Assessment of CO_2 Emission in the Soil–Cement Brick Industry: A Case Study in Southwest Paraná

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Abstract This article discusses a case study about the analysis of greenhouse gases (GHGs) emissions into a soil–cement brick industry in southwest Parana. A literature review was carried out on the relevant themes, carbon footprint calculation methods, technologies to reduce emissions and perceived benefits for the sustainability of the planet. The case study analyzed the whole process of manufacturing and the supply chain, collecting data for the assessment of GHG emissions. It used the GHG Protocol (Greenhouse Gas Protocol) tool to know how much would be the total of CO_2 emitted by the brick industry studied. It also addressed technological measures that can be adopted to contribute to the reduction of these emissions. In response, specifically to the production method of the evaluated industry and considering the current geographical conditions, the process generates a total of 2.16 tons of carbon dioxide (CO_2) per month. Based on the study details, it was evident the importance of the geographical location of the property in relation to suppliers of raw materials to reduce the impact that is currently caused.

Keywords Carbon footprint · Green production · Sustainability · Ecological brick · Soil–cement brick

1 Introduction

To reduce environmental impact, sustainable attitudes are seen as a priority. Less aggressive products derived from green production gain relevance. Green production is the application of environmental and socially sensitive practices to reduce the negative impact of manufacturing activities and at the same time, harmonize the pursuit of economic benefits [1].

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The parameters for measuring emissions of greenhouse gases are given from the carbon footprint measurement. The carbon footprint is a measure of the exclusive total amount of carbon dioxide which is directly or indirectly caused by an activity, or emissions driven through the stages of a product's life [2].

According to The Ministry of Environment [3], the Brazilian government is committed to reducing emissions of gases into the atmosphere when formulating its Intended Nationally Determined Contribution (INDC) in the Paris Agreement in 2016. On that occasion, it proposed to reduce gas emissions in the country by 43% by the year 2030.

This study fits as a contribution focused on sustainability and the environment. Sustainability means meeting our own needs without compromising the ability of future generations to meet their needs [4].

In India, was observed that the soil–cement brick is the most efficient material of the alternative for walls, consuming only a quarter of the energy of burnt clay brick [5]. The production of ceramic bricks in the conventional method of production with the burning, consumes 1.4 m^3 of wood to curing a thousand bricks units with temperatures in the range of 750 to 900 °C during 18 h [6]. The production process of soil–cement bricks does not require burning in furnaces; therefore, it does not burn firewood and consequently reduces the emission of gases into the atmosphere [7].

In Brazil, the soil–cement brick is popularly known as ecological brick, which is produced by compacting a mixture of sandy soil (material which is above the level of water sources and that does not degrade springs and adjacent regions) and 12.5% of cement [7]. These bricks are produced by pressing and do not require subsequent burning, therefore they are called "green bricks" [8].

In this scenario, the purpose of this article is to analyze the total emission of carbon dioxide in the manufacturing process of soil–cement bricks. So, how much would be the total CO_2 emitted by a soil–cement brick industry? Based on the results, what technological measures can be adopted to contribute to the reduction of these emissions?

To deepen the theme and better support this analysis, a methodological procedure of content analysis was adopted by identifying and using relevant tools with parameters already certified by the literature.

2 Methodological Procedures

2.1 Procedures for Selecting Articles from the Bibliographic Portfolio

The articles in the references of this research were selected according to the procedure and the methodological rigor of the Fast Systematic Literature Review (FSLR). The FSLR aims to optimize the traditional Systematic Literature Review (SLR) by simplifying tasks necessary for the implementation of the research, allowing better focus on the content without losing quality considering a shorter period of time [9].

The search was restricted to assess only articles because they are classified by the authors as more reliable information materials. All documents specified in the English language and published between 2009 and 2019, only indexed in the Scopus database. The search keywords included the Operations Management knowledge area, with a bias in the use of technologies to reduce CO_2 emissions.

At first, in the FSLR four search terms were developed: Carbon Footprint Methods and Sustainable Operations, Carbon Footprint Methods and Sustainability, Carbon Footprint Methods and Operations Management, and finally, Carbon Footprint Methods and Green Production. Thus, a set of 486 articles were formed with these combinations.

The 486 items were entered into the repository Mendeley, however, as the search was considered an extensive to analysis, a sample was defined by statistical calculation, considering margin of 95% confidence with an error margin of 5%, resulting in 215 articles to adhesion test. With the titles whether or not aligned to the theme, the next filter considered for the adhesion test was reading the summaries. Selecting the articles, another portfolio was created in sequence with the agreement of the keywords. After the adherence test, it came to the number of 37 items perfectly aligned to the theme. Finally, it was verified the documents that made the contents available in full to enable qualitative analyzes. Two of them were not located in full, ending with the number of 35 articles in that study.

3 Content Analysis

With the content analysis, the selected articles undergo approaches, called lenses. Specific lenses were adapted on the subject, to filter out only those considered relevant by the authors, meeting the objectives of this research. To the extent that the information obtained it is confronted with existing information, you can reach broad generalizations, which makes the content analysis one of the most important tools for the analysis of mass communications [10].

Content analysis is the set of communications analysis techniques aimed at obtaining, by systematic and objective procedures for describing the content of messages, indicators (quantitative or not) that allow the inference of knowledge relating to production/reception conditions (inferred variables) of these messages. As shown in Fig. 1, it is possible to visualize the sequence of the procedures adopted

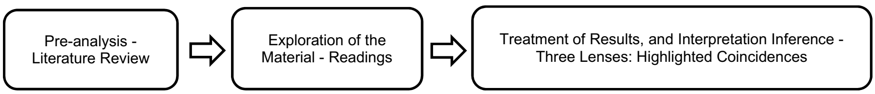

Fig. 1 Content analysis steps—prepared by the authors (adapted from Bardin, 2016)

for the result in three lenses with coincident connections [11].

3.1 Lens 01: Carbon Footprint Calculation Methods

Some tools are already considered relevant among the various methods of calculating the carbon footprint. In the research, many articles were noticed using The Compound method based on Financial Accounts (MC3) developed around the year 2000 by Juan Luis Doménech, who initially designed a tool to assess the ecological and carbon footprint of organizations. Currently, the MC3 is recognized by the Spanish Observatory for Sustainability (SOS) as a valid methodology to assess and reduce GHG emissions [12].

In addition to ISO 14,064–1/2006 established by the International Organization for Standardization (ISO), the approach to GHG Protocol also stands out with its methodology. The GHG Protocol is the most respectable guidance for assessments of greenhouse gases [13]. This tool was developed by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) in 2004. Noting several inferences, the authors have chosen to use the spreadsheet method GHG Protocol in evaluating the case study of this article.

3.2 Lens 02: Technologies for Emissions Reduction

Clean technology should be understood as a tool for eliminating pollution through lower impact production, which involves reducing pollution at its source by replacing inputs, in addition to recycling in the process or creating radically new production processes [14].

Metrics for sustainability refines to collect data covering the environmental, economic, and social dimensions of industries. As in a two-way street, the industry also gains by identifying improvements to more sustainable management. New techniques, technologies, and new products emerge. As an example, the photovoltaic power generation expanding. In the same direction, the SUB-RAW index aims to compare materials performance for the replacement of raw materials by reusable materials, focusing on more viable solutions due to the depletion of finite resources [15].

3.3 Lens 03: Perceived Benefits for Sustainability

The carbon footprint is one of the indicators that contribute to the quantification metrics, in order to assess the damage by CO_2, reduce or eliminate them. Along the same lines, there is the preservation of the chemical footprint, water footprint, soil, biodiversity, social footprints, economic, ecological footprint, among many others [16].

In common among the various articles, we could see the highlight for the Life Cycle Assessment (LCA) of the products. LCA is a way to quantify the environmental impacts of a process or product by examining all stages of production, distribution, use, and recycling destination. The results can be used to improve the designs of these products that have less impact on the environment [17]. LCA is conventionally characterized by the approach "cradle-to-grave" [16].

The intentions found in the articles analyzed are in alignment with the theme of this study, with good works for the common good of humanity and the entire ecosystem. The use of renewable and fewer corrosive sources is combined with the desire for an ever deeper awareness of preservation.

4 Case Study

4.1 Analysis of the Production Process of Soil–Cement Bricks

Company and Product

The organization object of the study is a soil–cement brick industry. The company has its own headquarters and a factory area of approximately 350m^2, situated in the city of Palmas, in the state of Parana. They started in the brick production industry in 2005 with only family members. The industry was not satisfied with the conventional method of brick production, so they developed some machines according to their needs to achieve better quality.

One-third of the gas that causes global warming is associated with construction [18]. This type of sustainable bricks assists in preserving the environment by not being burned and generate less waste in the constructions [19]. It also argues, the walls are not broken for electrical and plumbing installations, do not use wood to build columns and dispense the coating and mass for laying the bricks.

Production Characteristics

The main features of the soil–cement brick production system are linked to high volume with high repeatability and low diversity, providing well-defined parts, standardized and low unit cost.

Production Physical Arrangement

In the case studied, it was found a production physical arrangement by product, also known as in-line production, where the soil and cement pass through the sequence of processes in which the machinery and equipment were arranged physically. As shown in Fig. 2, it is a production line with two employees performing activities in the mixing and compaction sector.

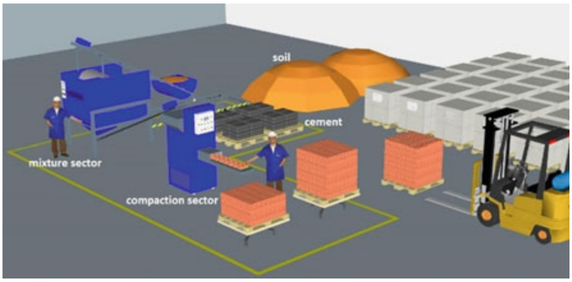

Fig. 2 Layout of production—prepared by the authors (adapted from Alroma, 2019)

For purposes of the calculation of CO_2 emissions, the two employees reside in a neighborhood in the host city, at a distance of 4.7 km of the company and they commute to work every day on their motorcycles.

Economical Order Quantity—Soil and Cement

At the Economical Order Quantity (EOQ) inventory levels of raw materials are based on production capacity [20]. The data are analyzed and the number of raw materials to be requested at the point of lowest stock level is calculated. In the study of a related case, the production line with an automatic compression press has nine seconds uninterrupted cycles, which provides an average production of 3,000 units per day on a working day of eight hours, already discounting the cleaning times of the equipment. Currently, the company produces the model measures the 250 × 125 × 70 cm (L × W × H) with a weight of 3.2 kg each in a proportion of eight parts of soil to one of cement (12.5%).

According to the company, preferably working with materials recently extracted impacts directly in the quality and strength of the final product. Therefore, special attention should be paid on the purchase of the soil, as shown in Fig. 3, with weekly supplies in a constant replenishment of raw material. With the data obtained, it can measure the monthly amount of raw material consumed and units produced. When considering a production of 40 h a week, in a month of 20 days, it obtained a

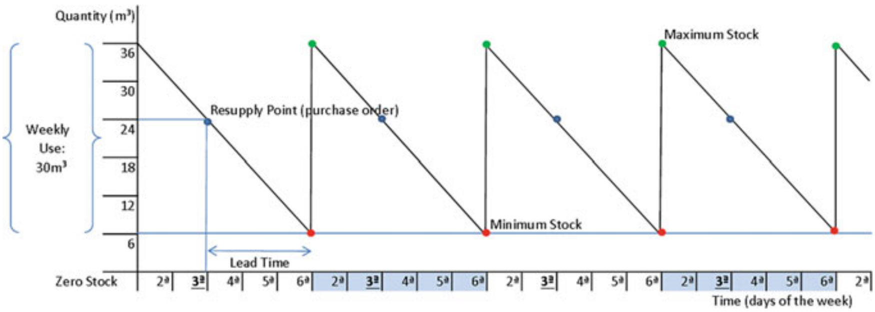

Fig. 3 Economical order quantity (EOQ) of soil (by the authors)

production of 60,000 units monthly. The delivery time of the raw material (soil) for each charge it is 3 days.

The sandy soil is from a mine extraction of sand from the city of União da Vitória - Paraná, whose supplier is 132 km from the headquarters of the brick factory. The sandy soil is transported by the extraction company, which owns a dump truck. This moves exclusively $30m^3$ loaded with material to Palmas-PR, returning empty by the same path.

The cement used by the company is of the Portland CPV-ARI type, it has the characteristic of high initial resistance and reaches 66% of its strength on the third day [21]. According to the company, even though the cement is valid for ninety days, the more recent its manufacturing date, the better the results obtained in the final product. Therefore, it is suggested lots of purchases in moderate quantities and carried out more frequently. For cement EOQ, the delivery time of product is three workdays.

In this case, it was not considered the amount of consumption as a metric reference to the minimum inventory, but the division of consumption to fortnightly purchases, according to Fig. 4. All this, taking into account the empirical knowledge of the company studied on the advantage of using newly produced cement. The EOQ's graphics allow analyzing and better understand the dynamics of the company to purchase supply, therefore facilitate the measurement of transport costs and its GHG emissions.

Two hundred and forty bags of cement are transported by truck from the city of the supplier Curitiba-PR to Palmas-PR with a total distance of 401 km. This service is performed via third-party freight in the freight-return mode (does not return), therefore, it is not considered double the mileage for the calculation of CO_2 emission.

Production Process

Its production process fits in the production batches, where the inputs go through the same sequence of machines and equipment resulting in standardized parts.

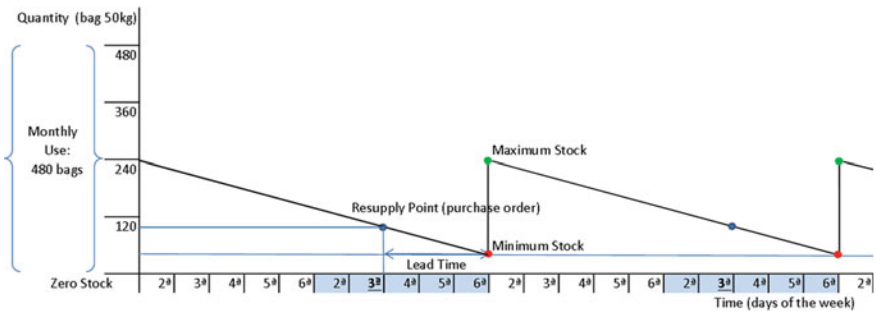

Fig. 4 Purchase economic Lot Cement (by the authors)

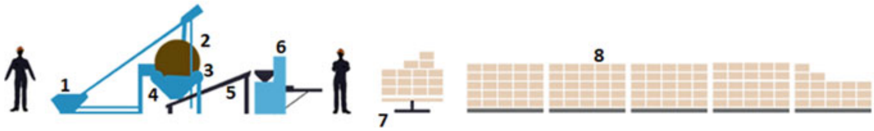

Fig. 5 Sequence of the production—prepared by the authors (adapted from Alroma, 2019)

In the process, the preparation of the raw material starts with a machine called multiprocessor. Figure 5 shows the process sequence which will be approached point-to-point. The 50 kg of cement is accommodated in the compartment called the dosing shell (1). Then the soil, in the natural conditions of extraction, is allocated over the cement in the dosing shell. This compartment has the size of a dosage of 400 kg of soil where the edge defines the level. A Clark 2 T forklift with a loader bucket attached works to fill the dosing shell (1) for one hour a day. Its operation generates a consumption of 10 L of gasoline per hour.

A geared device drives the dosing shell through rails to the top of the equipment to load the mixing cylinder (2), shown in Fig. 6, which is positioned on the top of the equipment. When the cylinder is filled, it starts to rotate slowly, while inside, a rotor axis rotates in high rotation, crushing and mixing the soil quickly with the cement.

The transfer of material from the mixing cylinder to the screening stage (3) takes place by gravity, taking advantage of the space below the cylinder through the sieve.

With vibratory and back-and-forth motions, the material reaches the storage silo (4) that is fully insulated from the wind, preventing evaporation of moisture established. The conveyor belt (5) drives the material to the press machine (6), which compresses the material with twelve tons by the hydraulic system as illustrated in Fig. 7.

According to the company studied, compact parts with high humidity makes it possible to achieve better quality levels of the final product. As the soil of the deposit comes naturally with a considerably high degree of moisture, the ideal humidity settings for the pressing vary with the addition of 1 to 10 L of water per batch, only when necessary. The company has no record of how much water it consumes because it uses only water collected from rainfall and natural sources.

An air compressor model 10 ft/100 L and it is required to drive the press and a command for cleaning the bricks when removed from the press. The bricks are then

Fig. 6 Mixing cylinder (ALROMA, 2019)

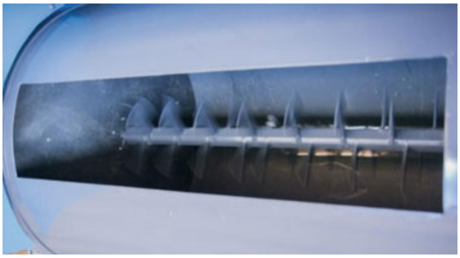

Fig. 7 Automatic press (ALROMA, 2019)

conducted on the pallet and positioned on a rotating table (7) with the appropriate ergonomic working height. The finished pallet is packed and accommodated in a large space (8) for healing. They rest for three days in the shadow. At that stage, the forklift is used for an average of one hour per day for accommodation and handling pallets in stock. According to the company studied, the high degree of moisture in the mixture is retained on the packaged pallet, which ensures sufficient moisture to cure the cement. Cement takes 28 days for full cure, however the third day the bricks are already sufficient strength for transport [21].

It was recorded the need for 30 min of the forklift to load 10 pallets (5,000 bricks) in the transport truck. This freight for the delivery of bricks, it is always hired by the client of the city/destination. Therefore, it was found that the product cycle for the industry encloses with the forklift loading onto the truck.

Since the production does not make dust, does not generate noise, waste or effluent, this type of plant does not require the state environmental license, being sufficient to Exemption from State Environmental License (abbreviation in Portuguese—DLAE) a legitimately accepted document in Paraná under Resolution No 51/2009/SEMA [22].

The process has a constant quality control, based on a sample of every 500 units produced. A total of 10 samples close the batch, so 5,000 units per batch (one load). These samples undergo resistance tests and water absorption, according to the procedures of the Brazilian Association of Technical Standards (ABNT), assessing the quality of that particular batch in accordance with the technical standards NBR 8491 and NBR 8492 [23, 24].

To measure the energy consumption the time of each activity and its power consumption (kWh) were measured, but it was found that the engines are not active full-time, switching operation by the operators several and indefinite times with each batch. Thus, the amount considered was 800 kWh/month for the calculation of emissions, projected on the average energy consumption history of the twelve-month payment invoices preceding the study. In this way, it included all the company

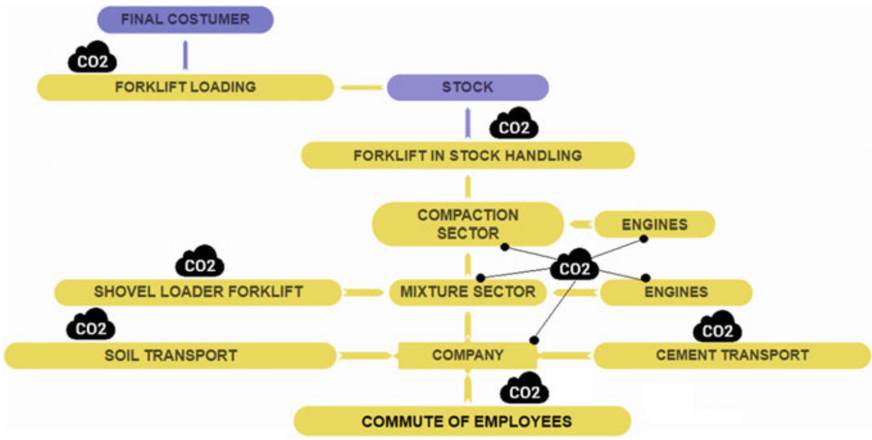

Fig. 8 CO_2 emission points (by the authors)

energy costs, such as lighting, computers, among other sporadic tools and electronic devices.

Carbon Footprint Calculation

Figure 8 illustrates the points found by the authors with CO_2 emissions. Each point was approached individually generating in Table 1 the main reference data for use in calculating the carbon footprint.

To process the data in Table 1, these were entered into the spreadsheet GHG Protocol, an open methodology tool for analysis of GHG emissions. The specifications of the GHG Protocol were adapted to the particularities and conditions of Brazilian organizations by developers. This tool was created by the WBCSD and WRI in 2004 and allowed to ascertain the results shown in Table 2.

5 Discussion of Results

The location of the factory, for being distant from the main suppliers of raw materials, it has a considerable impact on the level of emissions. Especially for soil transportation which contributes 35% of the total CO_2 issued monthly. That said, it is pertinent to study the possibility of a new geographical position of the factory, for the reduction in emissions and, consequently, production costs.

The soil–cement bricks can be made from Construction and Demolition Waste (CDW) [25]. Given the possibility of producing soil–cement bricks with CDW, besides eliminating the cost of raw material (soil) the industry activity would reduce 0.75 ton/month of CO_2 in the atmosphere. There is the possibility for an analysis of the implementation of a collection and processing unit for CDW in the host city.

Table 1 Footprint metric of points (by the authors)

Soil transport				
No. Loads	Distance	Displacements along the route/Load	Total km/Trip	Total km/Month
4	132	2	264	1056
Cement transport				
No. Loads	Distance	Displacements along the route/Load	Total km/Trip	Total km/Month
2	401	1	401	802
Commute of employees				
No. Employees	Distance	Displacements along the route/Day	Total km/Day	Total km/Month
2	4.7	4	37.6	752
Forklift shovel loader				
Hours/Day	Liters/Hour	Days/Month	Liters/Month	
1	10	20	200	
Forklift in stock handling				
Hours/Day	Liters/Hour	Days/Month	Liters/Month	
1	10	20	200	
Forklift loading				
Hours/Load	Liters/Hour	Loads/Month	Liters/Month	
0.5	10	12	60	
Electricity				
KWh/Month				
800				

Table 2 Result GHG protocol (by the authors)

GHG emission factor	Source emission	Unit of measurement	Consumption/Month	Total CO_2 (Ton/Month)
Soil transport	Diesel	liters	310.59	0.75
Cement transport	Diesel	liters	235.88	0.58
Commute of employees	Gasoline	liters	20.22	0.03
Forklift shovel loader	Gasoline	liters	200	0.32
Forklift in stock handling	Gasoline	liters	200	0.32
Forklift loading	Gasoline	liters	60	0.10
Electricity	Electricity	Kwh/Month	800	0.05
Total CO_2 (Ton/Month)				2.16

Despite electricity has a little impact it is still important to study the deployment of photovoltaic panels, with the possibility of self-sufficiency in energy by eliminating other GHG emission factors.

The authors consider the production of soil–cement bricks to significantly reduce environmental impact, including in the list as a replacement product for the old burnt method. The soil–cement wall, it does not require the burning of the production process and generates carbon credits compared to the burnt ceramic bricks. Carbon Credit is an electronic certificate issued when there is a proven reduction of greenhouse gases released into the atmosphere by industries [26].

The study has a local contribution and at the same time a global contribution, emphasizing the importance of measuring an organization's aggressive impacts. It thus makes it possible to encourage any company to create documents for new strategic visions, to reduce costs, to improve processes and, above all, to contribute to the sustainability of our planet.

6 Proposals for Future Studies

- Location feasibility study to reposition of the company in the city of União da Vitória-PR.
- Economic feasibility analysis of the implementation of a CDW processing plant in the city of Palmas-PR.
- Analysis of the economic feasibility of installing solar panels for clean energy generation in the studied industry.
- Study of proof of CO_2 reduction for certification of carbon credits generation in the soil–cement brick industry.

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