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Carbon footprint of coarse aggregate in Brazilian construction

Efigênia Rossi, Almir Sales *

Department of Civil Engineering, Federal University of São Carlos, Via Washington Luís, km 235, São Carlos, SP 13565-905, Brazil

HIGHLIGHTS

- The carbon footprint was 1.50 kg CO_{2-e} per ton of coarse aggregate in Brazil.
- The stages of CO_{2-e} contribution were extraction, transport and crushing process.
- The critical stage was the crushing process because of electric power consumption.
- The diesel total consumption was 2.91E−01 kg per m^3 of coarse aggregate.
- The electric power consumption was 10.77 kW h per m^3 of coarse aggregate.

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ABSTRACT

This research measures the carbon dioxide equivalent emissions (CO_{2-e}) of the extraction, transport and crushing process of coarse aggregate in Brazil. The goal is to quantify the carbon footprint and identify the critical stages of those activities. The quantification of CO_{2-e} was determined by the emissions of carbon dioxide (CO_2), carbon monoxide (CO), nitrous oxide (N_2O), methane (CH_4) and non-methane volatile organic compound (NMVOC). The results show that the crushing process is the critical stage because of its high electric power consumption. These factors should be addressed in future Brazilian environmental studies in order to find alternative solutions prior to exploring new quarries.

1. Introduction

1.1. Background

In terms of volume used, concrete is one of the most consumed materials in the world, totalling more than one cubic meter per person per year [1]. Concrete production commonly uses aggregates, cement and water in duly adjusted proportions. These aggregates can either be sand, coarse aggregate or gravel. Specifically, coarse aggregate varies between 30% to 60% of concrete, depending on the desired compressive strength, modulus of elasticity and other properties [2,3].

These aggregates are abundant in Brazil, and their consumption in 2011 was about 3.50 ton per inhabitant—a low rate compared with developed countries. For example, the average consumption in United States is about six to seven tons per inhabitant per year [4]. Nevertheless, the aggregates sector in Brazil is growing due to high investments in infrastructure and habitation, as showed in Fig. 1.

Studies show that during the process of manufacturing cement, and consequently in concrete, that a large amount of CO_2 is emitted [5–7]. The Intergovernmental Panel on Climate Change (IPCC) "has estimated that cement and ceramic manufacture were responsible for more than 20% of the world's industrial carbon dioxide (CO_2) production" [6]. But none of these studies quantifies the carbon emission of each material used in concrete mixtures, particularly the coarse aggregate and the critical stages to obtain it.

The anthropogenic GHGs intensify the phenomenon of global warming. According to the Intergovernmental Panel on Climate Change (IPCC), 'Carbon dioxide (CO_2) is the most important anthropogenic GHG. Its annual emissions have grown between 1970 and 2004 by about 80%, from 21 to 38 Gigatonnes (Gt), and represented 77% of total anthropogenic GHG emissions in 2004' [8].

Carbon footprint is defined as 'a measure of the climate change impact of the product where all the greenhouse gas emissions emitted during the product life cycle are taken into account' [9]. This total amount of other GHG is calculated by carbon dioxide equivalent emissions (CO_{2-e}) to establish an equal dimensional unit.

The life cycle incorporates product and process analyses before they can be dismissed or treated linearly from an environmental

* Corresponding author. Tel.: +55 16 33518659; fax: +55 16 33518262.
E-mail address: almir@ufscar.br (A. Sales).

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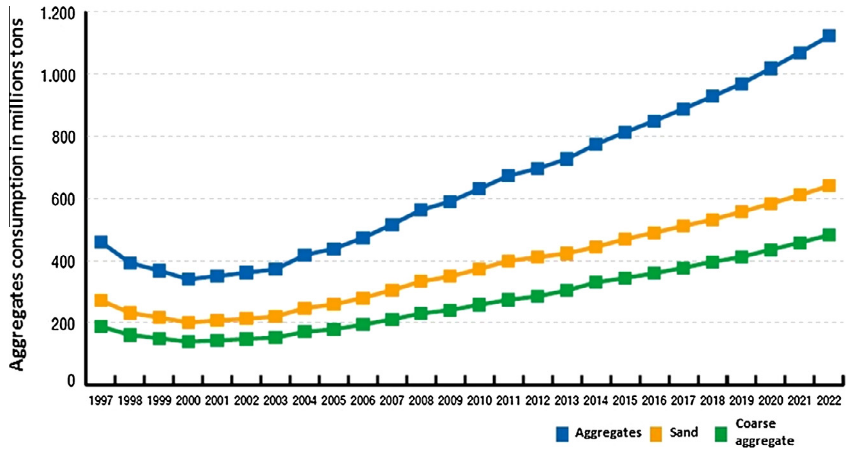

Fig. 1. Aggregates consumption in Brazil, in millions of tons [4].

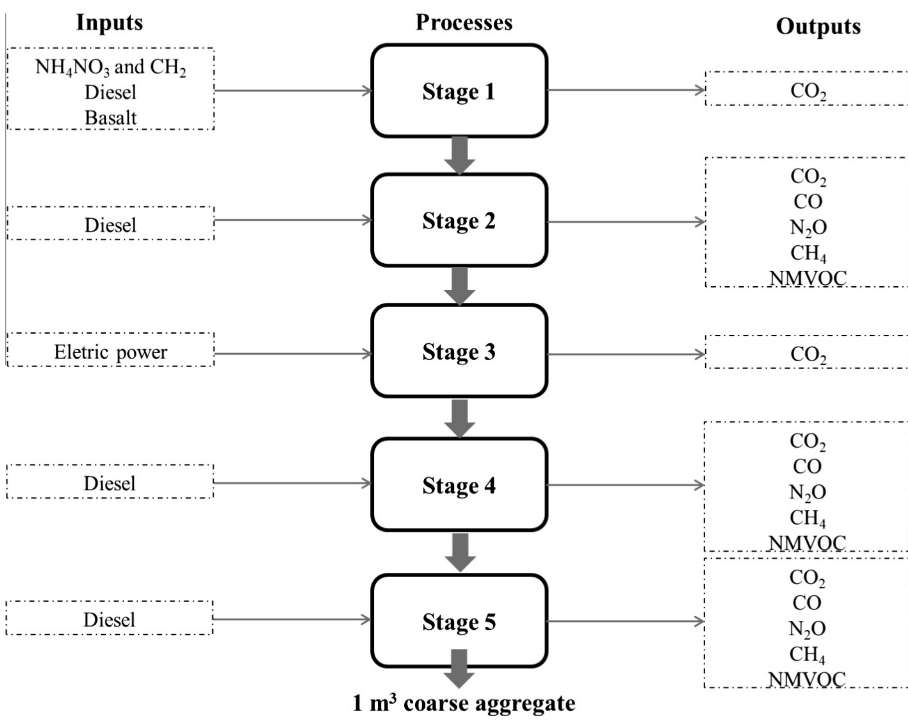

Fig. 2. System boundary.

perspective. In this view, production is seen as an end but also as an essential part of the product composition and must therefore be consistent with the earlier stages of extraction and subsequent final disposal [10]. The life cycle in this study is a product system from a cradle-to-gate view, considering since the extraction to the manufacturing process. But there are other ways such as cradle to cradle, considering the recycling in the manufacturing process and cradle to grave, analysing since the extraction of raw materials until the final disposal.

Some studies have been done to quantify the environmental impact of using concrete. A Life-Cycle Carbon dioxide ($LCCO_2$) method was used to quantify emissions in different types of concretes used in civil construction [11]. The life cycle inventory of a road must include the construction, operation and final disposal [12]. The Life Cycle Assessment (LCA) could include the results of different building materials [13]. The CO_2 emissions could also be quantified as factors applied in various materials [14]. However,

Table 1
GWP factors related to diesel.

Substance	g substance/L diesel [15]
CH_4	0.182
CO_2	2799.000
CO	60.500
NMVOC	14.720
N_2O	0.022

Table 2
GWP in kg CO_2.

Substance	kg CO_{2-e}/kg substance [10]
CH_4	4.00E−02
CO_2	1.00E+00
CO	5.00E−01
NMVOC	6.67E−01
N_2O	3.13E−03