MEASURING THE CARBON FOOTPRINT OF ROAD SURFACE TREATMENTS

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ABSTRACT

Road surface treatments are methods or materials for extending the lifetime of road pavements when they deteriorate, delaying the need for major maintenance or rehabilitation. Surface dressing is the most commonly used surface treatment in the UK but others are increasing in their use. Surface treatment contractors make environmental claims about the use of their treatments in comparison to conventional methods. These claims are not usually made on the basis of robust, standards led, assessments. This lack of standardization and consistency means confidence cannot be held in these claims and that comparisons cannot be reasonably drawn. In this paper, the carbon footprints of some road surface treatments in the UK are assessed. The Pavement Road Treatment Embodied Carbon Tools (*ProTECT*) are presented, which were used to calculate the carbon footprint of seven road surface treatment methods. The tools align with the PAS 2050 method and Asphalt Pavement Embodied Carbon Tool (*AsPECT*) protocol. Benchmark figures are presented for use in life cycle carbon footprinting for road pavements and to facilitate comparison. Conclusions are drawn as to the comparative impact of different treatments and the sensitivity of this comparison to their service lives. Without better understanding of surface treatment's service lives robust prioritization of treatments cannot be made on a carbon basis. Comparison between treatments can only be made when the functional units are simplified to be equivalent. In reality, the various treatments perform different functions.

INTRODUCTION

Road surface treatments are methods or materials for extending the lifetime of road pavements, delaying the need for major maintenance or rehabilitation. In this paper, the carbon footprints of some road surface treatments in the UK are assessed. Benchmark figures are presented for use in life cycle carbon footprinting for road pavements and to facilitate comparison. Conclusions are drawn as to the comparative impact of different treatments and the sensitivity of this comparison to their service lives.

The Pavement Road Treatment Embodied Carbon Tools (*ProTECT*) are presented, which can be used to calculate the carbon footprint of seven road surface treatment methods.

BACKGROUND

Surface Treatments

Road surfaces deteriorate by mechanisms including cracking, potholing and loss of skidding resistance. The condition of a deteriorated road surface can be improved by applying a road surface treatment, to delay the need to replace, or overlay, them. The most common surface treatment in the UK is surface dressing *(1)*, which, in its simplest form, is the spraying of bitumen on a road surface followed by the spreading of a layer or layers of aggregates *(2)*. It can improve surface texture, wet skid resistance, seal the surface against water ingress and stop disintegration of the existing road surface *(3)*.

Slurry seals (or micro surfacing) are cold mix surface treatments that can improve the skid resistance and evenness of roads and produce good ride quality *(1)*. The process consists of applying a 3-20mm layer of in-situ mixed: aggregate; (polymer modified) bitumen emulsion; adhesion agents; water; and cement or lime *(3,4)*. High Friction Surfacing (HFS) is used in locations at high risk of skidding accidents, to provide very high skid resistance *(3)* and is usually laid only on short road sections due to its cost.

Mechanical retexturing exists in a number of forms with the aim of improving skid resistance. The bush-hammering technique studied in this paper, is carried out by an automated machine that delivers many controlled impacts that produce local fracturing of the aggregate and restore microtexture *(2)*. These treatments do not require any additional material but their effectiveness depends on the quality of the existing pavement mix.

Inlay patches *(5)* are the conventional repair method for localized road surface defects such as pot holes and deteriorating edges. Velocity patching for defects 75mm or shallower, uses a stand-alone truck that holds emulsion and aggregate and is equipped with a high-pressure feed hose. Debris in the defect is blown away, a tack coat is applied and the asphalt is mixed and sprayed into the defect. The emulsion ’breaks’ almost immediately and so trafficking can resume straight away. Infra-red patching requires a ’burner’ to heat the bituminous material until it can be reworked. A small amount of additional material from a hot box is usually mixed into the existing material and a rejuvenator may be added. The patch is compacted in the conventional manner.

Many surface treatment contractors make environmental claims about the use of their treatments as a means to extend pavement life. These claims are not usually made on the basis of robust, standards led, assessments. This lack of standardization and consistency means confidence cannot be held in these claims and that comparisons cannot be reasonably drawn.

Existing Studies

There have been no robust studies into the impact of the road surface treatments considered in this paper and relatively few that have compared road maintenance options. Examples of studies which have considered road maintenance include: Hakkinen and Makela *(6)* include the assessment of several maintenance activities during a 50 year assessment period; The Athena Institute *(7)* studies include maintenance activities but they exclude any which do not require significant quantities of new material, such as surface treatments; Santero *(8)* made a comparison of the impact of pavements with varying design lives, including maintenance requirements; Huang et al *(9)* focused on maintenance events but specifically on assessing the carbon footprint of traffic delay. None of these studies looked into the use of road surface treatments. The impact of some of the methodological decisions made in the *AsPECT* protocol can be found in Huang et al *(10)* and Spray (*11)*. A review of pavement LCA tools and models developed in Europe can be found in Carlson *(12)* and Huang et al (*13)*.

***ProTECT* TOOLS**

Development of the *ProTECT* tools was a joint project between the University of Nottingham and the UK Road Surface Treatment Association (RSTA) *(11)*. The project began in 2009, due to RSTA members being asked by clients for the carbon footprint of their processes. There was a need for the development of new tools, developed in a standard way, for use by decision makers. From the outset, the aim was to develop a suite of tools which would allow members to generate the carbon footprint of projects to supply to clients and to allow them to make substantiated claims of environmental performance against conventional treatments.

Method

<u>PAS 2050 and *AsPECT*</u>

PAS 2050 *(14)* is a UK Publically Available Specification, which provides a standard method for assessing the carbon footprint of goods and services. TRL, in collaboration with the Highways Agency, Minerals Products Association and Refined Bitumen Association developed the Asphalt Pavement Embodied Carbon Tool (*AsPECT*) in 2009 *(15)*. It was recently updated in February 2014 *(16)*. This tool can be used to produce PAS 2050 compliant carbon footprints of asphalt pavement construction. It is highly adaptable due to its wide scope but it does not meet the needs of very specific users such as road surface treatment contractors and their clients. The *ProTECT* tools were also developed in conformity with PAS 2050 to provide a method and data by which surface treatments could be included in *AsPECT* assessments. The assumptions and boundaries adopted by *AsPECT* were also adopted in the development of the *ProTECT* tools.

<u>Industrial Involvement</u>

The development of the *ProTECT* tools was carried out with the support, primary data and process knowledge of RSTA members who deliver the products. A steering group was established with representation from client bodies (Association of Directors of Environment, Economy, Planning & Transport (ADEPT) and Transport Scotland) and suppliers (Mineral Products Association, The Bituchem Group) to ensure the maximum utility was delivered by the tools.

<u>Scope and Functional Units</u>

The surface treatments selected by RSTA members and included in the project were: mechanical retexturing (bush-hammering); velocity patching; infra-red patching; slurry/micro surfacing; surface dressing; and high friction surfacing (hot and cold applied). Surface dressing, slurry/micro surfacing and high friction surfacing (hot and cold applied) were selected due to the high volume and value of these treatments currently used in the UK and their importance in road maintenance activities. The other maintenance treatments were selected due to industry enthusiasm for carbon footprinting and tool development. The scope of the calculations is cradle to 'laid'. This includes all impacts from raw material extraction, material processing, material transportation, plant mobilization and plant operation. All greenhouse gases falling under the IPPC 2007 list of greenhouse gases are included and weighted in accordance with their global warming potential in the units of Carbon Dioxide Equivalents

(CO_2e). Although use phase effects, such as the change in rolling resistance due to improved road condition or the secondary effects of albedo have the potential to have significant environmental impact *(17)*, the measurement and estimation of their impact is not well understood *(18)*. They are outside the scope of this study due to the lack of understanding and high uncertainty in the use phase of surface treatments. The impact of traffic congestion and delay has been left outside the scope of the surface treatment calculations. Surface treatments tend to be quick to apply, need little time before the road is reopened, need little traffic management and are usually applied to low-mid traffic level roads. As such, the impact of traffic delay is likely to be small. The functional units vary for the different treatments considered. They were selected with the industrial partners to be equivalent to the units by which the products are usually sold. This allows for specification of the product by the contractor to clients in terms of both price and carbon synonymously. The functional units are shown below.

Data Sources

The data for carbon emission factors, Table 1, were selected to be consistent with *AsPECT* wherever appropriate. Secondary data were sourced from the ICE database *(19)* or *Ecoinvent (20)* when no data were specified in *AsPECT*. Within each calculator there are default material data if users do not have primary data. Users are encouraged to request specific supply chain data.

Table 1: Carbon Emission Factors

Item	Unit	Carbon Emission Factor ($kgCO_2e$/unit)	Source
Aggregate	Tonne	5.2	Hammond and Jones *(19)*
Articulated HGV (>3.5-33t)	Km	1.08	Defra *(21)*
Articulated HGV (>33t)	Km	1.21	Defra *(21)*
Bitumen Emulsion (Residual Bitumen)	Tonne	220	Eurobitume *(22)*
Calcined Bauxite	Tonne	124	Groundwork Pennine Lancashire *(23)*
Cement	Tonne	950	Hammond and Jones *(19)*
Compressed Natural Gas (CNG)	L	1.66	Defra *(21)*
Diesel	L	3.17	Defra *(21)*
EVA	Tonne	1,700	Hammond and Jones *(19)*
Gas Oil	L	3.60	Defra *(21)*
Heavy Fuel Oil	MJ	0.09	Jungbluth *(24)*
Lime	Tonne	780	Hammond and Jones *(19)*
LPG	L	1.72	Defra *(21)*
Mineral Oil	Tonne	420	Jungbluth *(24)*
Petrol	L	2.72	Defra *(21)*
Polymer Modified Bitumen Emulsion (Residual Bitumen)	Tonne	350	Wayman et al *(15)*
Polymer Modified Resins	Tonne	6,000	Hischier *(25)*
Resin	Tonne	5,800	Hischier *(25)*
Rigid HGV (>3.5-7.5t)	Km	0.72	Defra *(21)*
Rigid HGV (>7.5-17t)	Km	0.88	Defra *(21)*
Rigid HGV (>17t)	Km	1.19	Defra *(21)*
Ro-Ro Ferry	Tonne.km	0.06	Defra *(21)*
Shipping (Bulk Carrier)	Tonne.km	0.004	Defra *(21)*
UK Grid Electricity	kWh	0.59	Defra *(21)*
Water	Million L	344	Defra *(21)*

Tool Development

The tools were developed in *Excel*^{TM} using user forms and macros coded in Visual Basic for Applications. This framework was chosen due to the potential users' widespread understanding and familiarity with *Excel*^{TM}.

Practitioners are required to input data concerning plant. This includes fuel efficiencies and production data. The tool calculates a $kgCO_2e$/unit figure and a $kgCO_2e$/mile (km) figure. Materials data are required such as the distance transported to the company depot and the type of vehicle(s) used. A figure is calculated for the $kgCO_2e/t$ material. Users enter data such as utility usage at offices and warehouses, yearly productivities for the product.. Often the emissions from utilities need to be allocated between a number of different products due to shared offices/warehouses. Ideally this is done through attributing the actual usage to each product, but that can be impossible (or deemed too resource intensive) to measure. In this case, to comply with PAS 2050, the emissions must be allocated, preferably using economic allocation. All data must be revised on an annual basis or if there is a significant change of process in accordance with PAS 2050.

Project calculations bring together the figures calculated within the plant, material and other databases in order to calculate project specific carbon footprint. Mix designs for materials used are described and attributed to plant. Mobilization distances are also entered, along with the total amount of material to be laid on the project. Each major piece of plant is inputted and then the job carbon calculation is made. Results are shown on a results page within the spreadsheets with a graph that splits the total into different parts of the life cycle. This helps users to identify carbon hotspots. The project calculations can be used to calculate averages of whole year operations if required.

The tools are freely available on the RSTA website (www.rstauk.org). They are accompanied by a guidance document which explains the scope/boundary conditions as well as providing step-by-step instructions.

BENCHMARKS

Input data

The tools have been used by contractors to test the software and the results are displayed in Table 2 and Figure 1. The users were asked to input data from their previous year's operation. A 'sense check' was carried out through comparison of consumption data between similar treatments and other studies. The consumption values cannot be published due to the commercially sensitive nature of the data.

The data for the mechanical retexturing and velocity patching are full year (2011) averages of the major or only UK contractor offering the treatments, giving a high level of confidence in the representativeness of the benchmarks. The data for the infra-red patching represents full year (2011) average for one major contractor and there is good confidence in its representativeness. The slurry/micro surfacing and surface dressing data are full year (2011) averages for a contractor having about one third market share for slurry/micro surfacing. Many contractors are present in the surface dressing market. Confidence in the representativeness of the benchmarks for these two treatments is improved due to the conformity of practice amongst contractors. To date, there has been no contractor usage or data from the HFS tool and data from a high level hot-spotting exercise (average data from desktop research, multiple assumptions in data gaps) are used.

Results

Comparison per Unit and m^2

The results, Table 2, have been normalized from their functional units to one m^2 based on average spread rates/thicknesses supplied by contractors.

Table 2: *ProTECT* User Results

Treatment	Functional Unit	kgCO$_2$e/unit	Spread Rate (unit/m^2)	kgCO$_2$e/m^2
Mechanical Retexturing	m^2	0.51	1	0.51
Velocity Patching	m^3	46.60	0.3	13.98
Infra-red Patching	Repair (m^2)	5.52	1	5.52
Slurry/Micro Surfacing	t	90.70	0.032	2.87
Surface Dressing	m^2	1.00	1	1.00
Cold HFS (hot-spot)	m^2	16.38	1	16.38
Hot HFS (hot-spot)	m^2	18.22	1	18.22

The results show a significant range of cradle to laid values for the various surface treatments. It should be noted, however, that simple comparisons of this type do not account for the various functions fulfilled by the treatments. For instance, amongst the treatments for improving skid resistance some treatments fulfil only this function (e.g. mechanical retexturing), whereas others also repair localized defects, such as crack sealing (e.g. surface dressing). In addition to this, the typical depth of repair for the different treatments varies considerable. The patching solutions are often used to repair relatively deep potholes in comparison to thin layers of surface dressing or micro surfacing.

Because of these factors, the functional units for many of these treatments are not directly comparable. However, despite the non-comparability, there remains utility in discussing the results, in a consistent unit, relative to each other. It can assist users in understanding the typical range of values for activities of this type.

Figure 1 shows these results by life cycle stage. The breakdown of HFS emissions has not been made due to the uncertainty in the outputs given the lack of detailed consumption and emission factor data.

Figure 2 shows the relative impact of the different life cycle stages. The contribution of the different stages varies considerably between the different treatments. Mechanical retexturing has zero impact due to materials as it uses no material, and the total carbon footprint is dominated by the retexturing operation itself (64%). This is due to the energy intensive activity of fracturing aggregate. There is a low contribution by mobilization. The retexturing machine is carried to site in an articulated truck and this is a much more fuel efficient option than driving the heavy, fuel inefficient plant to site. The proportional impact of utility use at offices and depots is particularly high for mechanical retexturing because it has such a low overall impact. The absolute emissions from utilities for this treatment are not significantly higher than those for other treatments.

In contrast, for velocity patching 90% of the impact is due to raw materials. A contributing factor is the high embodied carbon specified by the aggregate supplier, 35% higher than the default aggregate value. At 2%, utility use is the smallest contributor to the carbon footprint but it is still of greater magnitude than the 1% PAS 2050 states as the materiality threshold.

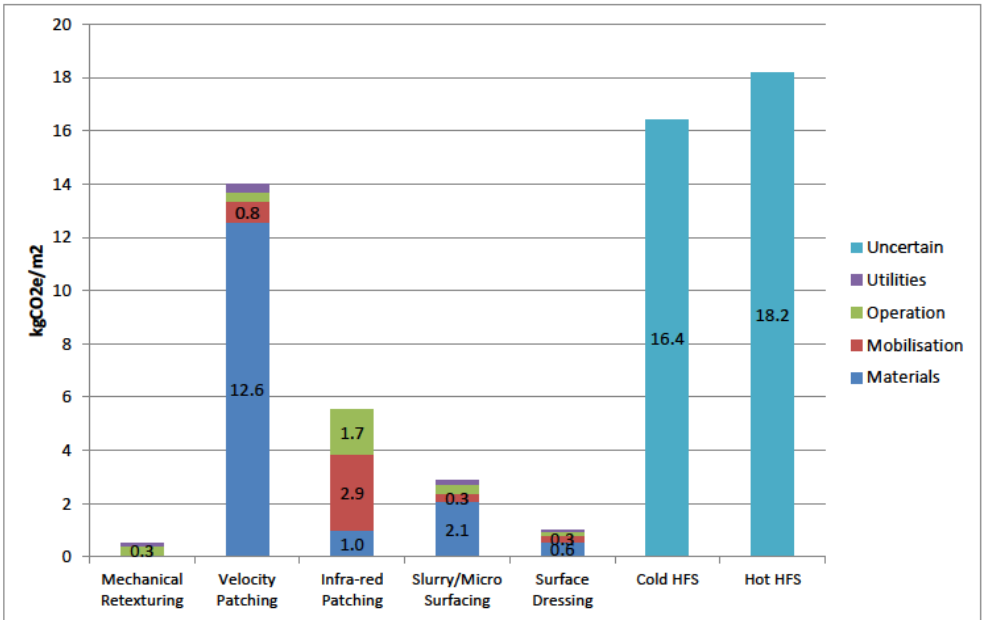

Figure 1: Comparison of the normalized cradle to laid impact broken down by life-cycle stage.

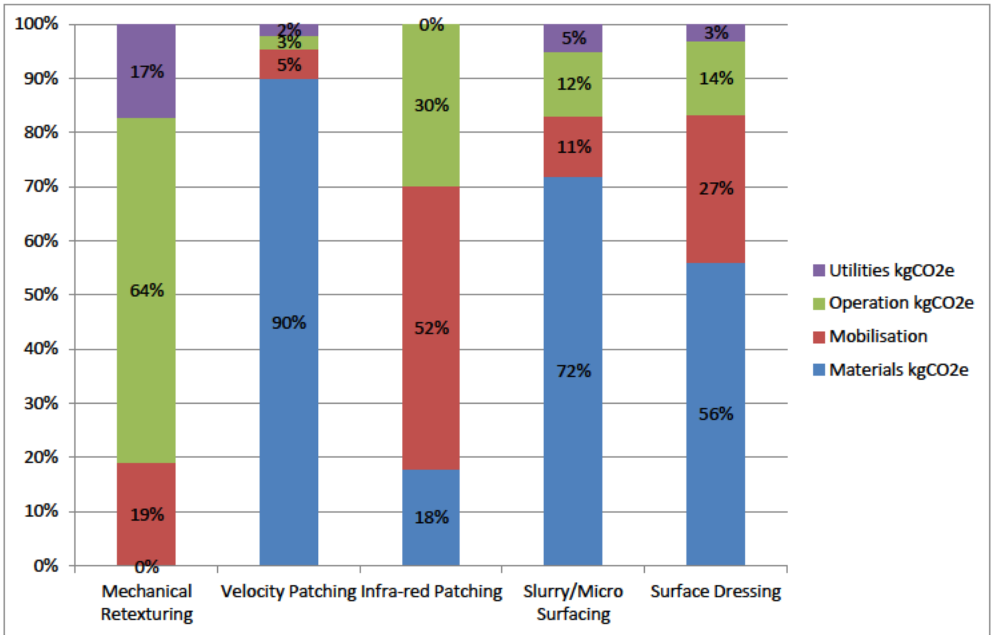

Figure 2: Comparison of cradle to laid impact contribution of the different life cycle stages.

Service Life Sensitivity

For treatments for the loss of skidding resistance, Figure 3 shows the potential variation in results due to uncertainty in service life. The upper and lower bounds are the results of normalizing the impact by the maximum and minimum service life. The predicted service life ranges used for this assessment can be seen in Table 3. The results are shown on an impact per meter squared per year basis. The results show an overlap between the ranges, except for HFS.

Table 3: Surface Treatment Service Lives

Treatment	Service Life Range (years)	Data Source
Mechanical Retexturing	1.5 – 6	Contractor
Surface Dressing	10 – 15	ADEPT/RSTA (2011) *(26)*
Slurry/Micro Surfacing	6 – 10	ADEPT/RSTA (2011) *(26)*
Cold HFS (hot-spot)	5 – 11	ADEPT/RSTA (2011) *(26)*
Hot HFS (hot-spot)	3 – 5	ADEPT/RSTA (2011) *(26)*

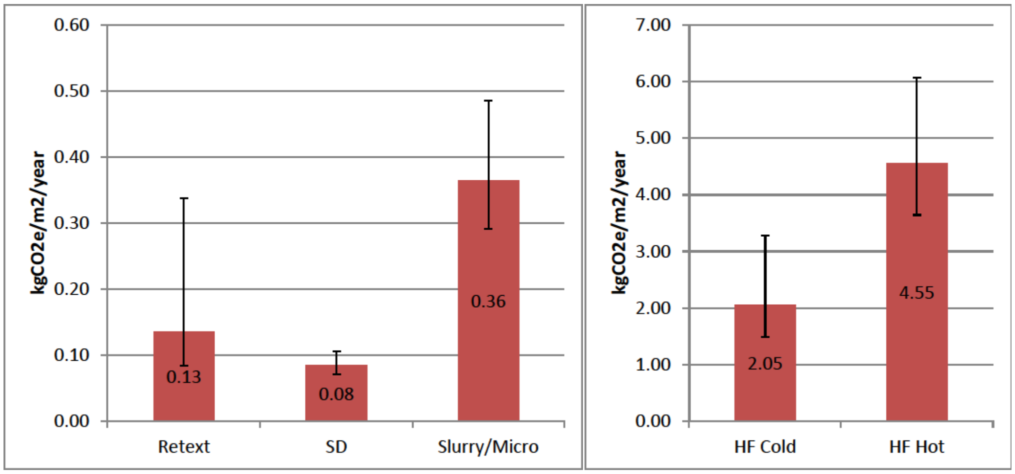

Figure 3: Uncertainty in skid treatment calculations due to service life.

DISCUSSION

Six 'carbon calculator' tools have been developed and launched in collaboration with the RSTA. The tools have consistent layout, data and function but vary in required inputs depending on the treatment. The tools enable users to calculate the 'cradle-to-laid' carbon footprint of seven road surface treatments, in conformance with PAS 2050. The associated user guides describe the step-by-step method required to complete a calculation (including data requirements) and the detail of the calculations behind the tools.

Benchmark results, using users' annual data, show a wide range of carbon footprints for the surface treatments considered. The contribution to the carbon footprint of the different life cycle stages was also significantly different between the different surface treatments. These are not surprising results as the processes considered vary significantly.

For the treatments in which materials are used, the embodied carbon of the materials (extraction, processing) tended to be the majority of the total carbon footprint (56% - 90%). The carbon footprint of utility usage in office, warehouses, etc. was a material (>1%) contributor in four of the five treatments considered (2% - 17%). This element is often excluded from studies despite it being a requirement of the standards. It is not included in *AsPECT* calculations or in most road pavement carbon footprints.

This type of contribution analysis can be useful to practitioners in attempting to find reduction opportunities in their processes. For example: a mechanical retexturing contractor might consider investing in more efficient plant or converting to an alternative fuel type as most of the impact (64%) is in the operations stage. A velocity patching contractor might investigate lower embodied impact material options as 90% of their impact is embodied in the materials supplied. Benchmark results have been calculated for all the processes considered with the exception of high friction surfacing for which no annual consumption data were supplied. The ability to edit calculations facilitates scenario modelling which will enable contractors to test the sensitivity of results to reduction opportunities and therefore deliver the maximum carbon savings.

The scope of the carbon footprinting was cradle-to-laid. This was chosen because surface treatment performance is very dependent on the road they are being applied to and so it is very difficult to attribute a conventional use or end of life stage. The use of this scope does have the potential to skew the perception of the results however, as some treatments studied are relatively short-term, ’quick fixes’, whilst others are medium-long term solutions. This is complicated by the uncertainty inherent in the service lives of these types of treatments.

Service life variability means that there is significant cross-over between the treatments’ maximum and minimum values. For example; a long lasting retexturing can be more carbon efficient than a short life surface dressing and all other treatments considered, while a short life retexturing would be less carbon efficient than a surface dressing or long life slurry/micro surfacing. Without knowledge of the distribution of the service lives therefore, it is not possible to rank all the treatments without introducing additional uncertainty. However, ranking and direct comparison of this type can lead to misleading conclusions because some treatments offer significantly different functions to others.

It is important to note that different treatments can provide additional functions e.g. high friction surfacing provides higher skidding resistance than the other processes, and surfacings provide a degree of renewed waterproofing to a road system potentially protecting lower layers. Direct comparisons are, therefore, inappropriate. The significance of service life highlights the importance of functional unit choice and transparency. Defining a functional unit for a road surface treatment without specifying the service life leads to significant uncertainty in the results. Although the surface treatments are compared on equal functional units (m^2), in reality they do not all perform the same function. Close functional unit definition should include expected service life and any additional structural or sealing benefits afforded to the road as a result of treatment. Defining the functional units this closely however would prevent comparison being made and many of these additional functions are often ’added benefits’ rather than the primary function of the treatment.

The tools are a valuable addition to carbon footprinting in road pavements. They provide a standardized framework for calculating the carbon footprint of these treatments in road surface maintenance. Benchmark figures (notwithstanding the data quality discussion) can be used in case study investigations, taken forward by the *AsPECT* protocol *(15)* to be used in their full life carbon footprint of asphalt road construction tool, used for benchmarking by contractors, clients and relevant stakeholders and used in wider road carbon footprinting.

The exclusion of the use phase in assessments has the potential to neglect what may be the largest impacts associated with road pavements – vehicle emissions. For heavily trafficked roads, the reduced fuel consumption from reduced roughness achieved through regular maintenance has the potential to be significantly larger than the impact of the materials used and construction processes. As Santero *(17)* suggests, the reduced emissions from low rolling resistance pavements may be very much higher than the emissions from other road pavement sources.

It is unfortunate that a more accurate study was not possible of the HFS treatments as they offer some interesting conflicts. They are significantly more expensive than more conventional treatments and also appear to be of considerably higher carbon footprint. They are favored by decision makers as they offer very high skidding resistance in areas of high risk therefore reducing accidents. Balancing the utility of accident avoidance against cost and carbon footprint is a challenging task into which more research is required.

Studies carried out at industry sector level can provide useful insight and benchmarking data which individual studies cannot. The results and conclusions from studies like this can be used to generate Product Category Rules which can then be applied across the sector. This is the approach encouraged in PAS 2050 and other standards *(27)*. It has been adopted in some other sectors for ensuring comparability when using standards or generating environmental product declarations (EPDs) *(28,29)*.

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