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Sensitivity of the LCA allocation procedure for BFS recycled into pavement structures

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ABSTRACT

The purpose of this paper is twofold: to investigate the problems involved when performing an environmental assessment of various pavements structures and to establish the method applied to solutions proposed by official French guidelines. This assessment will be performed by employing the life cycle assessment (LCA) methodology specifically adapted to road pavements through a parametric environmental evaluation tool developed by LCPC: ERM (elementary road modulus). The paper will also detail the assessment methodology using this same ERM method. The issues of resources conservation and waste allocation will be examined for the case of blast furnace slag (BFS) recycling. Special focus will be placed on the sensitivity of environmental indicators as regards to the waste allocation procedure implemented in the ERM. Two distinct mass ratios (0% and 20%) of steel production have been assigned to BFS and tested on indicators results as hypotheses H1 and H2, respectively. Classical indicators have been calculated using a simplified model to allocate output flows into several impact categories. Results show that the structure using BFS contributes to saving binder extracted from natural resources, yet also consumes a larger mass of natural aggregates. All indicators except for toxicity were found to be very sensitive to the choice of H1 or H2 hypotheses.

1. Introduction

Road construction and maintenance represent the largest consumer of aggregates in France: some 200 million tonnes per year, composed essentially of alluvial and hard sedimentary and igneous rocks (UNPG, 2005). Opening and operating new quarries creates and may cause environmental damage, which makes them increasingly difficult to gain approval by the population.

In France's northern and eastern regions as well as in some foreign countries where the iron extraction industry has developed, blast furnace slag (BFS) has been used for a long time as an alternative material for road construction (OFRIR, 2008; Alexandre and Sebileau, 1998). The iron industry is able to generate two kinds of BFS, depending on the speed with the molten slag cools. Air-cooled (i.e. crystallized) BFS can be a good to very good quality aggregate (AFNOR, 1991a) with respect to road construction requirements for pavement (AFNOR, 2004) and earthworks (MELT, 2000). Quenched (i.e. vitrified) BFS displays hydraulic properties that serve to enhance road binders (AFNOR, 1991b); vitrified BFS can also be incorporated into cements (CEN, 2000). The characteristics and properties of vitrified BFS, in its use as a major road construction material in France, have been codified through a number of material standards (AFNOR, 1995a,b). For both technical and commercial reasons, the current production of BFS in France is primarily directed towards granulated BFS (François and Fantozzi, 2004).

For several years now (Hoang, 2005; Sayagh, 2007; Ventura et al., 2008a) LCPC has been designing a parametric environmental evaluation method called the elementary road modulus (ERM); this work has led to a tool developed by replicating the life cycle assessment (LCA) methodology and adapting it to road structure specificities. The purpose of ERM is to conduct global environmental evaluations (resource and energy consumption, assessment of emission releases and their environmental consequences) of road pavements as a function of materials (extraction, production, transport, properties), construction techniques (structure, consumption and discharges associated with machines), and maintenance policy. From an environmental impact perspective, ERM makes it possible to carry out comparisons between various construction techniques and/or choices of construction materials.

A beneficial use of alternative materials contributes both to reducing wastes and preserving natural resources. Moreover, the functionalities offered by ERM are particularly helpful in assessing

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the global environmental benefit of alternative material use in road construction. As regards BFS, results obtained allow measuring the sensitivity of environmental evaluation to the hypotheses of allocating environmental loads generated by their production process. Various approaches have already been proposed for the waste allocation step. On the one hand, BFS or any other useful waste can be considered as a recyclable output produced respectively by steel plants (Lee and Park, 2005) or any other production process (Finneveden et al., 2005). The open recycling loop is incorporated into the system extension method: environmental benefits induced by the substitution of natural resources for waste are subtracted from the environmental loads of waste producers (i.e. steel production for BFS). On the other hand (Buhé et al., 1997) proposed a method for allocating environmental benefits to the waste user. This article will seek to examine the variability in results for BFS recycling, by means of implementing within the ERM tool the two following extreme allocation procedures: (i) BFS is considered as steel plant waste, in which case no steel plant environmental flows are allocated to BFS (hypothesis H1) and (ii) BFS is considered as steel plant co-product, in which case 20% of the steel plant environmental flows are allocated to BFS based on the BFS/steel mass ratio (hypothesis H2).

The objective of this article therefore is to present the environmental evaluation of a flexible bituminous pavement built with granulated BFS (used as a binder in the base layer), along with a classical rigid pavement that includes steel bars (i.e. a reinforced concrete pavement). These products are referenced to a very classical bituminous flexible pavement using natural materials.

After presenting the ERM methodology based on LCA, this article will discuss the three under study as well as the calculation hypotheses. Assessment results will then be provided and commented.

2. LCA framework of the ERM methodology

The LCA methodology requires: (i) a description of the functional unit used as the basis for comparison, (ii) identification of environmental system boundaries, (iii) a list of the environmental data sources, and (iv) the choice of impact categories and indicators. All of these items will be described below as part of the ERM model constitutive framework.

2.1. System boundaries

The environmental system has been diagrammed in Fig. 1. The following processes are included within the environmental system boundaries: (i) manufacturing processes of main materials (crude oil extraction and refining plant for bitumen, cement plant, lime kiln, iron ore extraction, quarry for aggregates, steel plant and BFS conditioning process); (ii) material transports and road works equipment; (iii) mixing processes (cement and asphalt concrete plants); and (iv) road works processes (milling, paving and rolling).

A number of other processes have not been included in this system because of the assumption that they do not directly influence pavement structure comparison (i.e. such processes are presumed to be identical for each of the studied cases); these include: (i) energy production processes; (ii) buildings and all equipments used by staff; (iii) road-related safety and signaling equipment; and (iv) typical road maintenance operations (e.g. trench digging, de-icing, tree cutting).

Moreover, other processes have been excluded from the system since no reliable information could be found on them, these include: (i) aqueous and solid wastes storage, transports and treatments (given that the nature of wastes is not always known) and (ii) equipment production processes (i.e. factories and road works).

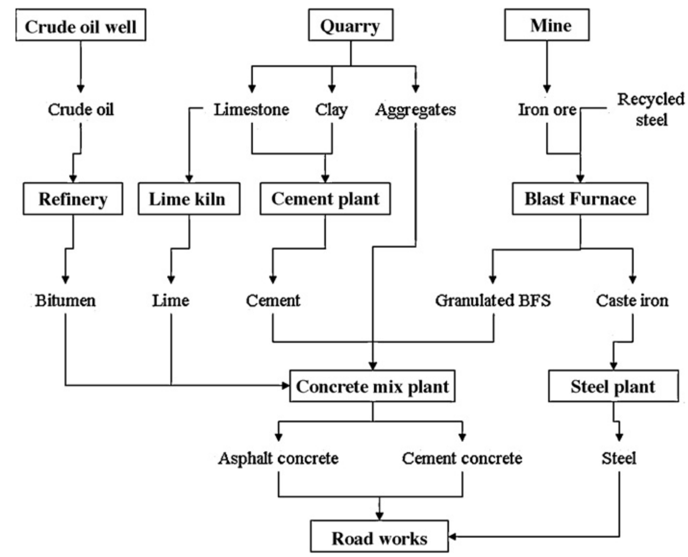

Fig. 1. Diagram of the environmental system.

2.2. Data sources

2.2.1. Used life cycle inventory (LCI) data used

Based on the selected system boundaries, a suitable dataset has been sought from the literature. Unfortunately, the author cited consider their system boundaries in accordance with their own objectives and at the scale of their particular processes, and these boundaries do not always correspond to the desired boundaries, as previously described in Fig. 1. Such differences pertain to inclusion of electrical energy production processes. In some cases, it is possible to deduct their contribution from the given data, but this is not so for all references. Furthermore, some authors consider that only generic data should be used, whereas others, (namely those in the field of civil engineering) produce local data tied to a given process.

Since the data itself is not the topic of the present paper, just a single reference has been chosen for each process. The selection procedure will be described next.

First of all, some processes have given rise to the publication of a large number of environmental reports. Generally speaking, the choice of references has been oriented towards preferring data appropriate for life cycle inventories (LCI) over environmental report data, which are not necessarily provided in a format suitable for LCI, thus requiring calculations and assumptions for their successful adaptation. Among the various LCI data sources, the preference lies with references derived from aggregate data (i.e. the average of several industrial sites and technologies). For cement production, the data used stem from averages of several environmental data aggregated from various cement manufacturing plants in UK (Lafarge, 2005). Environmental data for bitumen production stem from (Blomberg et al., 1999), steel production from (IISI, 2002), and lime production and cement concrete mixing plant from (Stripple, 2001). For steel plants (IISI, 2002) electricity production has actually been included. As for BFS conditioning processes, only one reference was found (Vares and Häkkinen, 1998).

In other cases, local LCI data have been introduced; this would be the case for aggregate production in which a typical pavement production process had been incorporated (Martaud et al., 2007). Such is also the case for asphalt mix plants (Monéron et al., 2006) where LCI data from a current hot mix process (parallel flow drying drum fed with natural gas) were used.

Lastly, some of the data are not at all available for the following production processes of additives, fibres, tacking dope, emulsifying agents, fillers, stripping and curing products, resins, etc.