were 7.5-17 Tonnes average laden
- Planning figures were from National Highways, they used:
 - 2021 UK Government factors
 - Planer > 17 Tonnes Rigid
 - Sweeper 7.5-17 Tonnes 50% loaded
 - 200 Tonne output per shift
- MPA EPD's were used for Asphalt calculations
- For the whole life carbon (WLC) project examples is period of 60 years was used. This mirrors the NH Cost calculator
- When electricity is used, T&D was included.
- Patching was calculated using a 400mm x 400mm size at a depth of 40mm
- Spray Injection patching was calculated using a 400mm x 400mm size at a depth of 20mm

Data was converted to kg CO₂e using either:

- UK Government GHG 2024 conversion factors from the Department for Business, Energy & Industrial Strategy and the Department for Environment Food & Rural Affairs.
- ICE v4 Database.
- MPA EPD's.
- Company specific EPD's.

Density factors were either obtained from the specific materials companies or from the Bath Inventory - Version 2.0 (2011). (National Highways, 2023). The Bath Inventory figures can be found in Appendix A.

6.2 Bitumen figure update

The RSTA Carbon emission 1st Edition report was produced in 2023. At the time the ICE (Inventory of Carbon and Energy) v3 database provided the bitumen data based on the Eurobitume 2012 Life cycle inventory, bitumen, 2nd Edition published by the European Bitumen Association. The bitumen figure used was 191 kg CO₂e/Tonne.

In March 2025, the 4th edition of Eurobitume's Life Cycle Assessment (LCA 4.0) was released providing data for bitumen most widely used in Europe.

The bitumen figure is now reported as 530KgCO₂e/Tonne. This new figure has been used in the all calculations within this report, except for the Asphalt figures from the MPA that when published used a draft figure of 510 kg CO₂e/Tonne.

The main difference between the 2012 and 2025 figures is related to a change in the LCA calculation methodology and background information, particularly the crude oil database used. (Eurobitume, 2025).

Differences in the results therefore are not related to changes in industrial processes or practices with regard to bitumen production. Physical emissions into the environment due to bitumen production are not higher since the publication of LCA 4.0, but they are accounted for differently. (Eurobitume, 2025).

This change provides an answer to the criticism raised in the external review of the previous LCI: the database for crude oil, IOGP, used in the LCI 3.0/3.1 underestimated methane emissions; few primary data were used as input. (Eurobitume, 2025).

6.3 Data Gathering

All contributors of this report were requested to send carbon relevant information for this assessment covering the relevant B section of the Carbon life cycle. This data was then reviewed and calculated into a carbon footprint in accordance with BS EN 15804 +A2. If data was not available then that section of the life cycle was not calculated.

6.4 Asphalt update

In 2024 the MPA (Minerals Product Association) published a number of Verified Sector-Level Environmental Product Declarations (EPDs), compliant to BS EN 15804:2012 + A2:2019. These were derived from collated and generic industry data, against which, each supplier can demonstrate and gain recognition for any reductions. (MPA, 2025).

The generic product types selected as being representative of the highest proportions of UK material supply, and the calculated GWP (Global Warming Potential) (A1-A3) are shown below:

Product Type GWP (A1-A3)	kg CO ₂ eq per tonne of asphalt
Asphalt Concrete (base & binder)	52.2
Hot Rolled Asphalt surface course	68.7
SMA type surface course (pen grade + fibre)	60.3
Thin surface course (AC-type with PMB)	73.0

Table 2: MPA Asphalt GWP A1-A3 figures

These figures were produced while the Eurobitume LCA for bitumen was being carried out. MPA stated that the EPD's, with the acknowledgement of Eurobitume, the MPA has used a GWP embodied carbon value of 510 kg CO₂eq / tonne of bitumen* in the calculations of these published EPD's. (MPA, 2025).

These figures have been used to support this project within the whole life carbon examples in Section 9.0 and 10.0 .



7. Glossary of Terms

- BSI – The British Standards Institution
- CO₂ – Carbon Dioxide
- EPD – Environmental Product Declaration
- GHG – Greenhouse Gas
- GWP – Global Warming Potential
- HFS – High Friction Surfacing
- HRA – Hot Rolled Asphalt
- ICE – Inventory of Carbon and Energy
- ISO – International Organisation for Standardisation
- kgCO₂e – Kilogram Carbon dioxide equivalent
- LCA – Life Cycle Assessment
- LCIA – life cycle impact assessment
- LHA – Local Highway Authority
- MPA – Minerals Products Association
- NH – National Highways
- PAS – Publicly Available Specification
- PCR - Product Category Rules
- PSV Polished Stone Value
- RSTA - The Road Surface Treatments Association
- SIP – Spray Injection Patching
- SMA - Stone Mastic Asphalt
- UK – United Kingdom
- WLC – Whole Life Carbon
- WTT – Well to Tank
- m² -square meters

8. Results – Overall

A total of 18 companies participated in this project. Please note that some participants contributed carbon figures for more than 1 type of treatment. For treatments that had more than 1 participant an average has been taken of their figures. A list of participants can be found in section 1.

Table 3 below shows an average carbon dioxide equivalent (kgCO₂e) per m² figure for all the treatments that have participated.

Treatment	Units	A1-A3	A4	A5	A1-A5 (Total)	B
Rejuvenation (under 40mph)	kgCO ₂ e/m ²	0.0268	0.0061	0.0014	0.0343	0.0645
Rejuvenation (over 40mph)	kgCO ₂ e/m ²	0.0268	0.0049	0.0001	0.0328	0.0328
Penetrative Asphalt Surface Preservation Systems	kgCO ₂ e/m ²	0.2458	0.0152	0.0657	0.3266	0.3278
Non-Penetrative Asphalt Surface Preservation Systems	kgCO ₂ e/m ²	0.2392	0.0356	0.0010	0.2758	0.2767
Surface Dressing – Single layer Carriageway	kgCO ₂ e/m ²	0.6059	0.1865	0.0128	0.8052	0.8135
Surface Dressing – Double Layer (Racked In) Carriageway	kgCO ₂ e/m ²	0.7974	0.1654	0.0175	0.9803	0.9836
Surface Dressing – Double 10mm	kgCO ₂ e/m ²	0.8941	0.2668	0.0220	1.1828	1.1959
Surface Dressing – Double 14mm	kgCO ₂ e/m ²	0.9400	0.2777	0.0364	1.2540	1.2556
Surface Dressing – Decorative	kgCO ₂ e/m ²	0.8395	0.5258	0.0212	1.3866	1.3915
Surface Dressing – Footway	kgCO ₂ e/m ²	0.7485	0.1124	0.0149	0.8759	0.8856
Surface Dressing – Encapsulation System	kgCO ₂ e/m ²	-	-	-	0.2457	0.2513
Microsurfacing	kgCO ₂ e/m ²	1.4394	0.2709	0.0539	1.7642	1.7892
Geosynthetics*	kgCO ₂ e/m ²	1.3703	0.0296	0.1084	1.5080	-
Crack and Joint repairs	kgCO ₂ e/m ²	4.5325	-	-	-	-
Spray Injection Patching	kgCO ₂ e/m ²	1.8594	0.2445	0.9791	3.0830	3.0830
Retexturing Techniques - Waterblasting	kgCO ₂ e/m ²	See A1-A5 Total			0.3118	0.3118
Retexturing Techniques - Shotblasting	kgCO ₂ e/m ²	See A1-A5 Total			0.3573	0.3853
Medium In Situ Cold Recycling - 150mm	kgCO ₂ e/m ²	3.9798	0.0257	0.7750	4.7805	4.7805



Deep In Situ Cold Recycling - 250mm	kgCO ₂ e/m ²	10.4018	0.0642	1.2775	11.7435	13.2778
Deep In Situ Cold Recycling -250mm (Calcined clay)	kgCO ₂ e/m ²	4.9500	0.0642	1.2775	6.2918	7.8261
Thermal patching	kgCO ₂ e/m ²	1.4200	0.6412	0.6317	2.6929	2.6929
Polymer Modified Mastic Asphalt Patching	kgCO ₂ e/m ²	0.4133	0.7562	1.3007	2.4702	2.4702
Conventional Asphalt Patching	kgCO ₂ e/m ²	6.0301	1.8449	0.1005	7.9755	9.7402
Ironworks – reinstatement systems	kgCO ₂ e/m ²	8.6452	-	-	-	-
Retread with 30mm SMA	kgCO ₂ e/m ²	6.7614	3.0717	4.1583	13.9913	13.9913
Retread with Surface dressing	kgCO ₂ e/m ²	2.3614	0.5167	0.2595	3.1375	3.1375
High Friction Surfacing (HFS)						

Table 3: Average kgCO₂e / m² for RSTA treatments

8.1 Overall results – patching

The following tables look at the carbon footprint for different patching approaches.

Treatment	Units	A1-A3	A4	A5	A1-A5 (Total)	B
Spray Injection Patching (20mm depth)	kgCO ₂ e/m ²	1.8594	0.2445	0.9791	3.0830	3.0830
20mm Traditional patch	kgCO ₂ e/m ²	2.8362	0.4950	0.3920	3.7232	4.0183
40mm traditional patch	kgCO ₂ e/m ²	5.6725	0.4951	0.3920	6.5596	7.2471

Table 4: Spray Injection Patching

Treatment	Units	A1-A3	A4	A5	A1-A5 (Total)	B
Thermal patching (40mm depth)	kgCO ₂ e/m ²	1.4200	0.6412	0.6317	2.6929	2.6929
PMMA Patching (40mm depth)	kgCO ₂ e/m ²	0.4133	0.7562	1.3007	2.4702	2.4702
40mm traditional patch	kgCO ₂ e/m ²	5.6725	0.4951	0.3920	6.5596	7.2471

Table 5: 40mm patching

9. Whole Life Carbon Project Examples – A&B

This section presents theoretical scenarios that are based potential carriageway maintenance strategies, that includes ‘replace on fail’, and preventative strategies with timely interventions of different treatments, to form a projection of an associated whole life, 60 year, carbon usage.

9.1 Resurface

Year	0	10	20	30	40	50		
Example	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment	Total number of years	Total (kgCO ₂ e/m ²)
Resurface	New road (100mm)	Surface course	Surface course	Binder and surface course renewal	Surface Course	Surface course	60	
kgCO ₂ e/m ²	17.4123	7.2471	7.2471	17.4123	7.2471	7.2471		63.8129

Table 6: Whole life carbon footprint of resurfacing on A&B Roads

9.2 Surface dressing

Year	0	10	20	30	40	50		
Example	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment	Total number of years	Total (kgCO ₂ e/m ²)
Surface dressing - double racked	New road (100mm)	Surface dressing	surface dressing	Surface course	Surface dressing	Surface dressing	60	
kgCO ₂ e/m ²	17.4123	0.9836	0.9836	7.2471	0.9836	0.9836		28.5938
Surface dressing - double racked and locked	New road (100mm)	Surface dressing and lock	Surface dressing and lock	Surface course	Surface dressing and lock	Surface dressing and lock	60	
kgCO ₂ e/m ²	17.4123	1.2349	1.2349	7.2471	1.2349	1.2349		29.5991

Table 7: Whole life carbon footprint of surface dressing on A&B roads.

9.3 Rejuvenation and preservation

Year	0	5	10	15	20	25	30		
Example	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment		Total number of years	Total (kgCO ₂ e/m ²)
Asphalt Surface Rejuvenation System	New road (100mm)	Rejuvenation	Rejuvenation	Rejuvenation	Rejuvenation	Rejuvenation	Repeat	60	
kgCO ₂ e/m ²	17.4123	0.0645	0.0645	0.0645	0.0645	0.0645			35.4696
Asphalt Surface Preservation System	New road (100mm)	Preservation	Preservation	Preservation	Preservation	Preservation	Repeat	60	
kgCO ₂ e/m ²	17.4123	0.3278	0.3278	0.3278	0.3278	0.3278			38.1026
Asphalt Surface Preservation/ Asphalt Surface Rejuvenation / SD	New road (100mm)	Rejuvenation	Preservation	Preservation	Preservation	Surface dressing (double racked)	Repeat	60	
kgCO ₂ e/m ²	17.4123	0.0645	0.3278	0.3278	0.3278	0.9836			38.8876

Table 8: Whole life carbon footprint of rejuvenation and preservation on A&B roads.

9.4 Microsurfacing

Year	0	10	20	30	40	50		
Example	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment	Total number of years	Total (kgCO ₂ e/m ²)
Resurface / Microsurfacing	New road (100mm)	Micro	Micro	Surface course (SMA)	Micro	Micro	60	
kgCO ₂ e/m ²	17.4123	1.7892	1.7892	7.2471	1.7892	1.7892		31.8162

Table 9: Whole life carbon footprint of Micro surfacing on A&B roads.

9.5 Geosynthetics

Year	0	5	10	15	20	25	35	45	55		
Example	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment	Total number of years	Total (kgCO ₂ e/m ²)
Traditional resurface + geosynthetic	New road (100mm)	Preservation	Preservation	Preservation	Retexture (water) + Preservation	Retexture (water) + Preservation	Surface dressing	Surface dressing	Surface dressing	60	
kgCO ₂ e/m ²	18.9206	0.3278	0.3278	0.3278	0.4677	0.4677	0.9834	0.9836	0.9836		23.7901
Traditional resurface + geosynthetic	New road (100mm)	Preservation	Preservation	Preservation	Retexture (shot) + Preservation	Retexture (shot) + Preservation	Surface dressing	Surface dressing	Surface dressing	60	
kgCO ₂ e/m ²	18.9206	0.3278	0.3278	0.3278	0.5779	0.5779	0.9836	0.9836	0.9836		24.0106
Traditional resurface + geosynthetic	New road (100mm)	Rejuvenation	Rejuvenation	Rejuvenation	Retexture (water) + Rejuvenation	Retexture (water) + Rejuvenation	Surface dressing	Surface dressing	Surface dressing	60	
kgCO ₂ e/m ²	18.9206	0.0645	0.0645	0.0645	0.3446	0.3446	0.9836	0.9836	0.9836		22.7541
Traditional resurface + geosynthetic	New road (100mm)	Rejuvenation	Rejuvenation	Rejuvenation	Retexture (shot) + Rejuvenation	Retexture (shot) + Rejuvenation	Surface dressing	Surface dressing	Surface dressing	60	
kgCO ₂ e/m ²	18.9206	0.0645	0.0645	0.0645	0.4181	0.4181	0.9836	0.9836	0.9836		22.9011
Year	0	15	30	45							
Traditional resurface + geosynthetic	New road (100mm)	Surface course	Surface course	Surface course	Repeat					60	
kgCO ₂ e/m ²	18.9206	7.2471	7.2471	7.2471							40.6619

Table 12: Whole life carbon footprint of geosynthetics on A&B roads.



10. Whole Life Carbon Examples – C&U

10.1 C&U - Resurface

Year	0	15	30	45		
Example	Treatment	Treatment	Treatment	Treatment	Total number of years	Total (kgCO ₂ e/m ²)
Resurface	New road (100mm)	Surface course	Surface course	Binder and surface course renewal	60	
kgCO ₂ e/m ²	17.4123	7.2471	7.2471	17.4123		49.3188

Table 13: Whole life carbon footprint of resurfacing on C&U roads.

10.2 C&U - Surface dressing

Year	0	15	30	45		
Example	Treatment	Treatment	Treatment	Treatment	Total number of years	Total (kgCO ₂ e/m ²)
Surface dressing:	New road (100mm)	Surface dressing	surface dressing	Surface course	60	
kgCO ₂ e/m ²	17.4123	0.9836	0.9836	7.2471		26.6266

Table 14: Whole life carbon footprint of surface dressing on C&U roads.

10.3 Microsurfacing – C&D

Year	0	15	30	45		
Example	Treatment	Treatment	Treatment	Treatment	Total number of years	Total (kgCO ₂ e/m ²)
Traditional resurface / Microsurfacing	New road (100mm)	Micro surface	Micro surface	Surface course	60	
kgCO ₂ e/m ²	17.4123	1.7892	1.7892	7.2471		28.2378

Table 15: Whole life carbon footprint of Micro resurfacing on C&U roads.

10.4 Preservation – C&D

Year	0	7	14	21	28	43	58		
Example	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment	Total number of years	Total (KgCO ₂ e/m ²)
Traditional resurface / asphalt surface preservation system	New road (100mm)	Preservation	Preservation	Preservation	Preservation	Surface dressing	Surface dressing	60+	
KgCO ₂ e/m ²	17.4123	0.3278	0.3278	0.3278	0.3278	0.9836	0.9836		20.6907

Table 16: Whole life carbon footprint of preservation on C&U roads.

10.5 Rejuvenation – C&D

Year	0	7	14	21	28	43	58		
Example	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment	Total number of years	Total (KgCO ₂ e/m ²)
Traditional resurface / asphalt surface rejuvenation system	New road (100mm)	Rejuvenation	Rejuvenation	Rejuvenation	Rejuvenation	Surface dressing	Surface dressing	60+	
KgCO ₂ e/m ²	17.4123	0.0645	0.0645	0.0645	0.0645	0.9836	0.9836		19.6375

Table 17: Whole life carbon footprint of rejuvenation on C&U roads.

10.6 Shallow In-situ recycling – C&D

Year	0	2	17	32	47		
Example	Treatment	Treatment	Treatment	Treatment	Treatment	Total number of years	Total (KgCO ₂ e/m ²)
Shallow In situ cold recycle 80mm retread + double dressing	New recycled road	Surface dressing	Surface dressing	Surface course	Surface dressing	60	
KgCO ₂ e/m ²	3.1523	0.9836	0.9836	7.2471	0.9836		13.3502
Shallow in situ cold recycle 80mm retread + double dressing	New recycled road	Micro surface	Micro surface	Surface course	Micro	60	
KgCO ₂ e/m ²	3.1523	1.7892	1.7892	7.2471	1.7892		15.7667

Table 18: Whole life carbon footprint of shallow in-situ recycling on C&U roads.

10.7 Medium in-situ - recycling – C&D

Year	0	1	10	20			
Example	Treatment	Treatment	Treatment	Treatment	Treatment	Total number of years	Total (KgCO ₂ e/m ²)
Medium in situ cold recycle 150mm + double dress	New recycled road	Single surface dress	Surface dress	Surface dress	Repeat	60	
KgCO ₂ e/m ²	5.7641	0.8135	0.9836	0.9836			17.0896

Table 19: Whole life carbon footprint of medium in-situ recycling on C&U roads.

10.8 Deep In-situ recycling – C&D

Year	0	5	10	15	20	25			
Example	Treatment	Treatment	Treatment	Treatment	Treatment	Treatment		Total number of years	Total (KgCO ₂ e/m ²)
Deep in situ cold recycle 250mm + 65mm over lay SMA	New recycled road	Preservation	Preservation	Preservation	Retexture (shot) + Preservation	Preservation	Repeat	60	
KgCO ₂ e/m ²	22.4963	0.3278	0.3278	0.3278	0.5779	0.3278			48.7708

Table 20: Whole life carbon footprint of deep in-situ recycling on C&U roads.

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13 Appendices

13.1 Appendix A: Density Factors

Material	Density	Units	Source
Cement: general	1.50	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Cement: general - 25% fly ash	1.86	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Cement: general - 50% fly ash	1.86	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Cement: general - 25% blast furnace slag	1.86	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Cement: general - 50% blast furnace slag	1.86	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Fibre Cement	1.86	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Portland Cement (dry kiln)	1.50	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Portland Ash Cement	1.50	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Soil-Cement	1.86	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Copper: general	8.90	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Recycled Copper	8.90	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Steel: general	8.00	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Aluminium: general	2.70	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Lead: general	11.34	t/m ³	Bath Inventory - Version 2.0 (2011)
Standard Paint	1.20	kg/litre	Bath Inventory - Version 2.0 (2011)
Mortar (cement:sand mix)	1.90	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Plastic (PVC)	1.40	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Quarried aggregate	2.00	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Recycled aggregate	2.00	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Asphalt	2.30	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Bitumen	1.00	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Standard Brick	2.30	tonnes/ 1000 bricks	Bath Inventory - Version 2.0 (2011)
Clay	1.90	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Sand	1.85	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Soil	1.70	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Stone: general	2.00	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Stone gravel/chippings	2.00	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Slate	2.70	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Timber: general	0.50	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Particle Board	0.75	kg/m ²	Bath Inventory - Version 2.0 (2011)
Plywood	0.54	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Sawn Hardwood	0.60	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Sawn Softwood	0.50	tonnes/m ³	Bath Inventory - Version 2.0 (2011)
Concrete	2.40	tonnes/m ³	Bath Inventory - Version 2.0 (2011)

Reference: National Highways, 2023.