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Gap between simplified and detailed calculation of the environmental impacts of road mixtures

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Abstract. In order to reach the COP21 objectives, solutions with low carbon contents must be used in road projects. However, the identification of the best materials to be implemented in the wearing course of roads is a daily problem faced by stakeholders. To overcome this knowledge gap, the present study demonstrates the environmental impacts of 120 mixtures calculated with simplified and detailed hypotheses and input data. Even though the variability of inputs significantly influences the impacts of the mixtures and do not allow for the identification of the best solutions, on average, warm mix asphalt presented lower impacts than hot mix asphalt or concrete.

1. Introduction

Construction and rehabilitation processes related to the global road network with a length of 16.3 million km were found large responsible of greenhouse gas (GHG) emissions [1-2]. On the other hand, as per the Paris Agreement, 197 countries have committed to limit their GHG emissions in order to prevent the global temperature from rising above 1.5°C before 2050 [3]. To reach this goal, stakeholders involved in road construction must develop projects that implement materials and processes with low embodied GHGs. Alternatively, regarding traditional materials used in roads, such as hot mix asphalt (HMA) and concrete, several solutions have been developed and proposed in recent years that present lower carbon content. These solutions can be classified into three categories: mixtures with lower production temperatures [4-5], mixtures with improved properties due to binder modification [6], and mixtures with reused asphalt aggregates/pavement (RAP) [7-9]. Produced in lower temperatures, cold mix asphalt and warm mix asphalt (WMA) were introduced as better solutions compared to traditional HMA [4-5]. Even though the overall embodied GHG of WMA is lower than those of HMA, the temperature decrement was made possible through the implementation of additives presenting an additional source of impacts. While cold mix asphalts are produced at ambient temperature, their mechanical properties are not considered sufficient to support all traffic load levels. Binder modification was made possible through the implementation of bitumen modifiers, such as polymers, extenders, oxidants, etc., which improve the mechanical strength of asphalt, but are additional sources of GHGs [6, 10]. Another solution is the implementation of RAPs to reduce the need for virgin resources, such as the aggregates and binder [7-9]. However, in most cases, RAPs are considered without burdens to neglect the impacts of asphalt dismantling in roads.

Limitations of the system boundary, the database used for calculation, as well as the variation of hypotheses and methods to assess the impacts are highlighted as barriers. These limitations bring into question the reliability of the calculated impacts and prevent a robust comparison of mixtures and the identification of the best solutions [11-12]. Motivated by this knowledge gap, in this study, we aim to calculate the environmental impacts of several solutions under homogenized hypotheses, inputs, databases, and methods. To that end, we performed a systematic literature review to identify various mixtures for HMA, WMA, and concrete. Next, their environmental impacts were calculated based on the hypothesis and data as extracted from the reviewed papers. Furthermore, the impacts of mixtures were also recalculated with detailed hypotheses and input data by adding the missing processes. Finally, the impacts were assessed, the hypotheses and data extracted from the reviewed papers (nominated simplified) were compared with the improved assessment (nominated detailed), and the materials with lower impacts were identified.

2. Systematic Literature Review

The mixtures analysed in this study were extracted from the papers identified in a recent systematic literature review published by Hoxha et al [11]. Among the studies dealing with the environmental impacts of roads, only 30 papers [4-9, 15-38] were found to be pertinent and provided information/data about the mixtures they analysed.
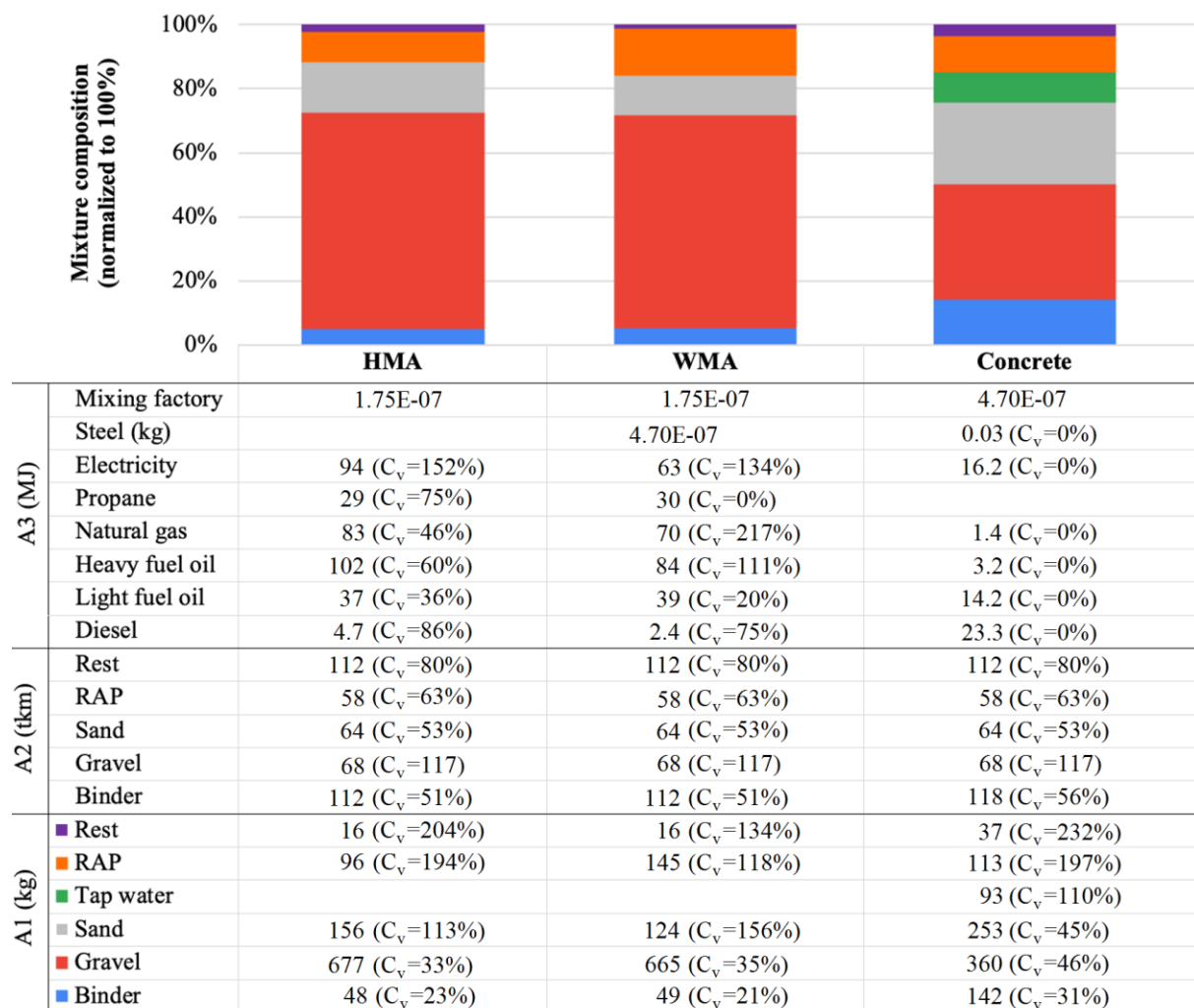

		HMA	WMA	Concrete
A3 (MJ)	Mixing factory	1.75E-07	1.75E-07	4.70E-07
	Steel (kg)		4.70E-07	0.03 (C_v=0%)
	Electricity	94 (C_v=152%)	63 (C_v=134%)	16.2 (C_v=0%)
	Propane	29 (C_v=75%)	30 (C_v=0%)	
	Natural gas	83 (C_v=46%)	70 (C_v=217%)	1.4 (C_v=0%)
	Heavy fuel oil	102 (C_v=60%)	84 (C_v=111%)	3.2 (C_v=0%)
	Light fuel oil	37 (C_v=36%)	39 (C_v=20%)	14.2 (C_v=0%)
	Diesel	4.7 (C_v=86%)	2.4 (C_v=75%)	23.3 (C_v=0%)
A2 (tkm)	Rest	112 (C_v=80%)	112 (C_v=80%)	112 (C_v=80%)
	RAP	58 (C_v=63%)	58 (C_v=63%)	58 (C_v=63%)
	Sand	64 (C_v=53%)	64 (C_v=53%)	64 (C_v=53%)
	Gravel	68 (C_v=117)	68 (C_v=117)	68 (C_v=117)
	Binder	112 (C_v=51%)	112 (C_v=51%)	118 (C_v=56%)
A1 (kg)	Rest	16 (C_v=204%)	16 (C_v=134%)	37 (C_v=232%)
	RAP	96 (C_v=194%)	145 (C_v=118%)	113 (C_v=197%)
	Tap water			93 (C_v=110%)
	Sand	156 (C_v=113%)	124 (C_v=156%)	253 (C_v=45%)
	Gravel	677 (C_v=33%)	665 (C_v=35%)	360 (C_v=46%)
	Binder	48 (C_v=23%)	49 (C_v=21%)	142 (C_v=31%)

Figure 1. Average data of processes and inputs for HMA, WMA, and concrete (Cv presents the coefficient of variation for the ratio between standard deviation and average).

In the 120 mixtures identified and classified, there were: 87 HMAs, 16 WMAs, and 17 concretes. The environmental impacts per ton of mixture were assessed for two situations: based on the hypotheses and input data as provided in the reviewed studies, improved the hypotheses and input data by adding the missing information about processes for asphalt production. The impacts were calculated following the European norm EN-17472 [13]. Only the modules of the mixture's components production (A1), transport (A2), and production (A3) were considered in the system boundaries for the calculation of the global warming potential (GWP) indicator. The generic database used for this LCA is the Ecoinvent 3.5 database, which is available in the SimaPro simulation tool [14]. The average values and coefficients of variation Cv of the inputs and processes for modules A1-A3 were calculated and the extracted data is presented in Figure 1.

3. Results

Results for global warming potential (GWP) indicators for hot mix asphalt (HMA), warm mix asphalt (WMA), and concrete calculated for bow scenarios with simplified and detailed inputs are presented in Figure 2. Based on the results, for the GWP score calculated with simplified inputs, HMA has an average value of 54 kg CO_2e/t. Impacts equal to 59 kg CO_2e/t for WMA are unexpectedly higher than those of HMA. Concrete presents the largest impacts (121 kg CO_2/t). On the other hand, for the detailed inputs' scenario, the impacts of the mixtures are significantly higher. By analysing the relative gap between these results, it was determined that the GWP score of HMA is increased by 19%, followed by WMA with 9%, and concrete with 5%. In this case, the impacts of HMA (67 kg CO_2e/t) are higher than those of WMA (65 kg CO_2e/t). Concrete remains the mixture with the largest impacts (128 kg CO_2e/t). Based on these results, we can conclude that the calculation of the environmental impacts with simplified inputs mislead the identification of the mixture with the lower GWP scores. A more detailed analysis of the environmental impacts of life cycle stages for HMA highlights the production module (A3) as the most significant sources of errors. This module presents an absolute gap of 8 kg CO_2e/t, followed by the impacts of transportation (A2) with a gap of 3 kg CO_2e/t, and the production of mixture components (A1) with a gap of 1 kg CO_2e/t. For WMA and concrete, the largest source of errors (4 kg CO_2e/t) is associated to the impacts of transportation (A2). The production of the mixture responsible for the gap of 2 CO_2e/t can be considered significant. While the impacts related to the production of WMA and concrete are unsignificant. Comparing the impact of the life cycle stages for HMA, the production module (A3) (36 kg CO_2e/t) is higher than that of WMA (30 kg CO_2e/t). On the other hand, the impact of mixture components for WMA (24 kg CO_2e/t) is higher than that of HMA (21 kg CO_2e/t).
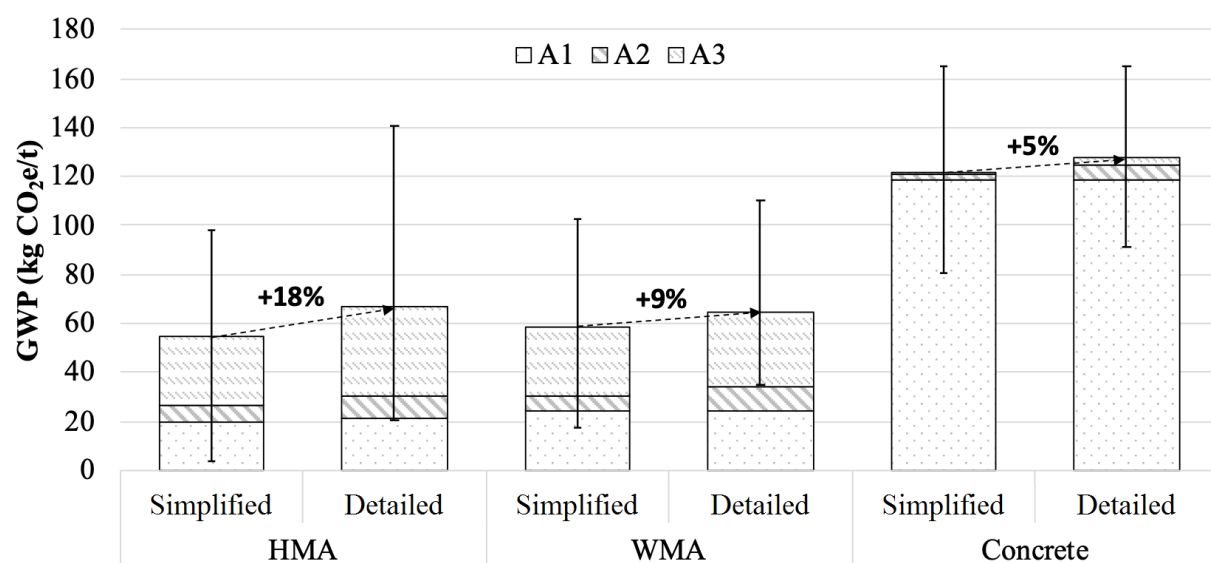

Figure 2. Comparison of the impacts for simplified and detailed calculations.

The low impact of the production module (A3) of WMA is allocated to the reduction of temperature reduction of this mixture that consequently leads to less energy consumption. The increase of impacts for the production of mixture components is related to the need for additives. However, considering the interval overlap of impacts between HMA and WMA, it is not possible to conclude with robustness on the best mixture solution. Since the GWP score of mixtures is significantly influenced by the impacts of all life cycle modules, the identification of the solution with lower impacts should be made on a specific case using detailed input data.

To better analyse the gap between the simplified and detailed calculations, in Figure 3, the relative errors are presented on the basis of single cases. For HMA, the error gap of the impacts for the module of mixture components' production (A1), transportation (A2), and production (A3) are, on average, respectively 3.7%, 38.5%, and 26.4%. It should be noted that, in some studies, the impacts of modules A2 and A3 were not considered to fall within the system boundary of the study. Since these modules are responsible for 15% and 54% of the overall impacts, excluding them from the system boundary is a large source of uncertainties. The source of uncertainties of module A1 is mostly related to the non-consideration of the impacts of RAP. Most studies considered the use of RAP to be without burdens and neglected the impacts associated with the process of asphalt dismantling. The allocation of the impacts for reused components is highly debated in the scientific literature [42] and, consequently, the use of RAP in asphalt should not be considered without burdens.

For WMA, the transport module (A2) presented an average gap error of 56%, followed by the module of mixture production (A3) at 5.6%. Since these errors are linked with the environmental impacts of life cycle stages and have a significant influence on the overall GWP score, they can be considered as a large source of uncertainties. Meanwhile, for concrete, the relative errors related to module A2 and A3 are 52% and 65%. On the other hand, these modules do not have a significant contribution to the overall impacts of concrete and the related uncertainties can be considered unsignificant. Based on these analyses, we can conclude that the impacts of transport are the largest source of uncertainties for the impacts of HMA and WMA. In addition, for HMA, the impacts of the production module (A3) were identified as a significant source of uncertainties and should not be neglected during calculation.
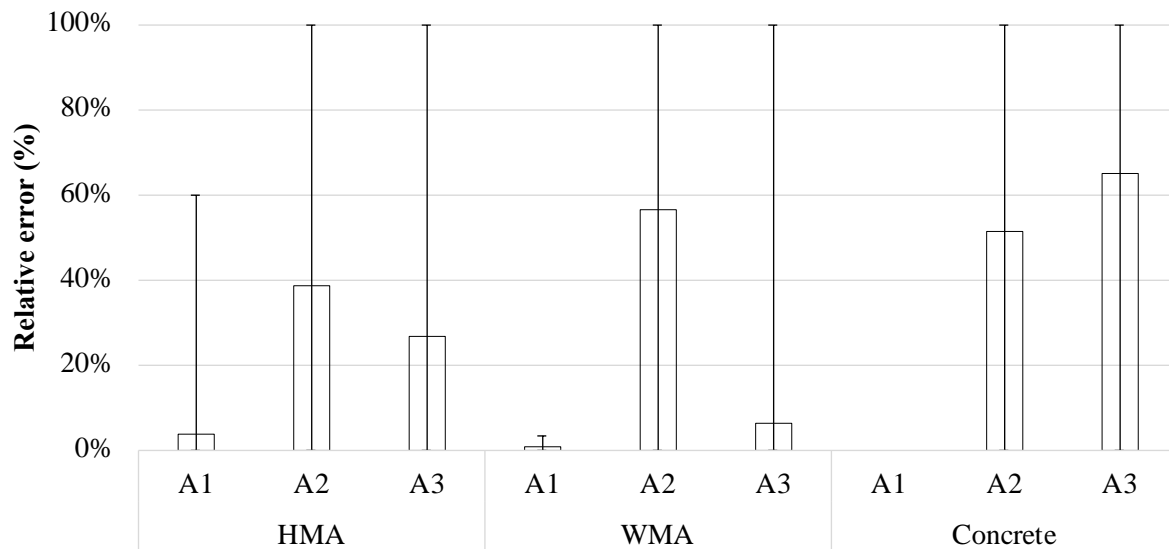

Figure 3. Variation of error gap of impacts of life cycle modules for HMA, WMA and concrete.

4. Conclusion

This study analysed the environmental impacts of 120 mixture scenarios assessed with simplified and detailed inputs. In conclusion, on average, the gaps between simplified and detailed calculations ranged between 18%, 9%, and 5% respectively for HMA, WMA, and concrete. The largest source of errors was the exclusion of the impacts of transport and mixture production from the system boundary. Even though

a robust comparison of mixtures was not possible due to the overlap of impact intervals, in general, WMA demonstrated lower impacts than HMA, while concrete presented the largest impacts. However, these analyses are at the material scale and it is recommended that more detailed calculations be completed in the perspective at the road scale for a better identification of the solutions with lower carbon content.

Acknowledgments

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