Life Cycle Assessment: Environmental Impacts Assessment of a Social Interest Housing Walls System

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Abstract

Considering the importance of civil construction and its environmental impacts, this article aims to quantify and evaluate the environmental impacts of the walls system of a social housing unit located in Brazil, based on the Life Cycle Assessment. The scope adopted refers to the stages of extraction of raw material, production of materials and transports to the building site with a functional unit of square meter of built area. Life cycle impact assessment step was performed using OpenLCA 1.9 software and Ecoinvent database version 3.6 with the cut-off system model and Market processes. Results were analyzed in three stages. The first referring to impacts of each component in relation to its subsystem: sealing masonry, framing and coatings. The second stage included results of each subsystem and its contribution to total result of impacts. Finally, total values of environmental impacts of the walls system were obtained.

Keywords: Life Cycle Assessment; Environmental Impacts; Social Interest Housing; Walls System.

1. Introduction

The pursuit for sustainable development in civil construction stimulates impacts management and evaluation resulting from production processes and materials used in building systems. In this way, discussions regarding the environmental impacts generated and alternatives to mitigate them grow.

According to Cabeza et al. (2014), any construction project will result in some impact on the environment. Thus, according to Agopyan and John (2011), building systems and their components may have positive or negative influence on the impacts generated by the building and, consequently, on the environment in which it is inserted. Therefore, the importance of the construction industry for the environment is remarkable. Global emissions of greenhouse gases, consumption of natural resources, energy consumption and waste generation are among the main impacts caused by this sector (CNI, 2017).

Regarding the issues of Brazilian housing deficit, civil construction sector stands out in relation to public housing policies. The importance of expanding social housing is noticeable, since a substantial part of the population living in Brazil is low income and needs public housing, or incentives from programs of this sort. However, in the current context, social housing is associated with lower-cost construction, in which architectural projects often disregard factors related to sustainability (MONTES, 2016).

According to Moraga et al. (2017), there is an increase on interest in researching environmental impacts generated by public housing construction activities. This is a sector that deserves further studies, since it contributes to housing development and materializes on a large scale. Montes (2018) highlights the influence of the decisions taken in the design phase of these projects, as they affect the entire building life cycle and, recognizing that buildings generally have a long useful life, these impacts affect the environment and buildings' users in the long run.

Regarding the environmental impact assessment of a building, the Life Cycle Assessment (LCA) becomes a tool capable of helping to understand the impacts generated and their quantification. LCA adopts a comprehensive and systemic approach to elaborate the environmental assessment. Thus, it is possible to identify an increase in interest in incorporating LCA analysis to evaluate methods for construction and decision making in the selection of environmentally preferable products, as well as to evaluate and optimize construction processes (MORAGA et al., 2016).

Regarding the construction systems of a house, Sposto and Paulsen (2014) affirm that the walls system participates in an expressive way in the total mass of a building, hence having great potential for reducing the energy consumed and consequently emissions of CO2 from this building in the construction phase. Caldas et al. (2017) point to the need of environmental analysis to assist in the election of building wall systems with a low carbon footprint. Since in their studies the authors proved that masonry represents more than 70% of the total mass of a residential building in Brazil, being responsible for a large part of the CO2 emissions generated during its manufacturing processes.

In this context, understanding the importance of constructive systems in generating environmental impacts of a building, the present research aims to quantify and evaluate the environmental impacts of the walls system of a social housing. To this end, this article brings as a case study a social housing unit of Canaã low-income housing development located in the city of Passo Fundo/RS (Brazil), evaluating its wall system consisting of masonry with ceramic blocks.

2. Literature review

Responsible for quantifying the impacts caused on the environment, Life Cycle Assessment (LCA) is a method that analyzes the entire life cycle of a product or service. This analysis is performed by: compiling an inventory, assessing inputs and outputs associated with the product and the assessment and interpretation of the environmental impacts related to these inputs and outputs (NBR ISO 14040, 2009). The tool makes it possible to analyze products and inputs to better understand their cycles and thus contribute on proposing solutions that reduce their impact on the environment. Silva et al. (2015, p.11) define the life cycle evaluation as: “Evaluation used to quantify the environmental load of a product since the elementary raw materials removal from nature that enters the production system (cradle) to the disposal of the final product (grave)".

The purpose of an LCA is to analyze the flows that come from nature and those that are directed to it, in order to mitigate the consumption of natural resources and the emissions derived from the activities performed during the processes of production, use and disposal of products (SAADE, 2017). As it is an holistic approach analysis, according to Tavares (2006), the applications of a LCA are comprehensive and results from this analysis are reliable according to the origin and transparency of the data collected.

Life Cycle Assessment is guided by NBR ISO 14,040 (2009) named “Environmental management - Life cycle assessment - Principles and structure”, and by NBR ISO 14,044 (2009) “Environmental management - Life cycle assessment - Requirements and guidelines”. NBR ISO 14,040 describes some minimum requirements, the principles and the structure to guide LCA studies. NBR ISO 14,044 embraces two types of research: life cycle assessment studies and life cycle inventory studies. This standard provides several guidelines and recommendations to ensure the transparency of the studies.

According to NBR ISO 14.040, an LCA must be structured in four stages, namely: Definition of the objective and scope; Inventory analysis; Impact assessment and results interpretation. The objective and scope stage is considered the main phase of the study, as it is at this point that the study is defined. In the LCA objective, the intended application must be described, as well as the reasons for carrying out the study (ABNT, 2009). In the scope of the LCA, the analyzed product system, the functional unit, the impact assessment methodology and the types of environmental impacts taken into account in the study, the data quality and the research limitations must be defined (SILVA et al., 2015).

The second stage of an LCA, inventory analysis, is defined by Silva et al. (2015, p.10, our translation) as: “LCA stage that involves the compilation and quantification of inputs and outputs of matter and energy over the life cycle of a product”. At this stage, the environmental impacts over the life cycle of a product are grouped, that is, the inventory is a list of product flows (Ciroth et al., 2011).

The impact assessment stage aims to provide an understanding of the significance of the environmental impacts addressed in the study throughout the product's life cycle. Finally, the results interpretation stage comprises the identification of the significant results found in the Inventory Analysis and Impact Assessment phases. Findings of this stage must be related to the objective and scope defined in the initial stages of the LCA structure (ABNT, 2009). Figure 1 shows in a schematic way the operation of an LCA.

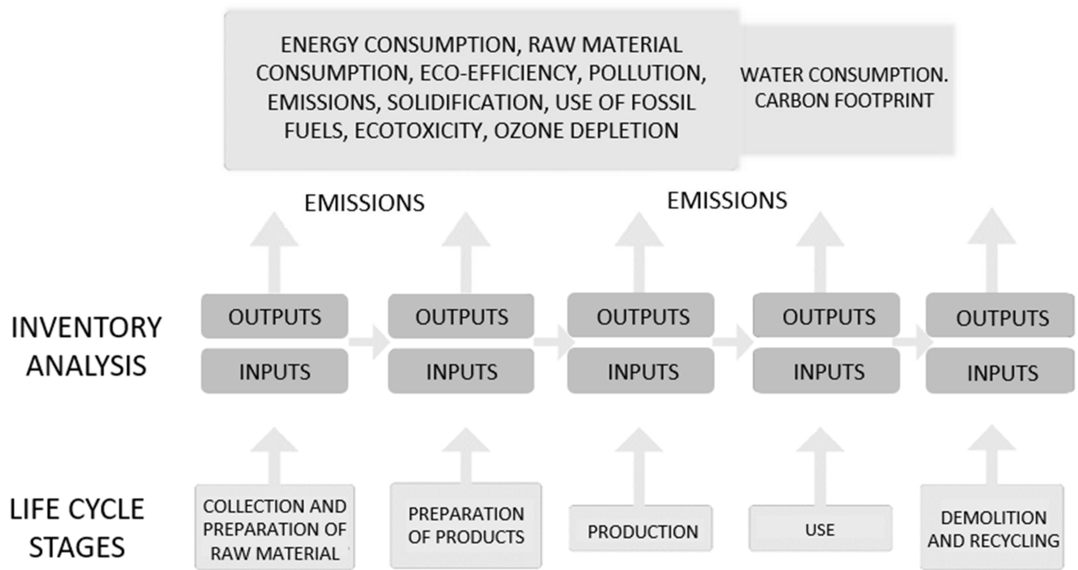

Figure 1: Schematic of an LCA.

Source: Adapted from IBICT (2015).

In civil construction sector, the use of LCA is recent. Its application in this sector is internationally known and allows several kinds of studies, such as environmental impacts assessment of construction materials or the whole building, post-operational studies and research regarding energy consumption of materials and buildings, and others. Regarding LCA applied to construction materials, Bribián et al. (2011) compare the most used building materials in civil construction and environmentally friendly materials in Spain. These authors report that the use of innovative ecological techniques can reduce the environmental impacts generated in buildings. Thus, authors warn about the importance of replacing materials that use non-renewable raw materials for environmentally friendly ones.

Petrovic et al. (2019) present a case study applying LCA in construction materials used in residential housing in Sweden, following the standards ISO 14,040, ISO 14,044 and EN 15,804. Results found demonstrate that concrete slab is the element that contributes the most to total environmental impacts of the building, whereas wood-based systems have shown to inflict lower environmental impacts. Albuquerque et al. (2018) used LCA to quantify and evaluate carbon dioxide emissions from two different mortar coating techniques, the conventional one a projected one. Their results indicate that the projected coating produces 50% lower percentage of CO_2 emissions than the conventional method.

Other studies evaluate building environmental impacts in social housing. Caldas et al. (2016) applied LCA in four building facade systems. They were able to verify that the concrete wall system had the least impacts during its processes. In addition, they analyzed the CO_2 emissions in the life cycle of two social housing units. Moraga (2017) and Braga (2018) also applied LCA in social housing. The first evaluated the impacts from a case study, covering the entire building, identifying the greatest impacts in each analyzed construction system. Braga (2018) compared different walls systems, concluding that the use of reinforced concrete system is favorable when compared to conventional wall system with ceramic blocks.

3. Methodology

In order to meet the proposed objective of this article, the Life Cycle Assessment of the walls system of a house of a social housing settlement was performed. For this purpose, for quantitative means, a case study of a housing unit (Figure 2), at Canaã Residential Housing, located in Passo Fundo/RS (Brazil), was carried out.

The housing units of the settlement cover an area of 45.19m² each. The residential settlement has 210 housing units. As they all follow the same standard design and footage, the case study of this research will focus in one housing unit.

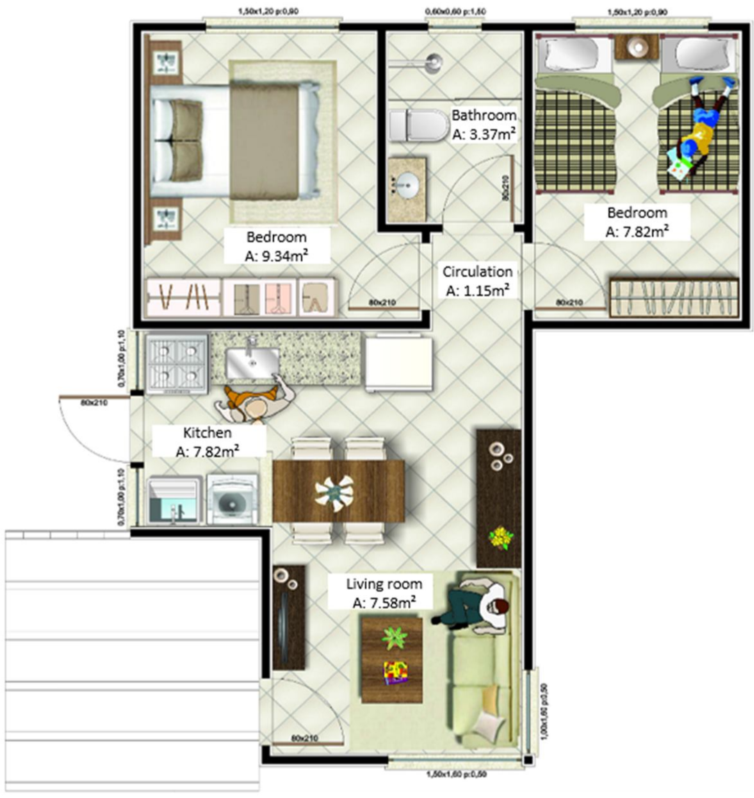

Figure 2: Blueprint design plan of a house in Canaã residential housing.

Source: Adapted from Martins et al. (2013).

The house's walls system consists of sealing masonry with ceramic blocks laid with cement mortar, lime and sand in the 1:0.5:8 mix ratio and aluminum frames. Mortar coating is composed of roughcast with 5mm thickness and plaster of a single mass with 1cm thickness. Hydraulic walls of the kitchen and bathroom were covered with tiles laid with adhesive ACI mortar.

Final coating of the external walls was made with acrylic paint and internal walls with PVA paint. As a way of delimiting the LCA, structural systems and window frames will not be considered in this study. The systems are specified in Table 1.

The method used in this research for the application of LCA is based on NBR ISO 14040 (ABNT, 2009) and NBR ISO 14044 (ABNT, 2009). The product system adopted in this study is the life cycle of the materials that make up the construction system of the housing unit already mentioned beforehand. The scope adopted meets the stages of raw material extraction, materials' production and transport to the building site.

The functional unit, according to Pedroso (2015), aims to provide references for the study of LCA. Thus, to ensure compatibility, functional units used in the construction industry are adopted. In this sector, the author indicates that the unit to be used is built area per square meter (m^2). Therefore, following these guidelines, the functional unit used in this study is built area per square meter (m^2).

The quantitative inventory of materials used is shown in Table 1. In order to obtain these quantities, data from SINAPI (2019) were used for gathering materials' specifications of Canaã housing units and data regarding material yield per m^2 were found in the manufacturers' specifications of the materials used. The specific type of paint used was not found in the database. Thus, generic material was adopted and considered for internal and external painting. To calculate painted area, areas with tile covering were discounted.

Inventory survey was carried out using secondary data available in Ecoinvent database version 3.6 and the cut-off system model with Market processes. In a simplified way, Market type data represents data related to the product transformation activities plus transportation. To assist in the organization of the inventory data, OpenLCA software was used.

All data available in Ecoinvent have a geographic location, so, at first, GLO geography data was prioritized for this study, in order to obtain results for global estimates and trends. However, some materials of the case studied are not available in this geography location (GLO) and it was necessary to combine different geographies. Thus, for data relating to mortar and painting, ROW type data were used, which in Ecoinvent represents the rest of the world.

Table 1: Building materials descriptions and quantities of the assessed system.

Building System	Materials Description	kg/m²	Area (m²)	Mass (kg)
Sealing Masonry	Ceramic blocks with 8 holes in dimensions 11.5x19x19 cm.	82.5	91	7507.5
	Mortar, cement, lime and sand. In mix ratio 1:0.5:8	15[1]	91	1365
Framing	Aluminum window 1.50 x 1.20 (2 units)	14.20	3.60	51.1
	Aluminum window 1.50 x 1.60 (1 unit)	14.20	2.40	34
	Aluminum window 1.00 x 1.60 (1 unit)	14.20	1.60	22.70
	Aluminum window 0.70 x 1.00 (2 units)	10.89	1.40	15.20
	Aluminum window 0.60 x 0.60 (1 unit)	10.89	0.36	3.90
	Aluminum door 0.80 x 2.10 (2 units)	12.00	3.36	40.3
	Flat glass 4 mm	10	9.36	93.6
Coatings	Internal and external roughcast: cement mortar and medium sand in 1:3 mix ratio	17	182	1550
	Internal and external plaster: prefabricated mortar	17	182	6188
	Tiles in 30x30 dimensions. Commercial class.	13	12.65	163.15
	Adhesive mortar ACI	5	13	65
	Internal and External Painting	0.26	169.45	44

Source: Authors.

GLO data represent activities that are considered a valid average for all countries in the world. Data with ROW geography are data sets that were calculated from an estimate of several countries, that is, it is a copy of the GLO data with uncertainties regarding the adjusted geography (ECOINVENT, 2020).

The approach using data from different geographies generates uncertainties regarding specificities of the studied location; however, because they originated from the same base and specifications, and both represented trends for the whole world, they can still be compared with each other. Despite the uncertainties generated by the difficulty of finding local bases, the results help to understand the impacts generated on the components and assess which materials have the greatest contribution regarding general impacts of the system, in a generic way. These results can also be compared in the future with new studies to be carried out when local inventories are available.

[1] According to ANICER (2012).

For the life cycle impact assessment stage, OpenLCA 1.9 Software was used to calculate the environmental impact assessment. Impact categories were evaluated and are present in the EN 15804:2012 impact method with CML baseline. This method contains indicators to be used in the description of the environmental impacts of civil construction products in accordance with EN 15804:2012. This standard establishes basic criteria for environmental declarations of civil construction products and services. It also provides rules for calculating impact assessments including indications for assessing impacts to be taken into account for studies of civil construction products. The categories of impacts analyzed are specified in Table 2.

Table 2: Environmental Impact categories evaluated according to the EN 15,804: 2012 method

Impact Category	Reference unit
ADPE: Abiotic depletion potential for non-fossil resources	kg Sb eq.
ADPF: Abiotic depletion potential for fossil resources	MJ
AP: Acidification potential of soil and water	kg SO_2 eq.
EP: Eutrophication potential	kg $(PO_4)_{3-}$ eq.
GWP: Global warming potential	kg CO_2 eq.
ODP: Depletion potential of the stratospheric ozone layer	kg CFC 11 eq.
POCP: Formation potential of tropospheric ozone	kg C_2H_4 eq.

Source: Authors

4. Results and Discussion

Using the OpenLCA Software, with the insertion of the database used, it was generated a list with the inputs and outputs of the components of the masonry system. The results obtained were analyzed in three stages. In the first stage, each component was analyzed in relation to its subsystem: sealing masonry (A), framing (B) and coverings (C) regarding the case study quantities. Outcomes obtained in the second stage include the result of each subsystem and its contribution for the total environmental impacts of the walls system. Finally, the total number of impacts of the walls system of the house under study was obtained.

The results of the seven environmental impacts categories described in EN 15804:2012 impact method with CML baseline are presented as follows. Regarding the Abiotic Depletion Potential for Fossil (ADPF) and Non-fossil (ADPE) Resources, participation in the evaluated building materials is mainly related to the production process present in them. Acidification Potential of Soil and Water (AP) is the impact related to acid rain. It occurs due to the emission of acidic pollutants, in the form of acid rain. They affect the soil and water, flora, fauna, in addition to affecting buildings (MORGA, 2017). Eutrophication Potential (EP) is the impact responsible for the excessive nutrition of ecosystems with nitrogen (N) and phosphorus (P), increasing the amount of algae in the water, reducing the available oxygen (ILCD, 2011), causing marine imbalance.

The Global Warming Potential (GWP) indicates polluting emissions that enhance global warming. These emissions are related to CO_2 gases, hydrocarbons, NO_x, etc. composing what is called CO_2-equivalent. "The equivalent carbon dioxide is the result of multiplying the tons of GHG emitted by its potential for global warming" (MINISTRY OF THE ENVIRONMENT, p.1 2012).

The Depletion Potential of the Stratospheric Ozone Layer (ODP) indicates a decrease in the ozone layer, caused by the emission of chemical gases. This layer allows protection against ultraviolet solar radiation; its decrease has effects on human health and biosphere (WMO, 2011). The presence of pollutants causes an imbalance in this layer, making it weaker and allowing harmful solar radiation to affect living beings.

Finally, Formation Potential of Tropospheric Ozone (POCP) occurs when nitrogen oxides (NO_x), carbon monoxide (CO) and other compounds, react in the atmosphere and are capable of originating ozone. Ozone is known to inflict several health effects at concentrations common in urban air mainly related to respiratory system illnesses (CCAC, 2020).

The environmental impacts incorporated in the sealing masonry components are represented in Figure 3. Analyzing the graphs, it is possible to affirm that in general, comparing the two components of the masonry system, the impacts were greater for the ceramic blocks due to its greater total mass (kg) in relation to the mortar. Regarding mortar, a large part of CO_2 emissions is related to cement production, due to clinker processes. As for ceramic blocks, emissions are concentrated in the process of burning the blocks, since, according to Crivelaro and Pinheiro (2016), the main source of energy used in this process in Brazil is firewood.

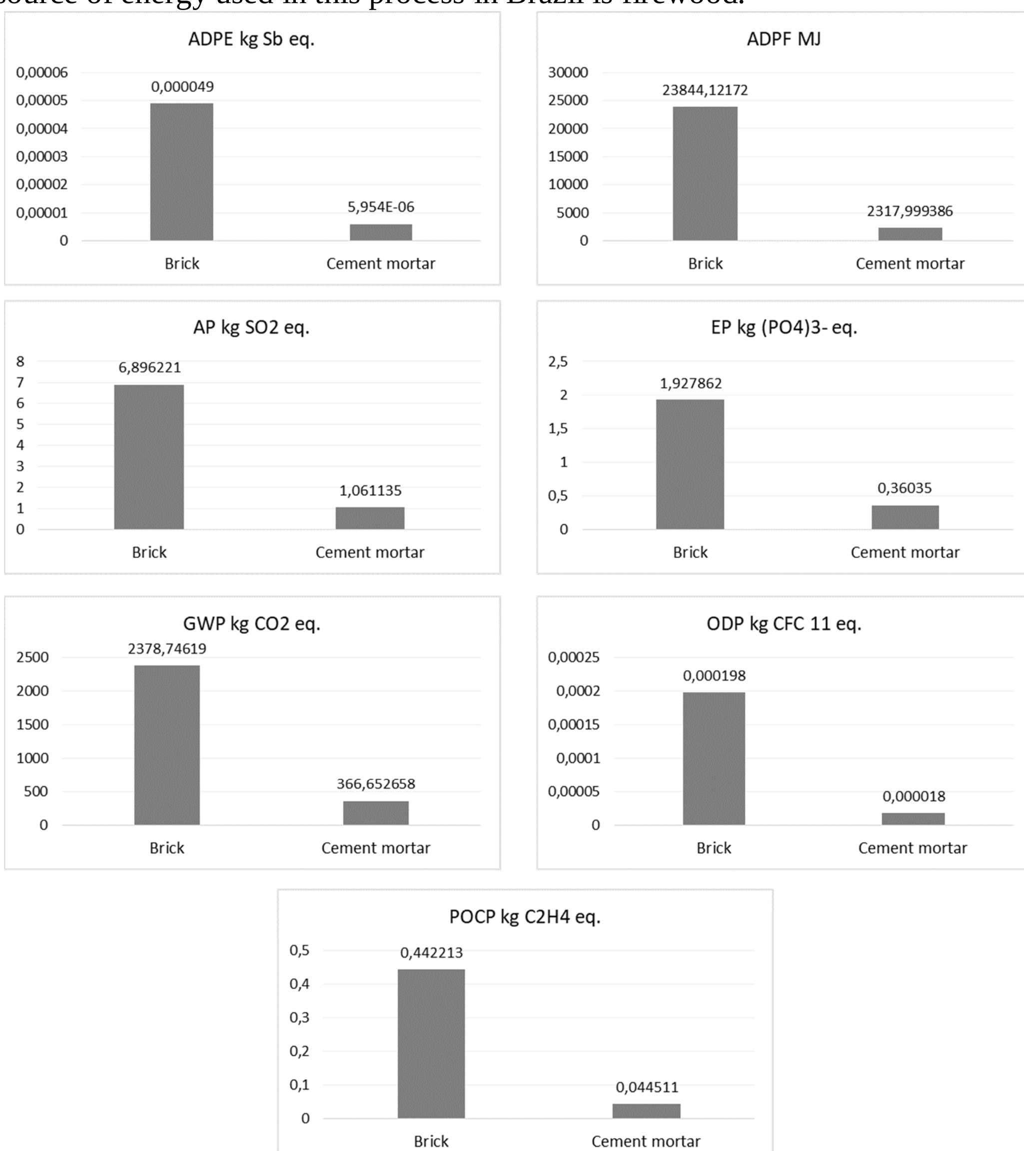

Figure 3: LCA results related to environmental impacts of sealing masonry (A).

Source: Authors.

In the framing system, aluminum windows showed the greatest impacts in all impact categories (Figure 4). According to the Brazilian Aluminum Association, the production of aluminum generates impacts from the extraction of bauxite to the transformation of aluminum, producing several polluting gases (mainly CO_2), in addition to the generation of insoluble waste during this process.

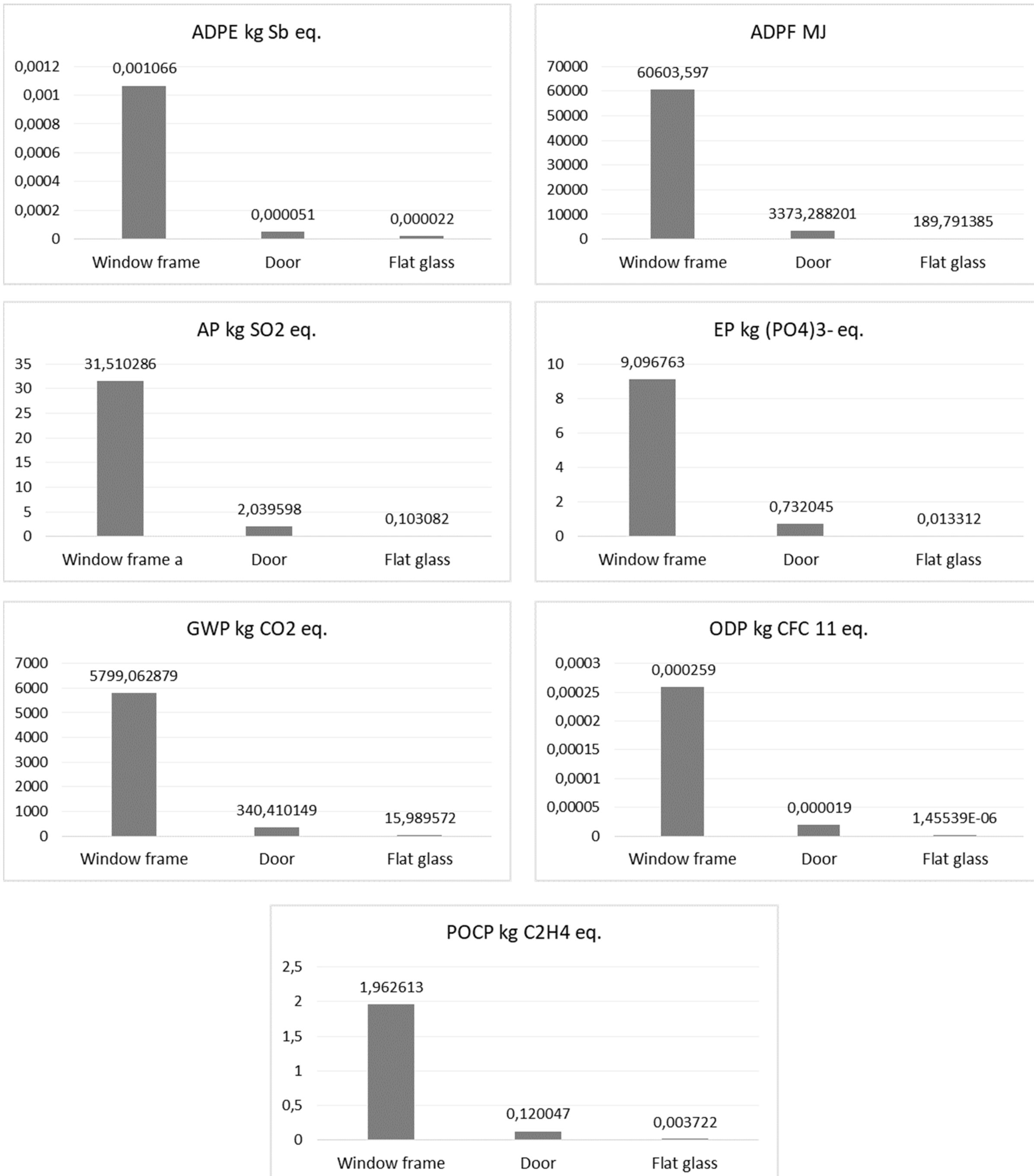

Figure 4: LCA results related to environmental impacts of framing (B).

Source: Authors.

However, no data were found that corresponded with the frames generally used in social housing in the database used (Ecoinvent). These frames tend to be simpler. Thus, similar data was adopted. Though, considered data comprises windows with elements related to thermal insulation, very common in European countries, but absent in the housing frames of this case study. This can present impactful results when referring to the Brazilian context. Figure 5 shows graphs resulting from the environmental impact assessment for the case study coating system.

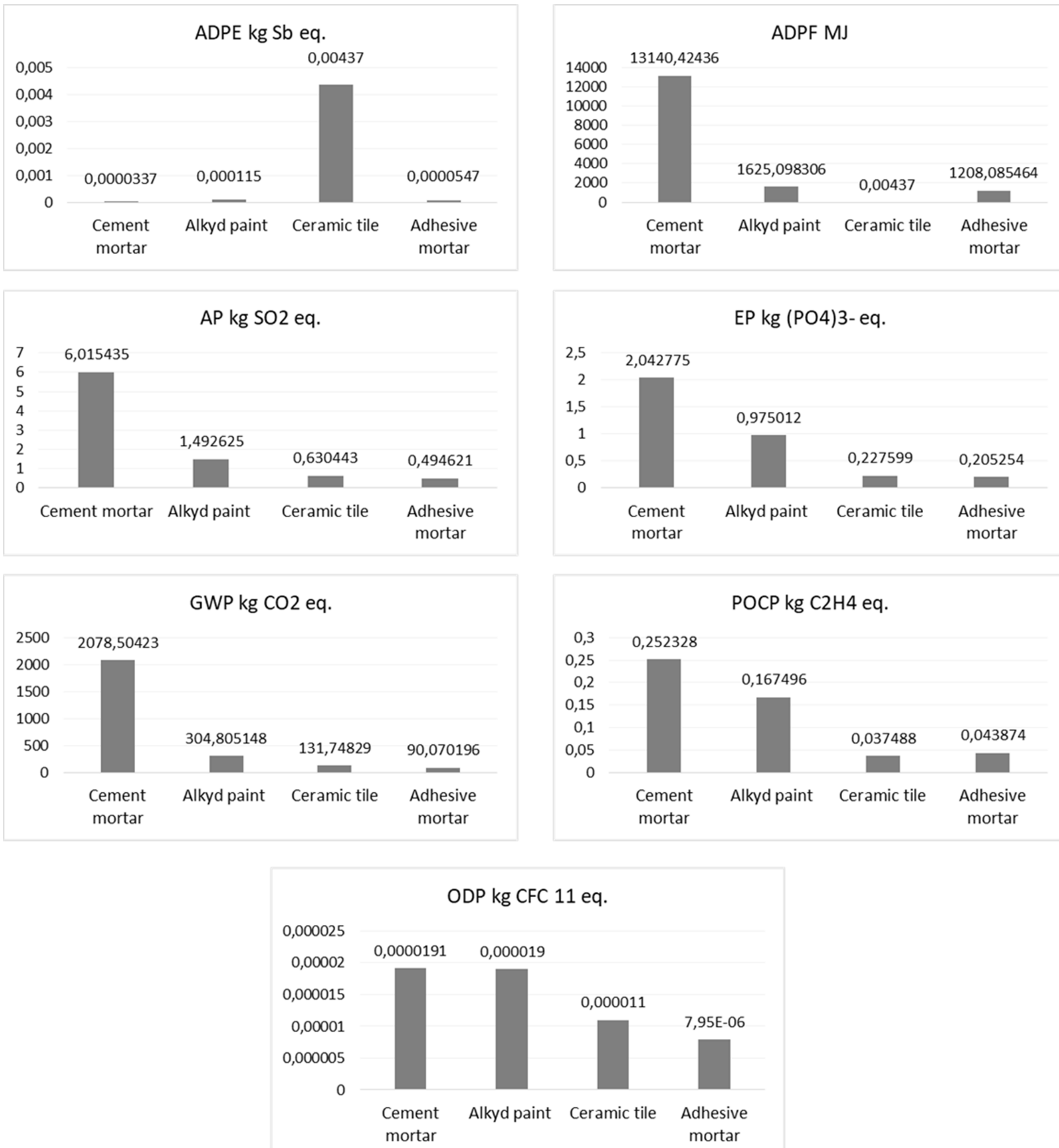

Figure 5: LCA results related to environmental impacts of coatings (C).

Source: Authors.

To quantify the environmental impacts related to the coatings subsystems, data used for mortar allocated in the roughcast and plaster was also used for mortar used in sealing masonry, due to the difficulty in finding specific data. In the Ecoinvent database, no inventories were found for the paints used in the case study, therefore, alkyd paint was adopted. Despite it is not frequently used in social buildings, it was also used, with the same purpose, in the study made by Moraga (2017).

Comparing the elements of subsystem C (Coatings), it is possible to perceive the large participation, in almost all the impact categories analyzed, of the mortar used for roughcasting and plastering in the environmental impacts. The presence of cement in this component is responsible for a large part of the impacts, since cement production processes, such as clinker, involve steps that generate many environmental impacts. The total mass that the mortar represents in this system also contributes to the greatest generation of impacts. Only in the category of impact depletion potential of non-fossil origin (ADPE) that cement did not present greater impacts in relation to the other components. In this category, the greatest impacts are embedded in ceramic tiles.

After this first simulation, the three subsystems (Sealing Masonry (A), Framing (B) and Coatings (C)) were analyzed in relation to the walls system. Figure 6 shows the distribution, in percentage, of each system for the seven impacts calculated in this article.

Analyzing the graphs in Figure 6, it is noted that subsystem B obtained the greatest contributions, except in the category of Depletion Potential of Abiotic Resources of Non-Fossil Origin (ADPE). This great contribution is linked to the large impacts generated on aluminum windows production, resulting from their thermal insulation systems. For the ADPE impact category, subsystem C presented the greatest contribution in relation to total impacts.

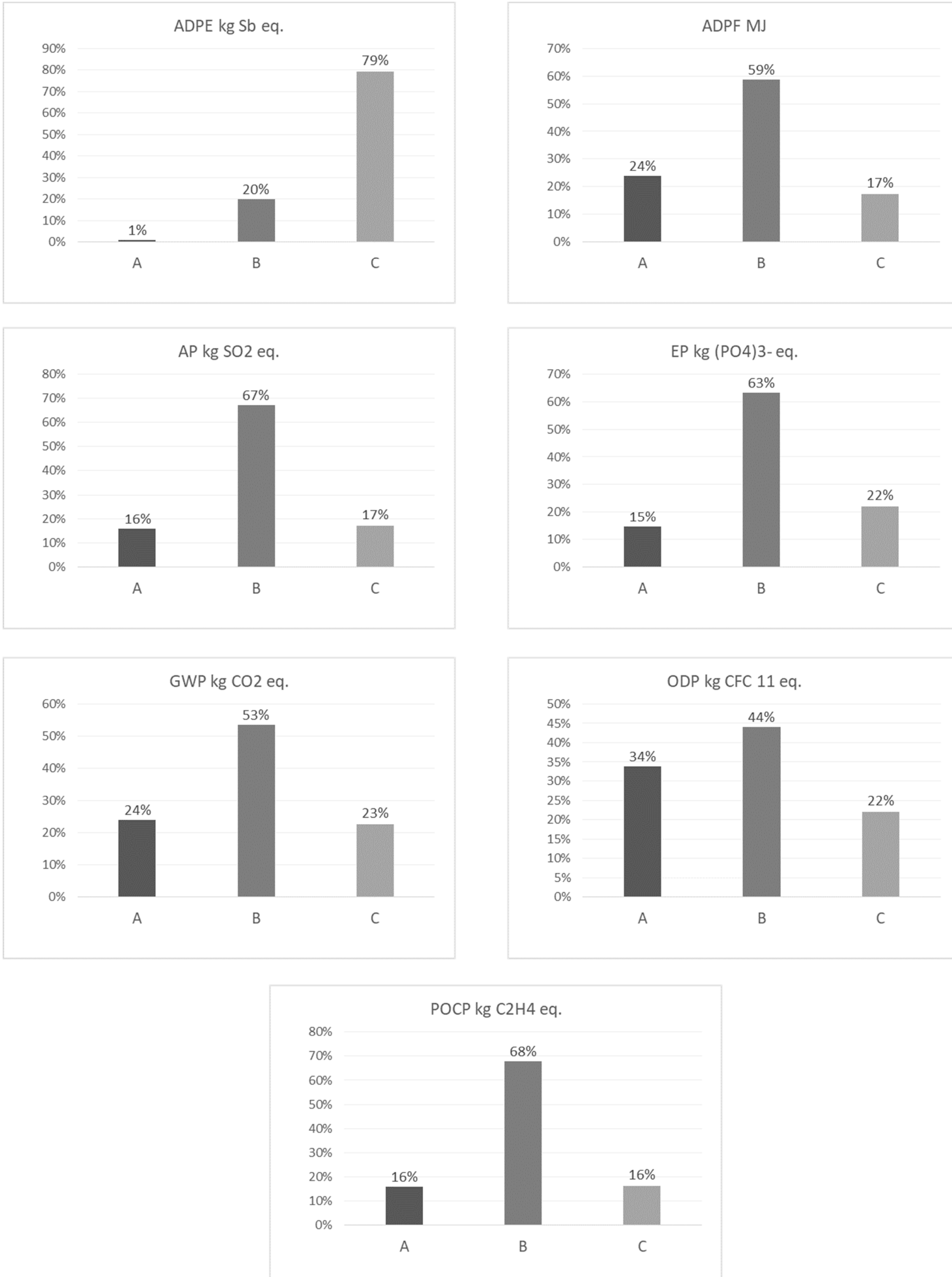

Figure 6: LCA results comparing environmental impacts of all three systems analyzed.

Label: A- Sealing Masonry B- Framing C- Coatings

Source: Authors.

Finally, it was also possible to quantify the total impacts of the walls system of the case study. Table 3 presents the results of each subsystem and the total impacts of the case study (A + B + C). From the analysis related to environmental impacts, it is possible to identify the greatest contributors and thus define strategies for their mitigation.

Table 3: Results of Environmental Impact categories evaluated according to the EN 15,804: 2012 method

Impact Category	Reference Unit	Result (A)	Result (B)	Result (C)	Total Result (A+B+C)
ADPE	kg Sb eq.	5.56402E-05	0.00114	0.004574668	0.005770387
ADPF	MJ	26162.12111	64166.68	18783.23827	109106.9415
AP	kg SO_2 eq.	7.957357205	33.65297	8.633126583	50.24111907
EP	kg $(PO_4)_{3-}$ eq.	2.28821221	9.842122	3.450641937	15.58018375
GWP	kg CO_2 eq.	2745.398849	6155.463	2605.127866	11505.18349
ODP	kg CFC 11 eq.	0.000216301	0.000281	0.000140669	0.000637821
POCP	kg C_2H_4 eq.	0.486724818	2.086383	0.501187443	3.07419735

Source: Authors

5. Conclusions

This article aimed to assess the environmental impacts of the walls system of a housing unit of social interest through the application of the Life Cycle Assessment. The approach used data from the inventory of Ecoinvent version 3.6, the current version available globally.

For evaluating environmental impacts of the analyzed system, EN 15,804:2012 impact method with CML baseline was used. The system modeling and calculations were performed in the OpenLCA software. It resulted in seven categories of environmental impacts for the walls system and also for its subsystems separately.

From the subsystems results, it is possible to perceive particularities in relation to the impacts of each element. For the sealing masonry, ceramic blocks presented the greatest impacts in all the impact categories adopted; in the window subsystem the aluminum windows resulted in the greatest impacts; in coatings, the mortar used for roughcasting and plastering had the greatest impacts in six of the seven categories analyzed. Regarding the total impacts, the results showed that the frame system presented the greatest impacts.

With the study, it was concluded that the Life Cycle Assessment is a promising alternative to contribute in making project decisions that result in buildings with less environmental impacts. With this sort of information in hand, architects and engineers could project future buildings with less environmental impacts, since they would be aware of each components impacts and could choose less impactful ones.

In relation to possible limitations of the study, not using adapted data generates uncertainties in relation to specific aspects of the place where the study is inserted, which may cause miscalculation of some results. However, its contribution to the analysis of the environmental impacts generated is not null, since the database used in this article follows global standards. In new studies, the results can be compared with different databases and, when available, with an inventory based on regionalized data.

This article is an initial study referring to the Life Cycle Assessment study of the social residential housing units of Canaã (Brazil). As future studies, it is suggested the Life Cycle

Assessment of different housing construction systems, increase the scope proposed here, analyzing maintenance steps and final stages of the life cycle and compare results obtained from secondary database and regionalized or adapted data.

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