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Review

Life cycle assessment of road construction alternative materials: A literature review

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ABSTRACT

Research on Life Cycle Assessment (LCA) was initially performed to analyze specific products; however, it evolved to assess environmental impacts of more complex systems, such as roads. In this, the construction, use and maintenance stages are usually considered. The results of different studies revealed that all stages have relevant environmental impacts like topsoil loss, change in the use of land, modification of natural drainage and groundwater patterns, landslides, erosion, sedimentation, landscape degradation, increase in noise and dust levels, fuel and oil spills, waste generation, and air, soil and water pollution.

This paper presents the results of a literature review on the application of LCA in road construction as a tool to quantify the potential impacts derived from the use of traditional and alternative materials. The research showed that the most common materials found were recycled asphalt (concrete and bitumen), fly ash, and polymer. In addition, the environmental impact categories more commonly assessed were energy consumption and global warming potential (GWP). These results claimed that the construction of roads should be directed towards the fulfilment of technical, social, economic and environmental criteria. Finally, it was found that most of the studies were performed for high traffic volume roads; therefore, for developing countries, research is needed focussed on low traffic ones.

1. Introduction

Academy and industry are adopting a holistic approach considering environmental, economic and social aspects in the management of sustainability problems (Carvajal et al., 2014). Environmental issues of sustainable development refer, for example, to the depletion of natural resources, global warming, chemical pollution and loss of biodiversity. Based on this, it is necessary that environmental sustainability is evaluated through quantitative measurements, which can support the analysis of environmental impacts.

Based on the above rationale, in the construction and use of roads, it is necessary to consider sustainability criteria, because they are a needed contribution to the growth and development of nations, which provides access to employment, social, health, and education services. In addition, the incorporation of environmental aspects guarantee a reduction of impacts, by reducing the use of traditional materials and replacing them for alternative ones.

This paper is a literature review of studies conducted using the Life Cycle Assessment (LCA) methodology for roads construction with alternative materials. These alternative materials may be: rubber (Chiu et al., 2008), steel slag (Ferreira et al., 2016), polymer (Araújo et al., 2014; Butt, 2014), recycled asphalt (RAP) (Araújo et al., 2014; Aurangzeb et al., 2014; Bloom et al., 2017; Celauro et al., 2015; Chiu et al., 2008; Del Ponte, 2016; Huang et al., 2009; Sanger et al., 2017; Thenoux et al., 2007; Vidal et al., 2013), Recycled concrete pavement (RCP) or Recycled concrete asphalt (RAS) (Bloom et al., 2017; Chowdhury et al., 2010; Del Ponte, 2016; Sanger et al., 2017; Yang et al., 2015) or fly ash (Bloom et al., 2017; Chowdhury et al., 2010; Del Ponte, 2016; Huang et al., 2009; Kucukvar and Tatari, 2012; Sanger et al., 2017). There is an opportunity to apply them on unpaved roads in developing countries, which are normally being stabilized with traditional materials such as natural aggregates (Larrea-Gallegos et al., 2017) or lime (da Rocha et al., 2016).

Thus, an added value of this review is to set the state of the art of the use of alternative materials not only as a substitute for the asphalt layer but as a soil stabilizer; and to apply those materials not to developing countries but to developing ones.

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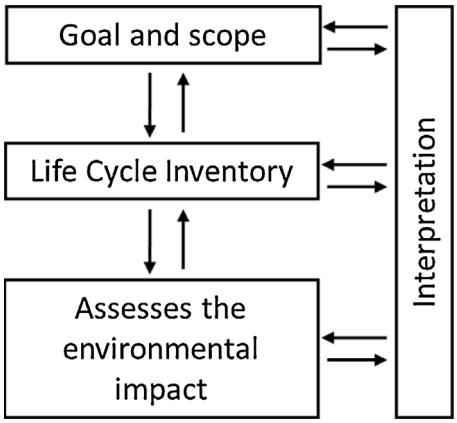

Fig. 1. LCA stages according to ISO 14044:2006.

1.1. Life cycle assessment and product carbon footprint

1.1.1. Life cycle assessment

Life Cycle Assessment (LCA) is defined as "the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO, 2006d).

This methodology describes and analyzes the resources involved in a system under study and the emissions or wastes derived from its life cycle: from raw materials extraction to waste management activities. As main characteristics, it is important to mention that LCA: a) is an analytical method; b) follows an iterative step-wise procedure; and c) considers multiple potential environmental impacts of a product or service according to certain stages analyzed or throughout its life cycle.

During 1970 and 1980 decades, LCA studies were mainly performed to analyze consumer products (within a cradle-to-grave perspective) or mainstream materials or components (cradle-to-gate). However, over time, LCA has evolved to assess the environmental impacts of more complex systems, including those within the building and construction sector such as roads, the one this paper focuses in (Fig. 1).

According to the methodology proposed by the ISO 14040 standard (ISO, 2006d), an LCA has four steps, which are not merely sequential. As Fig. 2 shows, LCA is an iterative technique that allows increasing the level of detail in successive repetitions. The first stage is the definition of goal and scope, which means the reason why the study will be performed and offers a description of the product system related to its limits and its functional unit (Finnveden et al., 2009). The second stage is the Life Cycle Inventory (LCI), where all processes within the system are described, and resources and emissions are allocated (Rebitzer et al., 2004), using different tools and methods to collect them (Fullana et al., 2008). The third stage assesses the environmental impact produced by the resource use and emissions found in the inventory, including a previous collection of impact categories and indicators. The last stage is the interpretation, where the results from the previous stages are analyzed in terms of significance, variability, quality, etc. The interpretation also includes the conclusions and recommendations to improve or change any process/product, considering the goal and scope of the assessment.

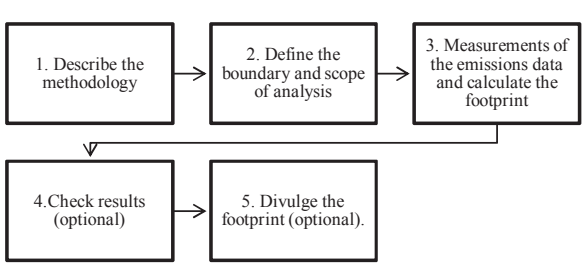

Fig. 2. Global footprint methodology scheme defined by ISO 14064: 2006.
Source: ISO (2006b)

1.1.2. Carbon footprint

Carbon Footprint (CF) is a method used to quantify the amount of greenhouse gas emissions associated with a company (Corporate Carbon Footprint, CCF) or with the life cycle of an activity or a product/service (Product Carbon Footprint, PCF) in order to determine its contribution to climate change (Fullana et al., 2008).

CF not only involves CO_2 emissions but also other greenhouse gases – GHG- which contribute to global warming as well, converting the individual results of each GHG to CO_2 equivalents. In other words, the PCF is a limited version of an LCA, and used as an LCA proxy (Baitz et al., 2013; Bala et al., 2010), in which only one impact category, relative to Global Warming, is considered.

ISO has developed a series of standards numbered between ISO 14064 (ISO, 2006b) and 14069 (ISO, 2006c) for its quantification, aiming at giving credibility and assurance to GHG emissions reports, both for quantification or for reduction. The World Resources Institute – WRI- has written a number of GHG protocols for different scopes and sectors: agriculture, Portfolio Carbon Initiative, Potential Emissions from Fossil Fuels, public sector, Pharmaceutical Products and Medical Devices, Concrete Sector, etc. (World Resources Institute, 2004). Fig. 2 shows a five-step systematic approach, suitable for producing an accurate carbon footprint.

1.2. The construction sector and roads importance

Road infrastructures provide a fundamental basis for contributing to the development of all national economies, ensuring economic and social profits. Public roads are one of the largest sources of revenue for most countries, accounting for more than 500,000 km. Road transport represents between 3% and 5% of the Gross Domestic Product (GDP); a percentage that does not take into account inputs of transport equipment of fuel and infrastructure. In fact, the real contributions of the transport to the GDP are between 10% and 20% (European Commission, 2013).

Roads not only have advantages in economic terms. They ensure access for all restricted rural areas, allowing farmers to transport their crops. They also contribute to the reduction of absenteeism levels in schools. In addition, access to the main cities, where medical infrastructure is concentrated, can improve life quality of people. (World Bank, 1992).

Economic development has, firstly, a great influence in the techniques used to produce construction materials, as traditionally they must travel long distances between their source and the place where they will be used. Secondly, it has led to the depletion of nearby natural resources. Moreover, it has increased pollutant emissions due to industrial processes. Since the mid-twentieth century, the high demand for construction materials has increased the need to extract and process a high amount of natural resources, develop new materials, and treat large quantities of different types of construction and demolition waste – with the energy cost that this represents.

Roads are at the vertebrae of the transport sector. Their construction and maintenance are strategic and represent two of the most important sources of income and/or expenditure. For example, for European Union countries, roads accounted for 72% of freight transport in 2011. Developing countries are said to be mostly dependent on road transport and, most of the time, quantified information associated with costs is difficult to get, because access to it is complex due to the geographic location. Another critical situation is related with traffic level: there is a constant increase of new roads and maintenance (World Road Association, 2014).

However, decision makers do not properly dimension the importance of road construction and maintenance, since the justification for their financing does not include environmental, economic, social and safety criteria (International Development Commitiee, 2011).

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