IMPORTANCE OF SOME ASPECTS OF METHODOLOGY IN PAVEMENT LIFE CYCLE ASSESSMENT

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ABSTRACT

After years of development of Life Cycle Assessment (LCA) for roads, there are still some questions surrounding the data and methodology to use. Eurobitume's latest life cycle inventory (April 2011) uses two methods of allocating environmental impacts among petroleum products, including bitumen. Capital goods (i.e. refinery infrastructure) are also included. The UK publically available specification, PAS 2050 for assessment of greenhouse gases of consumer products is finding wide use in the UK but uses a different approach. The significance of these decisions for a road carbon footprint is investigated in this paper.

Recycling is a topical issue for pavement engineers. The challenges to LCA practitioners include how to allocate/credit the impacts/benefits of recycling within the life cycle. The significance of this decision for a road carbon footprint is investigated in this paper.

While the adoption of a standard methodology for road LCA will assist in transparency and decision making, the impact of the chosen approach on the results found has not been explored. In support of LCA method development in roads, a case study (focusing on carbon footprint) of a typical UK road is presented, in which the allocation approach and recycling scenarios are tested, and the model is checked for sensitivity to these parameters.

Keywords: Allocation, Embodied Carbon, Life Cycle Inventory, Recycling, Slag

1. INTRODUCTION

1.1. LCA and Carbon Footprinting

Life cycle assessment (LCA) addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave) [1]. As a subset, carbon footprinting is often used to estimate global warming potential of greenhouse gas (GHG) emissions of product life cycles.

Carbon footprinting is important in the road pavement sector for a number of reasons. The construction industry is a large GHG emitter and as such it is required to reduce emissions to help meet targets such as the Kyoto Protocol. The UK, for example, has committed to reducing its total greenhouse gas emissions by 20% by 2020 and 80% by 2050 compared to 1990 levels. Carbon footprinting is also important in this sector due to demand from clients who are required to report total yearly carbon footprints. Contractors are increasingly being required by clients to provide carbon footprint data relating to work done or being tendered for.

1.2. PAS 2050

As a result of the increase in importance of carbon footprinting, the UK Department for Environment, Food and Rural Affairs (DERFA) has developed a publicly available specification [2] which specifies requirements for assessing the life cycle GHG emissions of goods and services, and is finding wide use in the UK [3].

1.3. AsPECT

In 2009 Transport Research Laboratory (TRL), in collaboration with the Highways Agency, Minerals Products Association and Refined Bitumen Association, published the first part of the asphalt Pavement Embodied Carbon Tool (asPECT) [4], [5]. This UK based tool (www.sustainabilityofhighways.org.uk) has been developed to produce PAS 2050 compliant carbon footprints for asphalt. It has been gradually expanded and now allows calculation of full life cycle carbon footprints of asphalt pavements including maintenance activities. It is intended to cover all asphalt pavement laying.

1.4. Bitumen Life Cycle Inventory

In 2011 Eurobitume published its revised life cycle inventory (LCI) of bitumen [6]. This generic European ‘cradle to gate’ study covers extraction of crude oil, transportation to Europe, manufacturing of bitumen and hot storage of the product. This full LCI quantifies a number of the environmental emissions and impacts from the production of bitumen including the greenhouse gas emissions.

1.5. Methodological choices

1.5.1. Issues

After over 15 years of development of LCA for road pavements, there are still many questions surrounding the data and methodology to use. Some belong to the on-going development of the LCA methodology [7], others are specific to the road sector. The intention of this paper is to use a ‘typical road’ case study to test the sensitivity of methodological choices that were made in the development of PAS 2050, the asPECT protocol and the Eurobitume LCI.

The methodological choices focused on in this paper are related to allocation. System expansion to avoid allocation usually begets more uncertainty and assumptions, thus allocation of environmental burdens, among co-products or at end of life recycling, is applied in pavement LCAs. Allocation rules are put under the spotlight when people attempt to verify or challenge conclusions and this can hinder decision making. This paper will consider the allocation issues surrounding bitumen, where a variety of petroleum products are produced, and Blast Furnace Slag (BFS) where different assumptions can make a significant difference to the carbon footprint. It will then show the importance of the choice of recycling credit allocation ratio in the case study.

1.5.2. Allocation among co-products

Environmental burdens of bitumen are advised to be allocated at the ‘lowest possible sub-process level’ within a refinery. This involves the attribution of the energy consumption of different refinery units to intermediate product streams to develop a process-based allocation [8]. This approach is vulnerable to lack of data on the yields and energy use at the fundamental processing level in the refinery, and to the connection between process units [9]. Eurobitume’s life cycle inventory uses two methods of allocating environmental burdens among petroleum products, including bitumen [6]:

- At crude oil extraction and transport stage, where the oil products are considered as raw materials, the allocation is based on mass.
- At the refining stage, the allocation is based on economic value, i.e. market price of the outputs factored by their physical yields.

According to a study in 2010 granulated blast furnace slag (BFS) used as aggregate replacement for a road with 30-year design life have very different impacts when the burdens of steel making are allocated to BFS from 0% (treated as waste) to 20% (allocation by mass) [10]. AsPECT treats BFS as a waste and the sensitivity of this assumption as well as that of various bitumen allocation methods will be tested for sensitivity for the carbon footprint of the case study.

1.5.3. Allocation at end-of-life recycling

Recycling is a topical issue for pavement engineers. Apart from resource efficiency reasons, some products of high embodied CO2 can be partially replaced by outputs from other industries that are often treated as waste. For instance, the reduction of the carbon footprint of concrete by replacing some cement with industrial by-products is well known [11-14].

The challenge to the LCA community includes how to credit the benefits, or allocate the burdens, of recycling to manufacture and use of recyclable materials. Complex products such as buildings and cars have different disposal scenarios for components that are product (assembly) based, rather than material based; the allocation to EOL recycling usually involves both the open-loop and closed-loop scenarios, based on both physical and economic relationships [15]. Products of more uniform components such as road pavements often deal only with material based, closed-loop recycling.

In that sense, the route taken by recycling metals is worth referring to. For instance, the steel industry has a methodology for closed-loop recycling, based on physical recycling rate that requires the assumption of EOL recovery rate and the ratio of steel to scrap yield [16], as shown by Eq.1 below. The aluminium industry based the allocation on economic factors such as the price elasticity for primary and secondary aluminium. Frees found that some 60-70% of the demand for aluminium is made from primary source; and the avoided production when recycling will hence mainly be of primary aluminium [17]. This ‘scrap’ deficit is similarly seen by the European asphalt industry, where available reclaimed asphalt makes in general less than 35% of the annual production [18].

$$\text{LCI for steel production including recycling} = LCIpr - R \times Y \times (LCIpr - LCIre) \quad \text{Eq.1}$$

Where[1]:

- R = the total recycling rate of the steel product
- Y = the process yield of the EAF (i.e. >1kg scrap is required to produce 1kg steel)
- LCIpr = the cradle-to-gate LCI for 100% primary metal production. This is a theoretical value of steel made in the BF/BOF route, assuming 0% scrap input
- LCIre = the cradle-to-gate LCI for 100% secondary metal production from scrap in the EAF (assuming scrap = 100%)

LCA development has proposed an array of allocation methodologies; they are firstly stated by Ekvall [19] and evolved by Nicholson [20]. The three methods most commonly used are:

- Cut-off method: each product is assigned only the burdens directly associated with the product; in other words, all benefits of recycling are given downstream to using the recycled material. This approach is also known as the recycled content [21], and followed by PAS 2050 [2], see Eq.2 below.

$$\text{Emissions / unit} = (1 - R1) \times EV + (R1 \times ER) + (1 - R2) \times ED \qquad \text{Eq.2}$$

Where:

- R1 = proportion of recycled material input
- R2 = proportion of material in the product that is recycled at end-of-life
- ER = emissions arising from recycled material input, per unit of material
- EV = emissions arising from virgin material input, per unit of material
- ED = emissions arising from disposal of waste material, per unit of material

- Substitution method: 'design for disposal', that burden of each product life cycle in the cascade is equal, which includes recycling to restore material properties each time the product is recycled. In other words, the producer of recyclable material is given the full benefits of recycling at EOL. Metals which maintain their inherent properties when recycled, such as steel and aluminium, take this approach, see Eq.1 above [16].

- 50/50 method: supply and demand for recycled material are both necessary to enable recycling. Half the benefits of recycling are hence allocated to using the recycled material, and the other half to producing it originally. This applies when the burdens of recycling are less than the combined burdens of raw material production and waste disposal. AsPECT, takes this approach except that it changes the ratio to 60:40 [22].

The international standards for LCA and PAS 2050 provide a framework rather than setting rigid rules and prescribing what assumptions to make in these allocation scenarios [23]. While the adoption of a standard methodology for road pavement LCA will assist in transparency and decision making, the impact of the chosen approach on the results has not been explored. The implementation of LCA in road pavements is evolving and disparate [24]. How to handle the above methodological aspects will to some extent determine the effectiveness of LCA in decision making for the road sector.

2. METHODOLOGY

2.1. Case Study

In support of LCA methodology development in roads, a case study (focusing on the carbon footprint) of a 'typical' UK road is presented, in which the allocation rules and recycling scenarios described above are used, and the results are checked for sensitivity to these parameters.

The study is of a 'typical' interurban road in the UK Midlands. The studied length is 1km and the road has a typical single carriageway width of 11m. The construction of the pavement is a 40mm HRA surface course, a 60mm binder course and a 100mm base course. All layers use Blast Furnace Slag (BFS) as the course aggregate (See Figure 1). BFS was chosen as the aggregate for all layers to represent an extreme case for the sensitivity of results to allocation method.

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[1] EAF: electric arc furnace; BF: blast furnace; BOF: basic oxygen furnace.

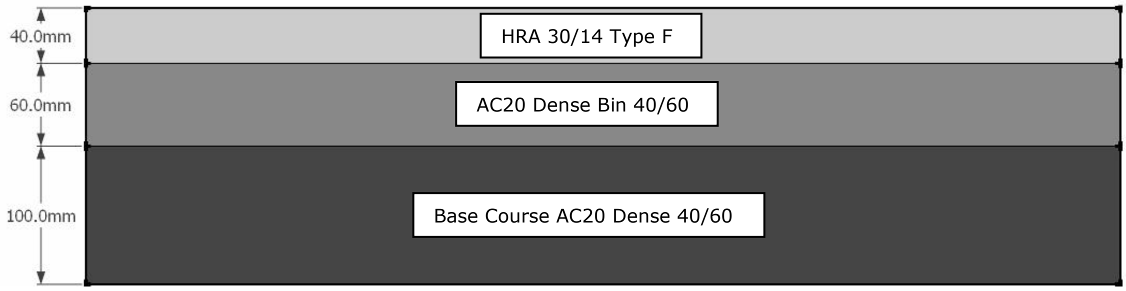

Figure 1: Case Study Pavement Construction

The construction is based on details provided by Lincolnshire County Council (LCC) and the standard pavement design in BS EN 13108 [25].

2.2. Model development

The maintenance scenario modelled is as in figure 2Figure 2, using SimaPro supported by data from contractors and UK averages. 60 years was selected as the analysis period. All data and assumptions were made to conform with the asPECT protocol, only one material allocation was changed at a time.

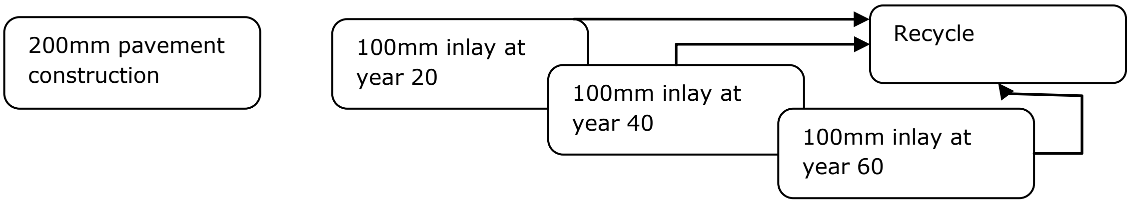

Figure 2: Construction & Treatment Scenario

The full depth inlays seen in figure 2 involve planning out of the top two layers of the system and replacing with identical mixtures.

The system boundary is illustrated in figure 3. Allocation of environmental burdens to BFS has followed both the mass and economic value route of the iron casting process in SimaPro, the ‘zero embodied carbon’ route has also been used. The BFS embodied carbon figures were calculated using the EcoInvent data for cast iron. Allocating the emissions was done using iron:BFS ratios of 1t:92.8kg [26] and 333£/t:7.74£/t [27, 28]. Eurobitume 2011 inventory data was used for bitumen. Allocation scenarios of mass, economic and the Eurobitume chosen ‘mixture’ were used for bitumen calculations. Asphalt production used the asPECT method which followed the 60:40 split at EOL, and was changed to ‘cut-off’ and ‘substitution’ methods for sensitivity analysis. Recycling asphalt was assumed to follow the weight ratio of: 100% stockpiled for reuse.

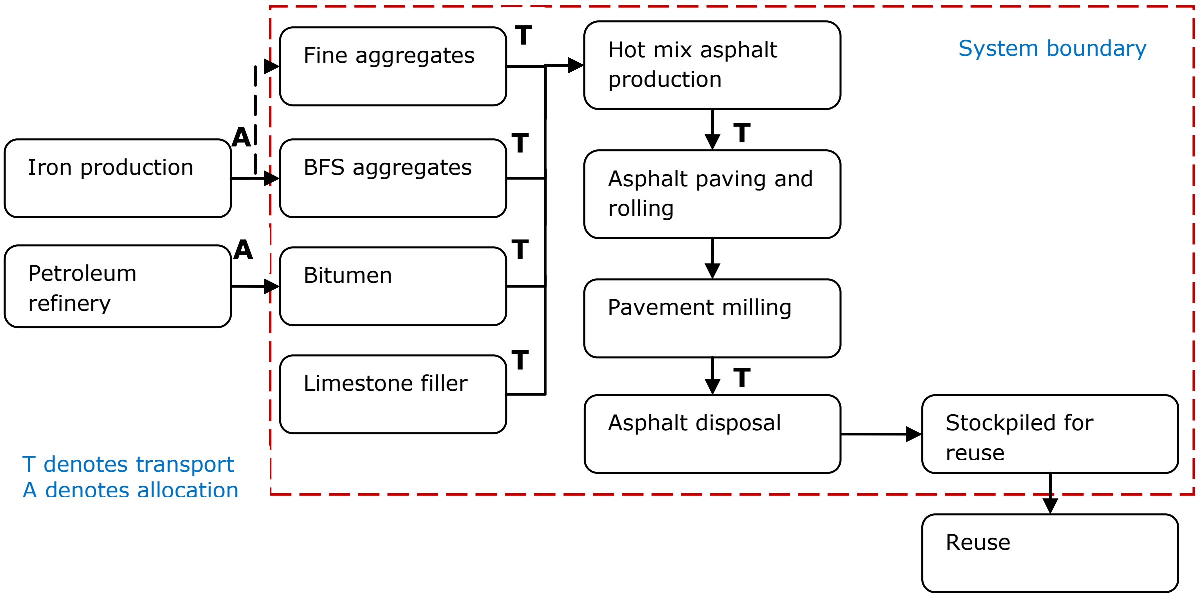

Figure 3: System Boundary for Asphalt Life Cycle

3. RESULTS

3.1. Allocation among co-products

The variation in results for the embodied carbon of bitumen and BFS can be seen in Figure 4. The embodied carbon of bitumen varies from 107 KgCO2e/t (economic allocation) to 234 KgCO2e/t (mass allocation). This is a predictable result but one that will be repeated for a lot of construction materials as they tend to be bulky and of relatively low value. The embodied carbon of BFS can vary from zero – if the assumption is made that it is a waste product and so all the carbon associated with production is allocated to iron – to 126 KgCO2e/t through mass allocation. This is a very high figure considering conventional virgin aggregates are usually in the range of 3.8 - 5.2 kgCO2e/t [29].

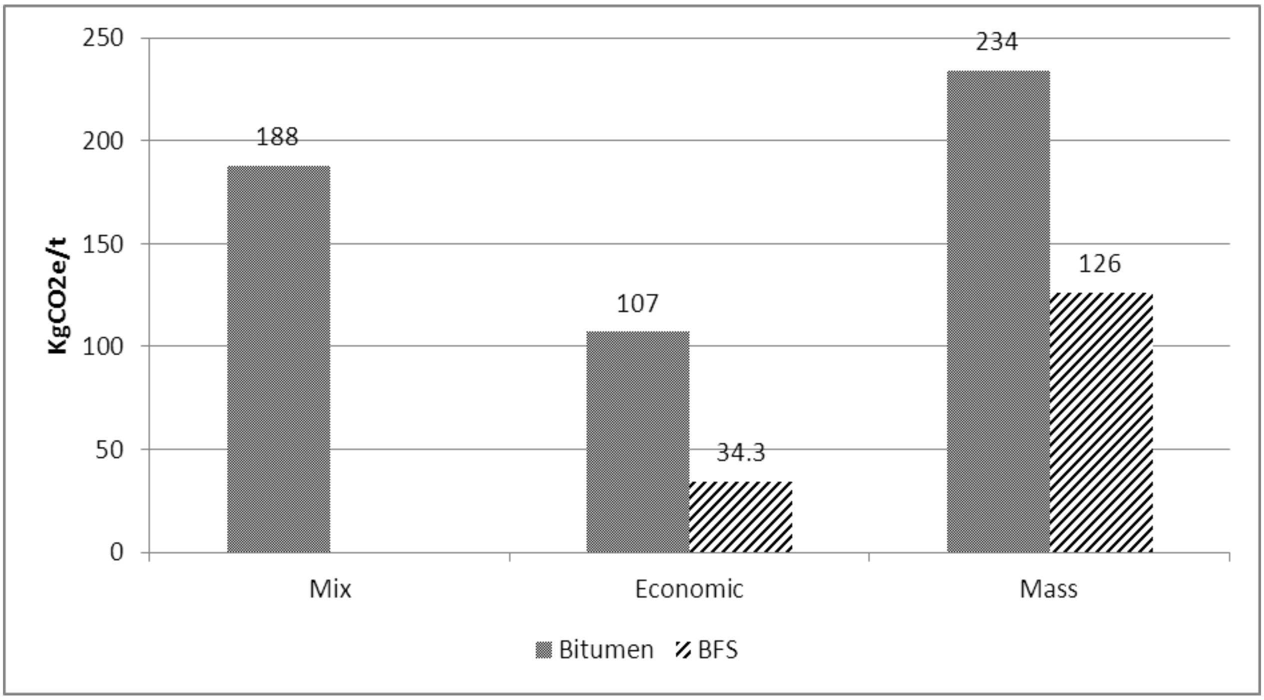

Figure 4: Embodied CO2e of Bitumen and BFS Using Different Allocation Methods

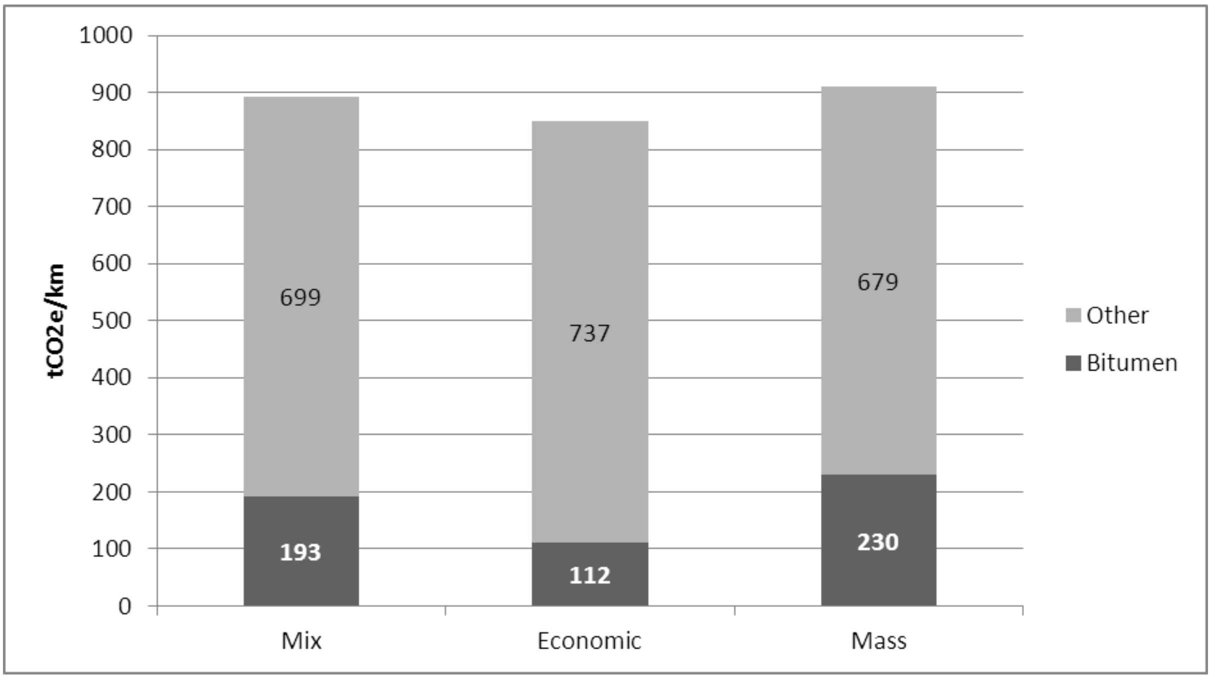

Figure 5: Embodied Carbon of Road Case for Different Bitumen Allocations Methods

Figure 5 shows the results per kilometre for the whole life case study across the different allocation methods for Bitumen. The change in embodied carbon of bitumen due to the different methods can lead to an increase in the total embodied carbon of the system by up to 7% (economic to mass method). In this case the BFS is allocated zero carbon footprint at point of production, as in asPECT. End of life allocation is set to 60:40 as in asPECT.

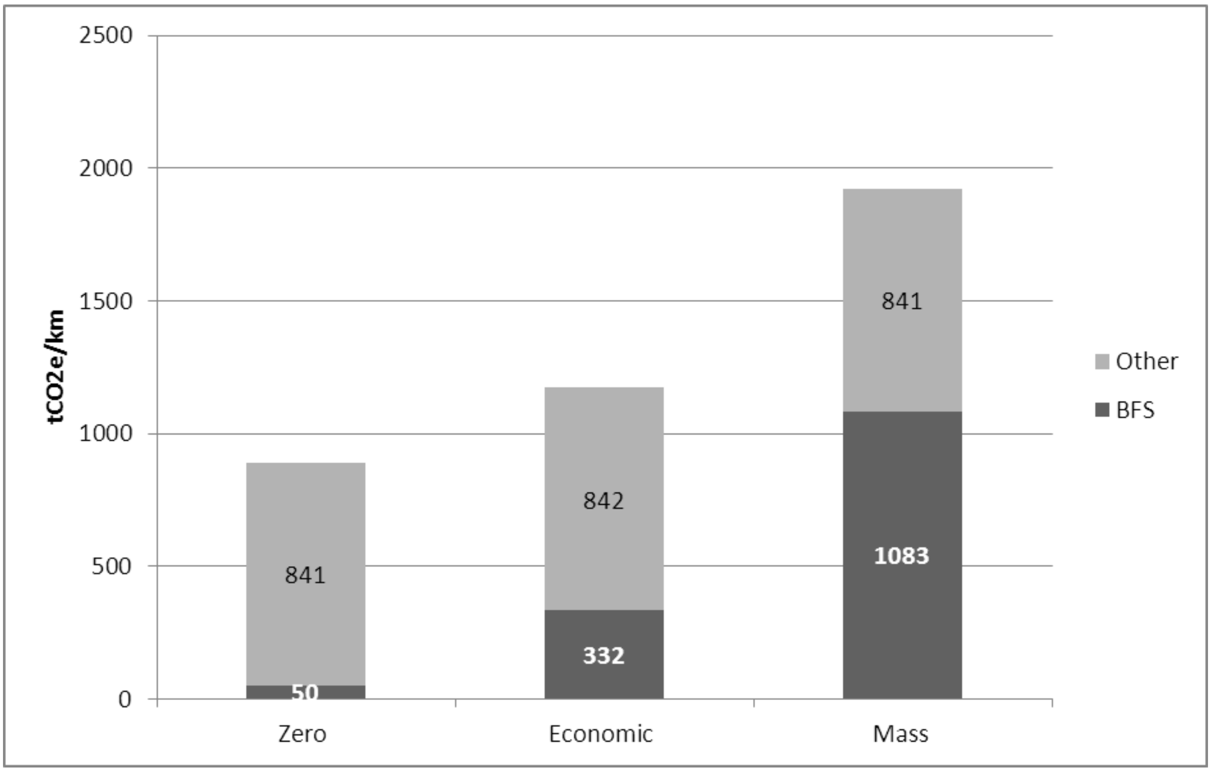

Figure 6: Embodied Carbon of Road Case for Different BFS Allocations Methods

Figure 6 shows the results per kilometre for the whole life case study across the different allocation methods for BFS. Due to the high level of BFS in the mix design and the large variation in embodied carbon of the material when allocation method is changed, the results of the whole system vary significantly. The difference between considering zero emissions to the mass based allocation increases the embodied carbon of the whole system by as much as 216%. Even the change between zero and economic allocation causes an increase of 32% over the life of the pavement. In this case the bitumen allocation is ‘mixed’ and the end of life allocation is 60:40, as in asPECT.

3.2. Allocation at End of Life

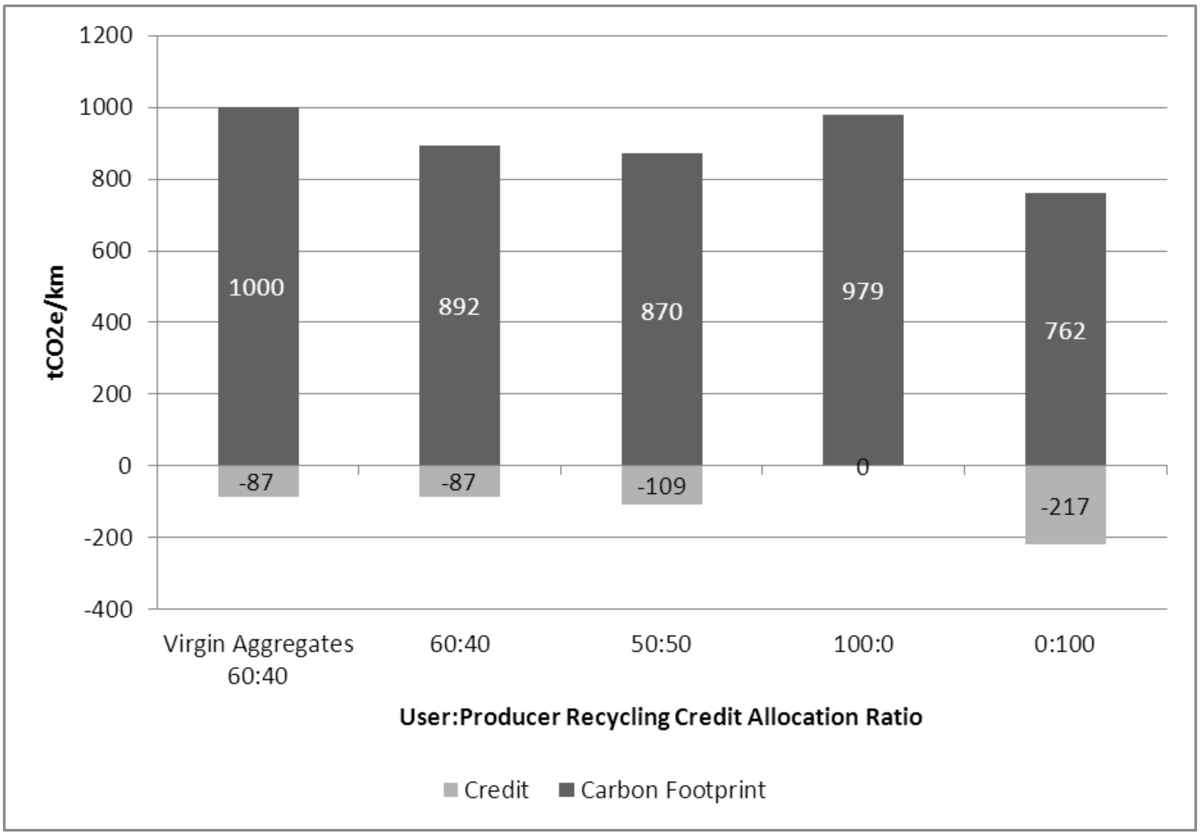

Figure 7: Embodied CO2e of Road Case Using Different Recycling Credit Ratios

Figure 7 shows the sensitivity of the road case study carbon footprint to changing the recycling credit ratio. The credit varies from 0 to -217000 KgCO2e. This variation leads to a change of 22% in the total carbon footprint. The change from the asPECT chosen 60:40 ratio to the often used 50:50 ratio results in a 2% decrease for this case. The results for the same study using virgin aggregates instead of BFS has been shown here for comparison.

4. CONCLUSIONS

Sensitivity analysis can help to understand the impacts of chosen allocation methods and boundary settings on the LCA results. The results from this study show how much the total carbon footprint of the life of the road case study can vary based allocation choice.

In the investigation the carbon footprint of BFS varies much more than that of bitumen and it leads to a much larger change in the whole case study footprint. The 7% change resulting from the bitumen allocation change is not very significant, as uncertainty of the footprint would be expected to be high in any case, from truncation errors and other factors.

The change in recycle credit option can also lead to significantly differing results. The different options considered are currently used in different situations. The sensitivity of the final result to the choice of ratio shows this is an issue that needs to be thought through in this domain and agreed upon in order to produce a level playing field for carbon footprinting.

Decisions such as allocation type and recycling credit are largely left to the LCA practitioner and this could lead to error and/or abuse. In the near future decisions of material choice or scheme design may be influenced by carbon footprints but if the results can vary so significantly, decision makers will find it difficult to place their trust in them.

5. RECOMMENDATIONS

These conclusions are based on one extreme case study, using BFS coarse aggregate with a number of other life-time assumptions. Other and broader studies are required to test the sensitivity of these and other issues further.

PAS 2050 includes a methodology that can be used to conduct a full LCA. However, it needs to be tailored to address the specifics of pavement construction and use.

There are many other methodological questions concerning LCA and carbon footprinting of road pavements [30]. Among the potentially most significant is the issue of boundary expansion. These elements which are not typical included in conventional pavement LCAs such as road traffic emissions, heat island effects and rolling resistance have been shown to potentially have a very significant effect on the overall environmental impacts of pavements [31]. Further investigation of these elements is required.

In order to have comparability, standard conditions such as type of allocation, and recycling credit must be used for all studies. Decision makers must be informed and be aware of these issues when attempting to use carbon footprint results for comparison.

Standard conditions should include the use phase and be agreed at a sector level. The standard conditions constitute what are referred to as Product Category Rules (PCRs). PCRs already exist in a number of sectors such as the automotive industry [32].

Conventional functional units consider pavement length and design traffic levels. When considering standard conditions, different functional units, may need to be defined in a pavement LCA model, to deal with pavements of different construction, condition, climate, location and traffic.

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