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LIFE CYCLE ASSESSMENT AND SENSITIVITY ANALYSIS OF ASPHALT MIXTURES WITH HIGHER RECLAIMED ASPHALT INCORPORATION

C. Moura[1], C. Loureiro[2], J. Oliveira[3] and H. Silva[4]
1 University of Minho, ISISE, Guimarães, Portugal, id8972@alunos.uminho.pt
2 University of Minho, ISISE, Guimarães, Portugal, id9629@alunos.uminho.pt
3 University of Minho, ISISE, Guimarães, Portugal, joliveira@civil.uminho.pt
4 University of Minho, ISISE, Guimarães, Portugal, hugo@civil.uminho.pt

ABSTRACT
This work aims to verify the viability of using Life Cycle Assessment (LCA) to evaluate the parameters influencing the sustainability of asphalt mixtures. Thus, the LCA tool was used for evaluating the changes in the environmental sustainability of an asphalt mixture when increasing the incorporation of reclaimed asphalt (RA) by 15%. Two asphalt mixtures with different RA ratio incorporation were studied, and an LCA study was carried out for both mixtures. A sensitivity analysis was performed to understand the influence of the RA incorporation parameter on the impact category results of both mixtures. This work demonstrated that LCA is a reliable methodology for assessing the influence of varying reclaimed asphalt incorporation on the sustainability of recycled asphalt mixtures.

Keywords: Life cycle assessment (LCA), reclaimed asphalt (RA), sensitivity analysis.

INTRODUCTION
The increasing search for ecological and sustainable solutions has been the basis for adopting asphalt mixture recycling solutions incorporating RA materials. The principal constituents of a typical asphalt mixture are the aggregates, and thus, the utilization of wastes to entirely or partially replace natural aggregates contributes to increasing environmental sustainability and cleaner production of asphalt mixtures [1, 2]. However, previous studies have not evaluated how reclaimed asphalt rate incorporation increase influences the environmental impacts of recycled asphalt mixtures, which is essential to find ways to optimize their sustainability.
The Life Cycle Assessment (LCA) is considered the most-recognized and globally-accepted method for evaluating and comparing the environmental impacts of processes and assessing their sustainability. Furthermore, it has received increasing attention as a methodology to evaluate the environmental sustainability of road pavements [3, 4].
This work utilized an LCA combined with a sensitivity analysis to understand the influence of increasing the RA incorporating ratio as a partial substitute of natural aggregates and bitumen used in asphalt mixtures on the reduction of their environmental impacts.

LCA METHODOLOGY
The LCA study was carried out following the recent standard EN 15804:2012+A2:2019. In this method, the following impact categories were considered: climate change (total – GWPt; fossil – GWPf; biogenic – GWPb; land use – GWPl); ozone depletion (ODP); acidification (AP); eutrophication (freshwater – EPf; marine – EPm; terrestrial – EPt); photochemical ozone formation (POCP); resource use (minerals and metals – ADPmm; fossil – ADPf); and water use (WDP).

Declared unit and System boundary
The declared unit is 1 ton of asphalt mixture.
The system boundary defined the unit processes considered in the LCA study and was drawn to cover the pavement life cycle from "cradle to gate". This approach covers Module A, the product

stage, divided into three phases: A1 – extraction and processing of raw materials and secondary material, A2 – transport of the material to the asphalt plant, and A3 – manufacturing process.

Life cycle inventory

The life cycle inventory (LCI) consists of the system's actual data collection and modeling and allows identifying the primary sources of emissions and environmental impacts. The inventory analysis is calculated through a mass balance between the inputs and outputs and estimates total production and its association with emissions and resource use.

The data for producing an asphalt mixture was considered for the LCI. In stage A1, the bitumen production and the extraction of natural aggregates were considered. In A2, the transportation of these materials to the asphalt plant was considered. Finally, the electricity necessary to keep the electrical equipment in operation at the plant, the loader movements, and the heating of the aggregates and bitumen were the processes considered in A3.

Sensitivity analysis

A sensitivity analysis was carried out to understand the influence of increasing the rate of RA incorporation by 15% on the environmental impacts of the resulting mixtures. The sensitivity ratio (SR) is calculated by Equation 1 [5] and considers the relative change in the impact assessment result and the relative change in the parameter value.

$$SR = \frac{\Delta result}{initial\_result} \times \frac{initial\_parameter}{\Delta parameter} \quad (1)$$

According to this method, the higher the ratio is, the greater the impact that a change in the parameter has on the results.

RESULTS

Based on the described LCA and LCI methodology, the potential environmental impacts were calculated for two asphalt mixes, the reference mixture (Ref Mix) and the alternative mixture, with a 15% increase in RA incorporation (15RA Mix).

In the LCA, RA's replacement of natural aggregates has mainly changed the impact values of bitumen production and natural aggregate extraction. Meanwhile, the sensitivity analysis (Fig. 1) showed that the impact categories most influenced by the incorporation of 15% RA are AP, EPm, EPt, POCP, and WDP, with 28% to 47% variations. Nevertheless, the total global warming potential was also reduced by 7%, and the reduction associated with the biogenic GWP was more than 19%.

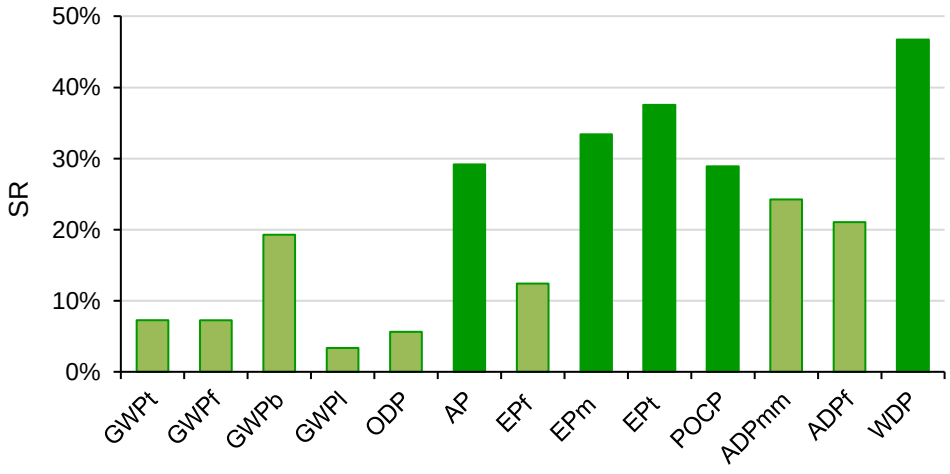

Fig. 1 – Sensitivity ratio results for changes in the percentage of RA incorporation.

Tab. 1 shows the variation of the impact category values of the two main processes influenced by the incorporation of 15% RA, i.e., bitumen production and natural aggregate (limestone) extraction.

Tab. 1 – Variation of the impacts of bitumen production and limestone extraction.

Impact category	Unit	Bitumen production			Limestone extraction		
		Ref Mix	15RA Mix	Variation (%)	Ref Mix	15RA Mix	Variation (%)
AP	[mol H+ eq]	0.045	0.036	20.0	0.018	0.005	72.2
EPm	[kg N eq]	0.011	0.009	18.2	0.006	0.002	66.7
EPt	[mol N eq]	0.121	0.098	19.0	0.088	0.022	75.0
POCP	[kg NMVOC eq]	0.030	0.024	20.0	0.019	0.005	73.7
WDP	[m^3 deprived]	0.544	0.438	19.5	0.753	0.188	75.0

The evaluation of the two main processes influencing the environmental impacts of these asphalt mixtures resulted in a decrease of 19% in the bitumen production impacts and 75% in the natural aggregate extraction impacts after increasing by 15% the incorporation of RA.

CONCLUSIONS

This study showed how the life cycle assessment methodologies could be used together with sensitivity analyses to understand the influence of varying RA incorporation on the sustainability of asphalt mixtures by calculating their environmental impacts and sensitivity ratios.

It can be concluded that the impact of bitumen production and natural aggregate extraction can be reduced by incorporating higher rates of RA in recycled mixtures. When RA is incorporated, a part of the aged bitumen present in that reclaimed material is used as a binder in the recycled mixture, thus decreasing the percentage of incorporation of virgin bitumen and the impacts associated with its production. Also, the RA is used in the new mixture as aggregate, which reduces the percentage of incorporation of natural aggregates and, consequently, decreases the impacts of extracting these materials from natural landscapes.

This analysis allows for verifying the influence of materials on the potential environmental impacts of asphalt mixtures and how to optimize the sustainability of asphalt mixtures production.

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