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Life Cycle Assessment of Steel Framing Wall Systems: Hotspots for Environmental Improvements and Possible Trade-offs

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Abstract

Purpose: Identify the processes with the highest contribution to potential environmental impacts in the life cycle of steel framing wall systems by evaluating their main emissions contributing to impact categories, and identifying hotspots for environmental improvements and the possible trade-offs.

Methods: The research is based on the Life Cycle Assessment (LCA) study of steel framing wall systems performed by the authors. The processes that have demonstrated higher contribution to environmental impacts were identified in the Life Cycle Impact Assessment (LCIA) phase using the methodology ReCiPe and a detailed analysis was carried out on the mitigation strategies and possibilities of trade-offs.

Results and Conclusions: The highest potential impacts in the life cycle of the steel framing wall systems can be attributed mainly to emissions coming from the production of steel and fiber cement in most part of the categories. However the highest contributions have shown to come also from fiber wood production for the categories Agricultural Land Occupation and from gypsum fiber board production for the category Particulate Matter Formation. The results of this LCA study are part of a major research on the comparative analysis of different typologies of external wall systems, which aims to contribute to the creation of a life cycle database of major building systems, to be used by the environmental certification of buildings.

Keywords: Life Cycle Assessment, Steel Framing Wall Systems, Contribution Analysis, Sensitivity Analysis.

1. Introduction

The importance of construction to the three elements of sustainable development, namely economic growth, social progress and effective protection of the environment should be considered in order to identify the issues facing construction in meeting the sustainable development agenda. Such issues include efficient use of natural resources, reduction of energy consumption, reduction of emissions, minimization of waste generation, more efficient land use, reduction of the impact on construction sites and creation of better employment conditions. The understand of the ways in which steel construction is addressing these issues, specially in the context of new buildings, where steel's impact on the construction process and the ways in which construction form can contribute to reducing the energy consumption in the building's lifecycle are extremely important to get to the environmental hotspots of this construction system. The role of steel in extending the life of existing building stock and design features for enabling re-use of steel components are highlighted nowadays as an argument towards sustainability (BURGAN and SANSOM, 2006).

Fujitaa and Iwatab (2008) proposed a reuse system of building steel structures to reduce environmental burden. The reuse system mentioned is an overall business system for realizing a cyclic reuse flow through the processes of design, fabrication, construction, maintenance, demolition and storage. In order for structural members to circulate as reusable members in the distribution system, it is necessary to establish a venous industry, as an arterial industry which would be responsible for production and supply of newly manufactured members.

The steel companies are also becoming increasingly aware about such sustainability challenges. In order to become a responsible corporate citizen, the industry has responded to these challenges through adoption of environmental management practices, starting with identification of sustainability indicators. Some indicators have been developed specifically for steel industry, but generally, it is quite difficult to evaluate the performance of company on the basis of large number of sustainability indicators, thus the integration of key sustainability indicators is quite essential for decision-making (SINGHA et al., 2007).

The Life Cycle Assessment (LCA) has proved to be a very useful tool to assess the overall impact throughout the life of a building (VERBEECK and HENS, 2010). Under the environmental viewpoint, the LCA provides inventories of material and energy flows to each system and allows a comparison of these balances against each other in the form of environmental impacts (SOARES et al., 2006). This procedure allows a scientific assessment, facilitating the localization of possible changes associated with different stages of the cycle, which results in improvements in its environmental profile. The life cycle of a building includes the production of building materials, construction, operation, maintenance, disassembly and waste management (GUSTAVSSON and JOELSSON, 2010).

The purpose of the present paper is to identify the processes with the highest contribution to potential environmental impacts in the life cycle of the masonry of concrete blocks by evaluating their main emissions contributing to impact categories and identifying hotspots for environmental improvements.

2. Methods

The research is based on the Life Cycle Assessment (LCA) study of non-load-bearing steel framing walls system with three internal dry wall panels and exterior fibercement boards performed by the authors. The processes those have demonstrated higher contribution to environmental impacts were identified in the Life Cycle Impact Assessment (LCIA) phase and a detailed analysis was carried out on the main substances derived from these processes.

The methodology was guided by ISO 14044 (2006) through the application of the script proposed by ILCD Handbook (EC-JRC, 2010).

The case study have been performed by using the software GaBi 4.4 (IKP, PE, 2002), and data from the Ecoinvent 2.01 database (FRISCHKNECHT, 2005), and the results were analyzed to get an overview of the potential environmental impacts coming from such wall typology.

The main aim of this research was to provide data on the selected type of wall system in order to identify its potential impact hotspots and possibilities of environmental improvement.

3. Case study

According to ISO 14044 (2006) a complete LCA study includes four phases: a) Definition of Objective and Scope; b) Life Cycle Inventory analysis (LCI); c) Life Cycle Impact Assessment (LCIA); and d) Interpretation. All these steps are presented below.

3.1 Objective and scope

The research have considered building with independent structure, where all the loads are discharged in such independent structural elements and the wall analyzed had only a sealing function. Thus, the functional unit addressed in this research was of 1m² of non-structural external wall which provides thermal and acoustic performance as required by relevant Brazilian standards for the application in the city of Sao Paulo, for a period of 40 years.

The analyzed typology is a 15 cm steel framing wall system with three 1.25 cm thick internal dry wall panels (gypsum RU) with 8 cm thick unventilated air chamber and 4 cm thick exterior cement fiber boards, filled with medium density wood fibreboard (MDF), and it was considered as not receiving any painting on its external and internal faces.

Based on these statements, the reference flow for the functional unit of 1m² of non-load-bearing wall consisted of 3m² of 1.25 cm thick dry wall panel (gypsum RU), 1m² of 4cm thick exterior cement fiber boards (MDF filled), 0.004375m³ of steel (framing).

The cut-off criteria allowed the exclusion of the elementary flows if their relevance in the final results was below 0.1%.

The product system studied in this LCA is shown in Fig. 1.

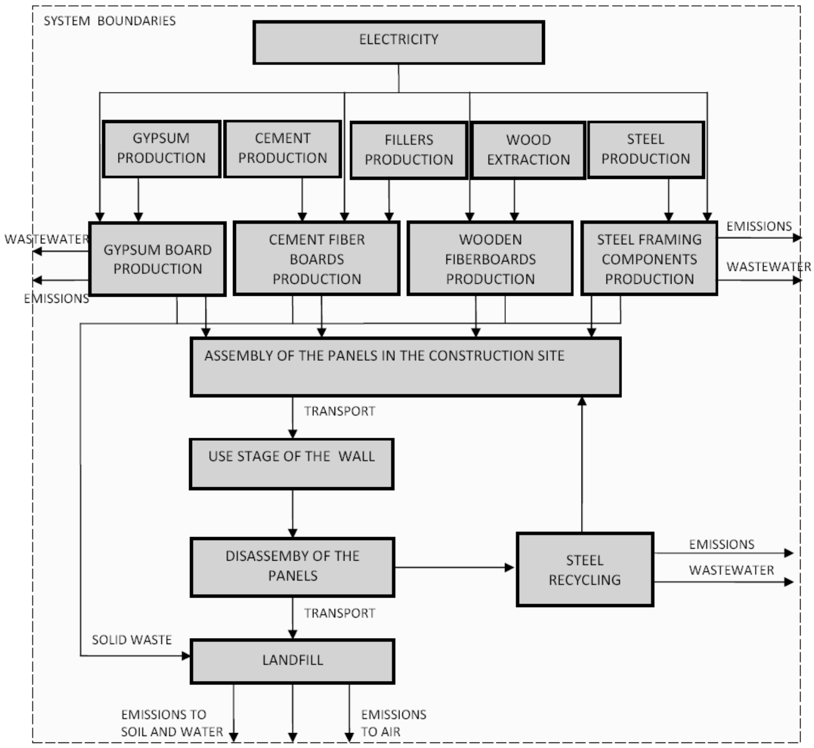


Fig. 1. System Boundaries of steel framing wall system with internal gypsum board and external cement fiber board.

3.2 Life Cycle Inventory Analysis (LCI)

This study was based on data from Ecoinvent 2.01 Database.

For the collection of inventory data on transportation processes regarding the distribution of blocks, a 100km-distance was considered for comparison purposes. Regarding the transport for disposal of demolition rubbish, a 10km-distance was considered.

As this LCA study is directed to the Brazilian context, the energy grid mix regards Brazilian government reports.

The Brazilian electricity grid mix is composed by 74% hydropower, 6,9% natural gas, 4,7% biomass, 3,6% oil products, 2,7% nuclear power, 1,3% coal, 0,4% wind power and 6,5% coming from imports (MME, 2011).

3.3 Life Cycle Impact Assessment (LCIA)

The Life Cycle Impact Assessment (LCIA) was carried out by using the ReCiPe 2008 methodology (GOEDKOOP et al., 2008), applying the midpoint impact categories, without applying normalization or weighting. The ReCiPe methodology was chosen due to its regional scope of application directed to Europe and not to any specific country, once there is still no methodology directed specifically to Brazil or Latin America.

3.4 Results and Interpretation

Fig. 2 shows the LCIA results at midpoint, however the analysis of the results requires the observation of each category of impact in isolation, since the most impacting processes may vary for each category. Thus a careful analysis is necessary to ensure the transparency of the study.

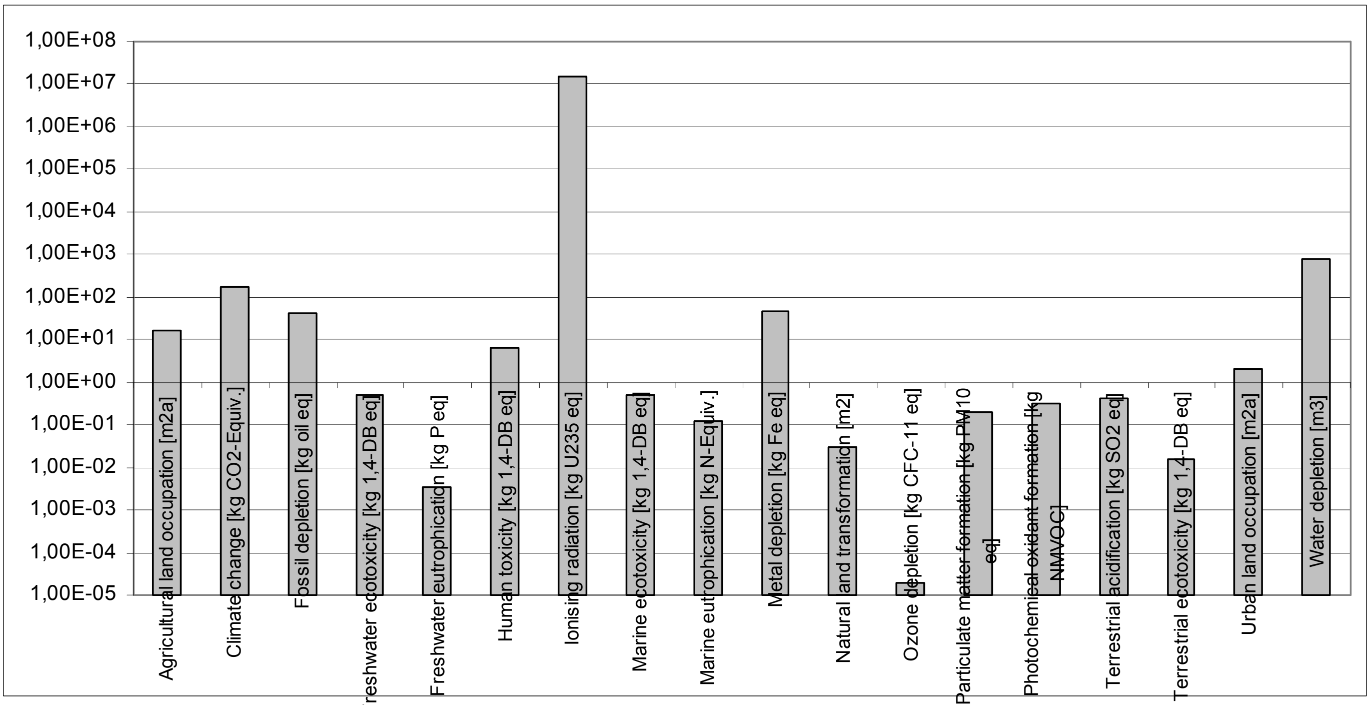
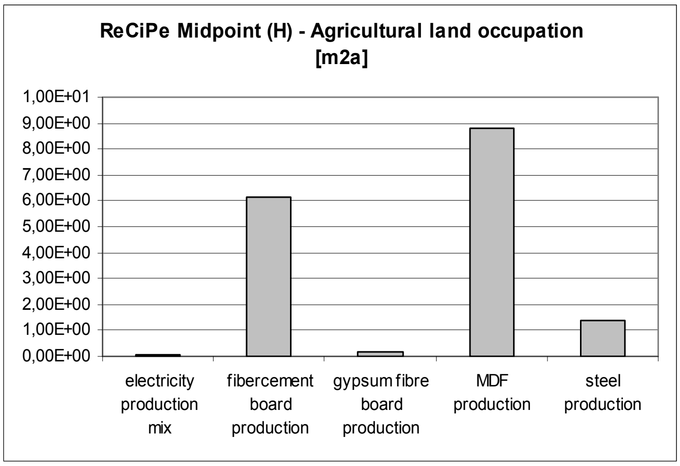


Fig. 2. LCIA results at midpoint.

Concerning Agricultural Land Occupation (Fig. 3), the MDF production has shown a higher contribution to potential environmental impacts. Such results lead to the conclusion that the impacts on Agricultural Land Occupation are due to the large agricultural areas need for timber growing.

On the other hand, the steel production has shown higher potential impact to the category Urban Land Occupation (Fig. 3).This result point out to the dimensions of the steel plants, all located in the urban area.

The same can be observed for the category Natural Land Transformation (Fig. 4), where the most contributing process is again the steel production. Such result is due to the mining for extraction of iron, for steel production.



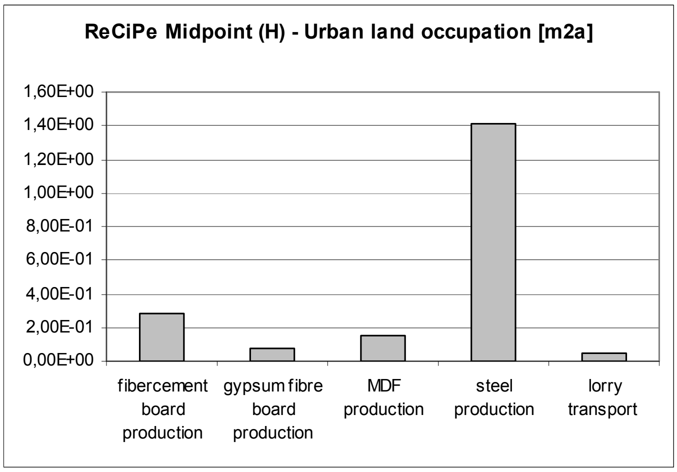


Fig. 3. Most contributing processes in the categories Agricultural and Urban Land Occupation.

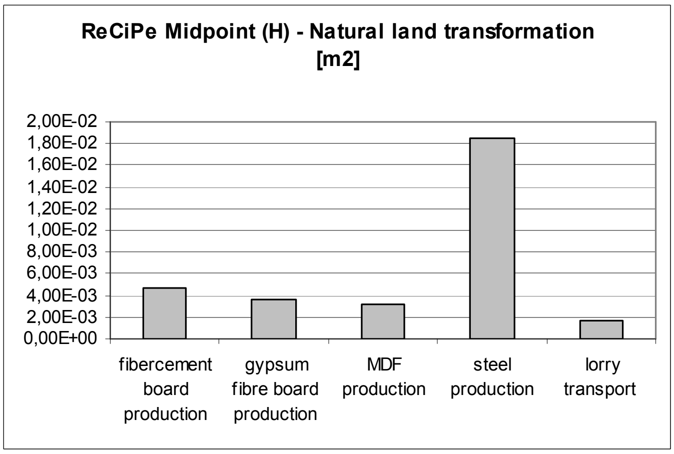


Fig. 4. Most contributing processes in the category Natural Land Transformation.

Fig. 5 shows the impact assessment results for the categories Climate Change. For this category a diverse scenario was found where steel production and fibercement boards production have shown larger contributions, due to the emissions from the cement and steel production process.

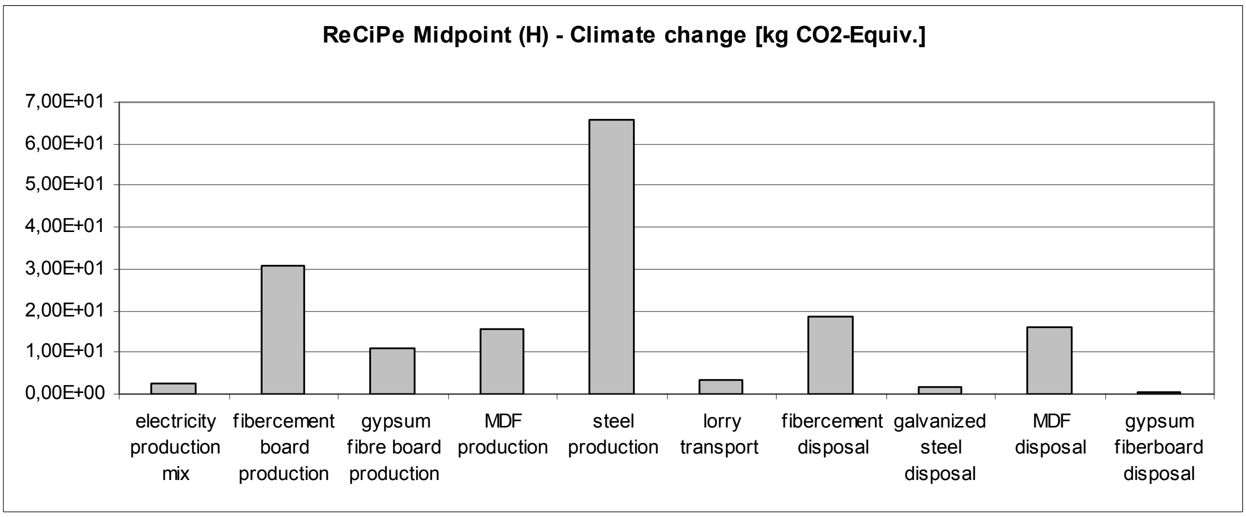


Fig. 5. Most contributing processes in the categorie Climate Change.

Fibercement board production has presented the highest contributions to Ozone Depletion category, while for the category Water Depletions the highest potential impacts are located in the electricity and steel production, as shown in the Fig. 6. This last result can be explained for the massive contribution of hydro power in the Brazilian energy mix as for the large use of water in the steel production process.

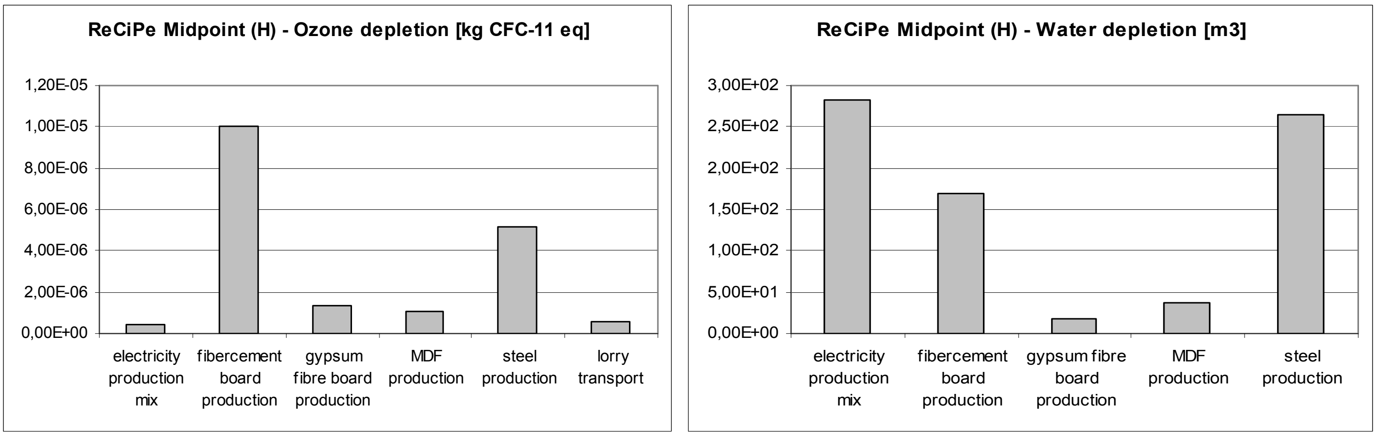


Fig. 6. Most contributing processes in the categories Ozone and Water Depletion.

Regarding the consumption of resources two very similar scenarios can be observed for Fossil and Metal Depletion (Fig. 7). It can be noted a substantially large consumption of fossil resources in most of the main process, especially those involving materials production. In the other hand, concerning Metal depletion, the highest consumption potential is concentrated in the process of production of steel, which is completely based in the use of metals.

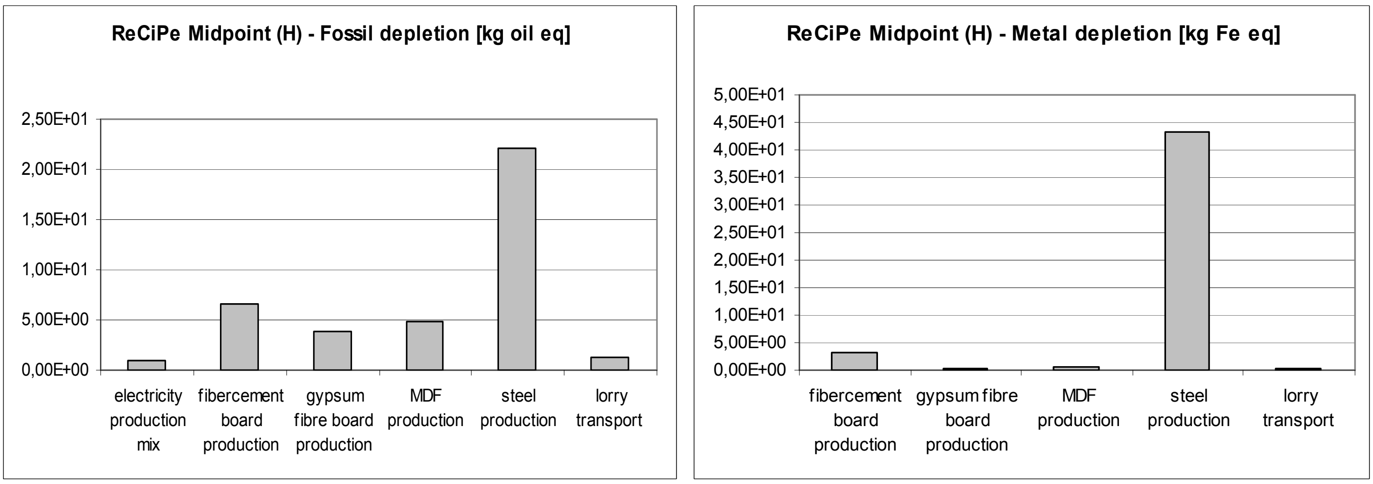


Fig. 7. Most contributing processes in the categories Fossil and Metal Depletion.

For the categories Freshwater and Marine Ecotoxicity and Eutrophication (Fig. 8 and 9) the impact potential profiles for processes in the life cycle of steel framing wall system with internal gypsum board and external cement fiber board are very similar, showing the larger contributions coming from the steel production process. Although the largest contributor process is the same, the impact profile of remaining processes varies among categories, keeping constant only the presence of contributions from the fibercement board production.

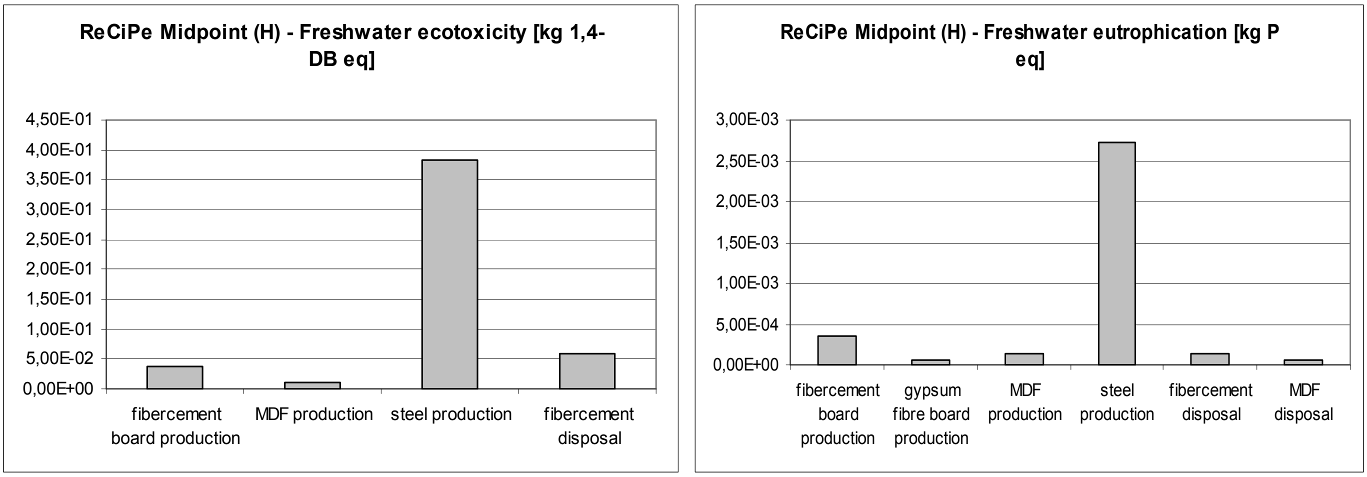


Fig. 8. Most contributing processes in the categories Freshwater Ecotoxicity and Eutrophication.

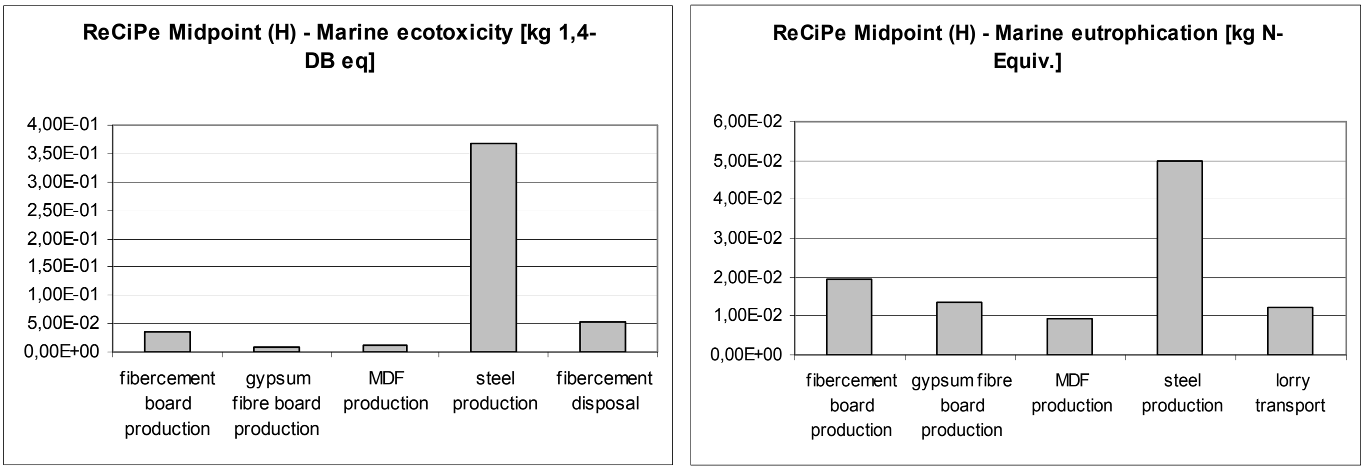


Fig. 9. Most contributing processes in the categories Marine Ecotoxicity and Eutrophication.

The Human Toxicity and Ionizing Radiation impact categories have shown the same typical profile of some of the categories discussed previously, with the highest impact magnitude in the steel production process, followed by the fibercement production process (Fig. 10). However, for Human Toxicity a significant contribution is also observed in the fibercement disposal, even higher than the same material's production.

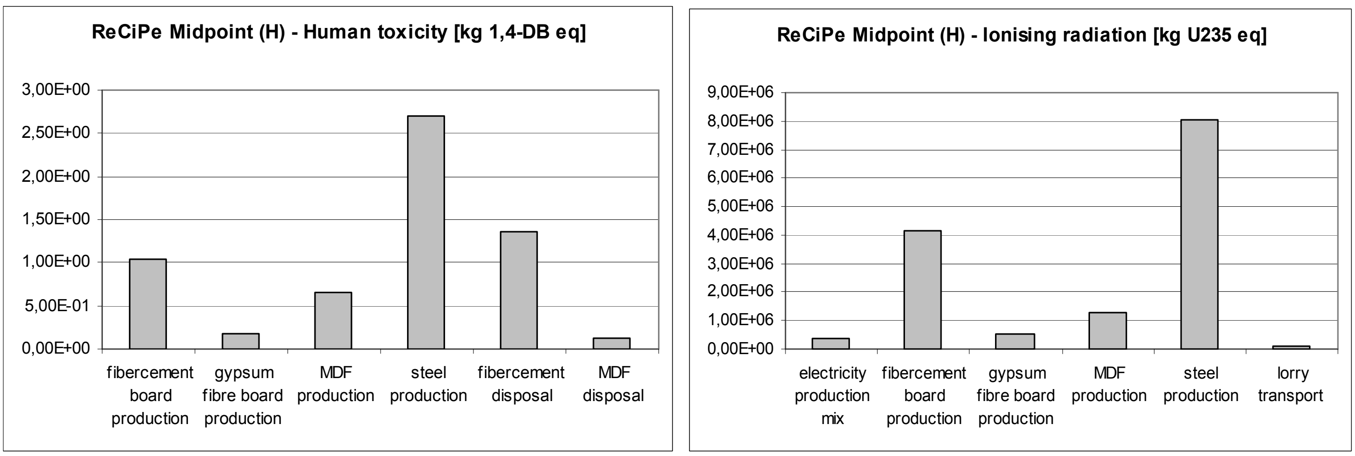


Fig. 10. Most contributing processes in the categories Human Toxicity and Ionizing Radiation.

Fig. 11. shows the potential impacts for the categories Particulate Matter Formation and Photochemical Oxidant Formation. Once more the highest impact is concentrated in the steel production, and other significant impact potentials are observed in the processes of production of other materials and transportantion.

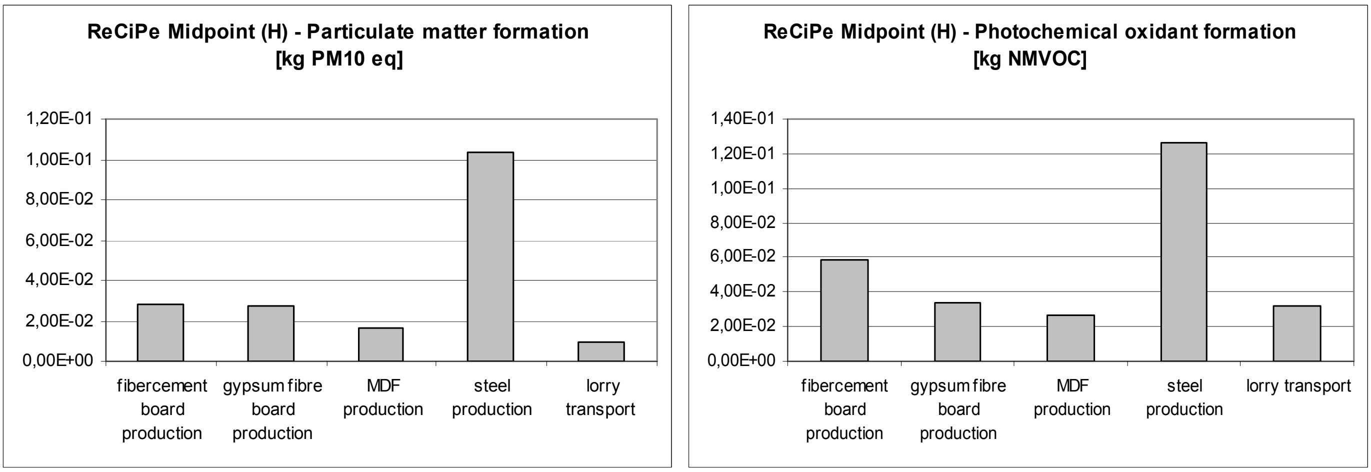


Fig. 11. Most contributing processes in the categories Particulate Matter and Photochemical Oxidant Formation.

Finally, regarding impacts to the soil, Fig. 12 shows the most impacting processes in the categories Terrestrial Acidification and Terrestrial Ecotoxicity. For category Terrestrial acidification the most contributing process is again the steel production, however, the highest impact potentials for Terrestrial ecotoxicity are located in the MDF production.

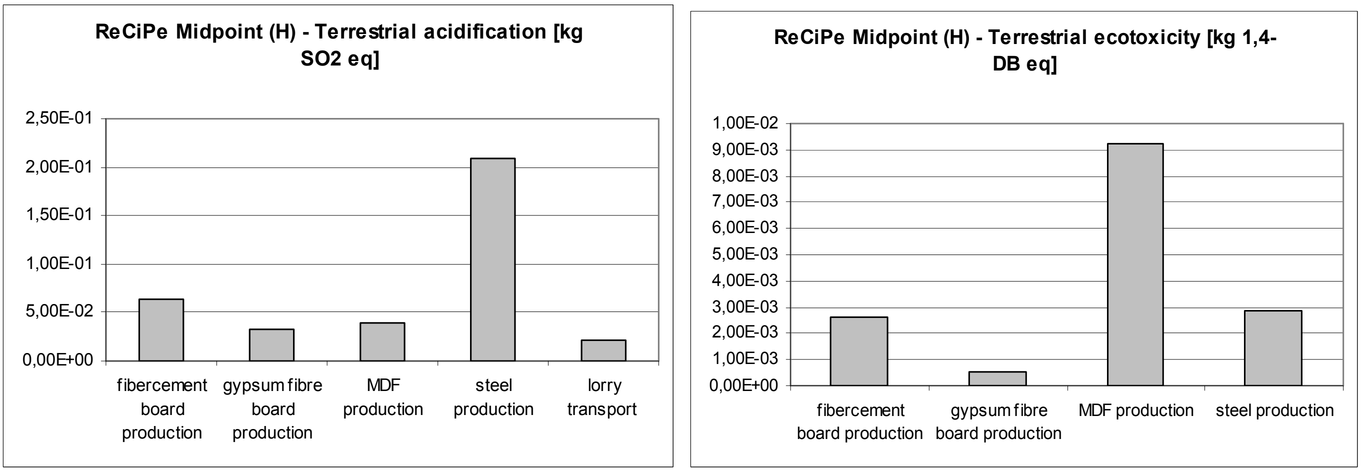


Fig. 12. Most contributing processes in the categories Terrestrial Acidification and Ecotoxicity.

3.4. Conclusion and Recommendations

The highest potential impacts in the life cycle of the steel framing wall system with internal gypsum board and external cement fiber board can be attributed mainly to emissions coming from the steel production processes, for most of the impact categories, followed by the fibercement production process, which also showed significant impact potential for most of the impact categories analyzed by ReCiPe methodology.

MDF production showed to be the most impacting process in the impact categories Agricultural Land Occupation and Terrestrial ecotoxicity, due to the large agricultural area needed for timber growing and the toxic emissions of MDF industrial production process, respectively.

Individually for the category Water Depletion, the most impact process was the Electricity production, however such impacts are not located specifically for the studied function, and are mostly due to the Hydro power-based Brazilian energy mix. Still the high energy consumption of the steel production process may be considered responsible for such impact.

Therefore it is possible to conclude by this Life Cycle Assessment study that the hotspots for environmental improvement in the lifecycle of the steel framing wall system with internal gypsum board and external cement fiber board are most specifically located in the steel production process, but fibercement and MDF production should also be considered for environmental improvements.

Other impacts which could be indirectly identified through the analysis of the categories Agricultural Land Occupation and Natural Land Transformation are those coming from the timber growing and mining activities. Such raw materials extraction are not directly assessed by the LCIA methodology but were clearly observed in the discussion of the results.

The results of this LCA study are part of a major research on the comparative analysis of different typologies of non-load-bearing external walls, which aims to contribute to the creation of a life cycle database of major building systems, to be used by the environmental certification systems of buildings. Further research point out to the sensitivity analysis of the results to the use of secondary data or primary data and also the application of different LCIA methodologies will be performed in order to identify which impact categories are the most significant in the assessment of traditional wall systems and which need thus further specific development.

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