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LCA Perspective and Biogenic: A Comprehensive Analysis of Environmental Impact in Infrastructure Construction

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ABSTRACT

In recent years, the research on the use of alternative materials in transportation infrastructures has allowed the partial replacement of traditional virgin materials, thus providing sustainable solutions to reduce the ecological impact caused by the infrastructure construction industry. The life cycle assessment (LCA) represents a valuable methodology for evaluating the environmental implications of using such alternative materials.

Among the several alternative options currently available in infrastructure construction processes, biogenic products play a crucial role. Biofuels, including biodiesel, represent a viable example of biogenic raw materials.

In this general framework, the primary goal of the present study is the assessment of the environmental impacts of materials used in the construction of infrastructures by means of LCA, exploring the potential benefits of incorporating biodiesel as part of biogenic materials. The study is focused on the production of a bituminous mixture for a base layer, employing a reference bitumen content equal to 4 % (by the weight of dry aggregates), and adopting a standard mixing and heating temperature of 180 °C.

This study employed a Life Cycle Assessment (LCA) methodology with a cradle-to-gate (A1 A3) approach, encompassing the extraction of raw materials, transportation, and manufacturing processes (activities coded by EN 15978 as A1, A2 A3, respectively). The functional unit for assessment was set at 1000 kg of asphalt production. SimaPro software and Ecosynergy360 web calculator served as the primary tool for conducting the LCA. The inventory analysis relied on various sources: bitumen data were referenced from Eurobitume 2020, aggregate production data were derived from e.g., ecoinvent 3.9.1 database, and bitumen transportation estimates were obtained from the hourly production of typical lorries. For the production process of 1000 kg of asphalt, the energy requirements at the asphalt plant were divided into four main activities. These are aggregate heating (388 MJ), generation of electricity for plant operation (19 MJ), aggregate transportation in plant (8 MJ), and bitumen heating (26 MJ). While natural gas is used for bitumen heating, diesel is used for all the other activities.

The study identified aggregate heating, requiring 388 MJ, as the most energy-intensive process in asphalt production. Consequently, the authors sought to investigate energy reduction strategies by lowering temperatures and substituting mineral fuel with biodiesel, examining potential impacts on CO_2 equivalent emissions. In the first scenario, the authors explored the relationship between heating temperature and energy consumption. LCA analyses were conducted by decreasing aggregate heating temperatures from the standard 180 °C to 140 °C, typical temperatures utilized in Warm Mix Asphalt (WMA) manufacturing. Results indicated a significant reduction in CO_2 equivalent emissions, with a 7% decrease observed for every 20 °C temperature reduction, thus leading to a total decrease of CO_2 equivalent emissions for aggregate heating in WMA by 14%.

Additionally, several studies have investigated the mechanical properties of both Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA). WMA mixtures may be more susceptible to moisture-induced damage, rutting, and fatigue compared to HMA. However, these issues can be addressed through the incorporation of modified binders, higher-grade materials, and additives. HMA exhibits greater resistance to rutting, whereas a specific WMA mixture demonstrated superior resistance to fatigue failure. WMA mixtures exhibit heightened resistance to high service temperatures under various loading conditions. Additionally, computing additives to WMA can enhance stability, although direct mechanical strength comparisons with HMA were not discussed. Thus, while WMA offers benefits such as reduced production temperatures and environmental advantages, its mechanical strength varies and may necessitate specific modifications to match or surpass HMA.

In the second scenario, the study emphasized the relevant role of energy consumption in CO_2 emissions, substituting diesel with a biogenic material such as biodiesel to achieve significant emission reductions. Data retrieved from research literature indicate that biodiesel, derived from sources like rapeseed oil emits approximately 41 g of CO_2 equivalent

every MJ during full combustion. By comparing results obtained by modelling the aggregate heating process with SimaPro, it can be highlighted that the substitution of diesel with biodiesel led to a saving of about 50 % in CO_2 equivalent emissions.

Moreover, it is important to note that biodiesel is mainly produced by lipid feedstock. The potential GHG saving offered by the use of biodiesel is strongly linked to the nature of the feedstock, varying from ~50%, versus equivalent fossil diesel DISI (Direct Injection Spark Ignition) in the case of rape seed oil, up to ~90% when waste oil routes are explored regardless the year and the level of hybridization considered.

Table 1. Summary of different diesel fuels during full combustion.

Fuel Type	Total CO_2 eq during combustion (g/MJ)
Biodiesel – EU mix	39
Diesel (BO)	73.2
Diesel B7 market blend	73.4
FT diesel	70.8

Furthermore, biodiesel exhibits a lower total of CO_2 equivalent compared to other fossil diesel due to the concept of Bio-credit. Bio-credit represents the quantity of CO_2 initially captured by trees during the photosynthesis process, resulting in a zero net effect. This carbon credit, or bio credit, offsets a portion of the CO_2 emissions from the combustion of biodiesel, resulting in a reduced CO_2 equivalent amount in comparison to fossil fuels.

Keywords: Life Cycle Assessment, Biogenic Materials, Infrastructure Construction, Hot Mix Asphalt, Warm Mix Asphalt, Environmental Impact, Sustainable construction.

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