Comparative Lifecycle Analysis of Sri Lankan Non-Conventional Roofing Materials

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ABSTRACT

Building materials, especially roofing products, play a major role as they are essential for any building construction. Knowledge of the environmental performance of building materials is vital when building life cycle assessment. However, only a few studies have been conducted in Sri Lanka in this regard. The present study focuses on the environmental life cycle assessment of two different non-conventional roofing materials used in Sri Lanka. Acrylonitrile Styrene Acrylate roofing sheets and Calicut-type clay roofing tiles have been selected for the study. In order to measure and calculate environmental impacts of both types of roofing materials, field data was collected quantitatively and noted as per ISO14040 and ISO14044. Using the Cradle-to-Gate LCA technique and OpenLCA software, the environmental impacts as midpoint and endpoint categories were evaluated. As the main output of the study, environmental performance of these two roofing materials were compared, the hotspots of the manufacturing process and the causes were also identified. . Accordingly, the global warming potential of Acrylonitrile Styrene Acrylate roofing sheets and Calicut-type clay roofing tiles is 13.5 kgs of CO_2 eq. and 8.95 kgs of CO_2 eq. respectively. Further, comparison of the endpoint categories showed the resource depletion was most impactful, indicating 0.814012 points and0.65305 points, respectively for the two roofing material types. Further, kiln firing was identified as the environmental hotspot contributing most to the endpoint and midpoint impact categories for clay roofing tiles, while mixing materials by hot mixer was the hotspot for Acrylonitrile Styrene Acrylate roofing sheets. In addition, the overall results demonstrated how the production process of clay tile influences more than the Acrylonitrile Styrene Acrylate roofing sheet on both the midpoint as well as the endpoint impact categories.

KEYWORDS: *Acrylonitrile Styrene Acrylate, Calicut tiles, Cradle-to-Gate, End-pint impacts, Mid-point impacts*

1 INTRODUCTION

Many resources are used for construction activities worldwide. It is evident that there are environmental impacts associated with each stage of construction. Among the building materials, roofing materials play a major role as they are used in all types of building projects. From the point of extraction of raw materials till manufacturing, roofing materials have different environmental impacts. Further, environmental performance data plays a vital role in building life cycle assessment as well. In order to understand the environmental performance of building materials, it is important to analyze their life cycle through a standard LCA methodology. This will allow the hotspot identification through the production process to reduce the environmental impacts.

According to previous studies carried out locally [1,2], there are only a few LCA based research carried out on roofing materials. Clay rooftiles, Asbestos roofing sheets were considered for LCA locally and Carlisle Sure-Flex PVC Membranes [3], White SPPR PVC roofing membranes [4] were some of the internationally considered roofing materials for LCA. Moreover, cradle-to-grave LCA

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Analyses covering the entire lifecycle of roofing materials are rare. Therefore, the objective of the present study is to conduct a process based LCA analysis for the most popular non-conventional roofing materials in Sri Lanka to identify the environmental/hotspots and compare the different manufacturing processes.

2 MATERIALS AND METHODOLOGY

2.1 Selection of roofing materials

The selection of roofing materials was done based on two criterion: the most used and the preferred roofing materials in Sri Lanka.

2.1.1 Selection criteria 01

The first selection criteria for roofing material selection focused on the usage of roofing materials in Sri Lanka. Table 1 shows the number of housing units in Sri Lanka with different roofing materials (Department of Census and Statics of the population and housing stock). According to Table 1 the most used roofing material type for house construction is clay roofing tiles [5].

Table 1: Roofing materials used in housing units (Department of Census and Statics data)

Roofing material	Number of housing units
Clay tiles	2,479,226
Asbestos	1,800,07
Concrete	213,587
Zink Aluminum sheet	49,433
Metal sheet	544,211
Cadjan/ Palmyrah/ Straw	109,62
Other	11,583

2.1.2 Selection criteria 02

As the second selection criterion for roofing material for the study, the preference for roofing material for house construction of individuals was assessed. An online survey was carried out using over 190 Google forms. The survey had 03 multiple choice questions, assessing the provinces of the participants, the roofing material they prefer, email, and the name of the participants. For the validation of the responses, the email of each participant was required and only one response from a single email was considered. Below are the results obtained from the online survey.

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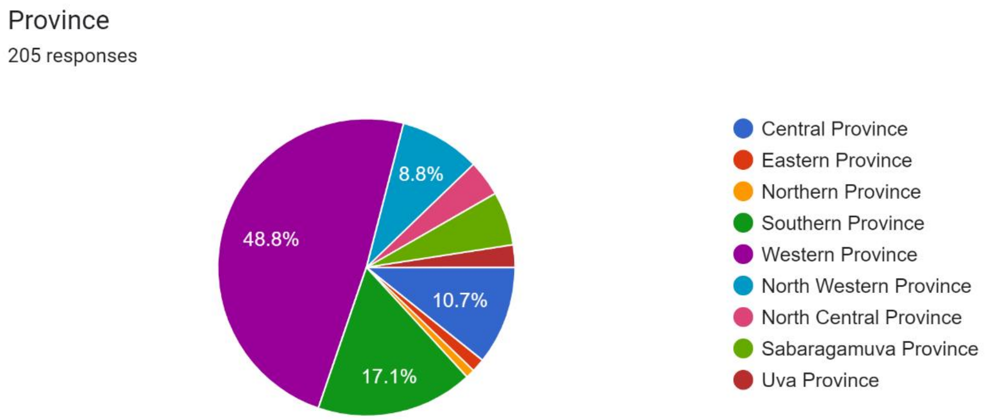

Figure 1: Geographic distribution of the participants the of online survey

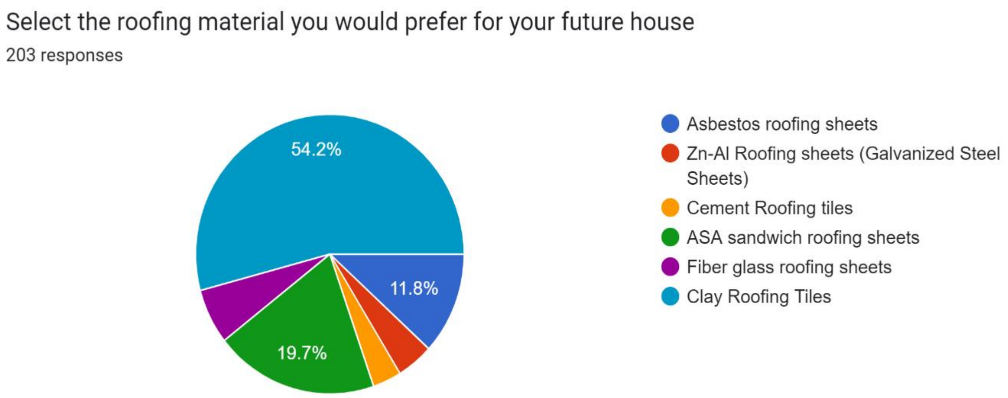

Figure 2: Different types of roofing material preferences of the participants

From the obtained results it can be seen that the highest percentage of participants preferred clay roofing tiles and as the second highest percentage ASA Sandwich roofing sheet type was preferred.

2.2 Defining the goal and scope

The study's main goals were to evaluate the environmental performance of two non-conventional roofing materials in the manufacturing processes. The scope of this study was established using ISO 14040 Section 5.2 (2016) as a guide. The goal of this study was to apply the "Cradle to Gate" approach of life cycle assessment.

2.2.1 Functional unit

The analysis was conducted for a functional unit of roofing materials needed to cover $1m^2$ of roof surface [1].

2.3 Life Cycle inventory analysis

Utilizing the ISO-recommended methods of data collection, the inventory analysis was completed. Data gathering was disrupted by the iterative nature of the inventory analysis.

2.3.1 Product system for clay roofing tiles

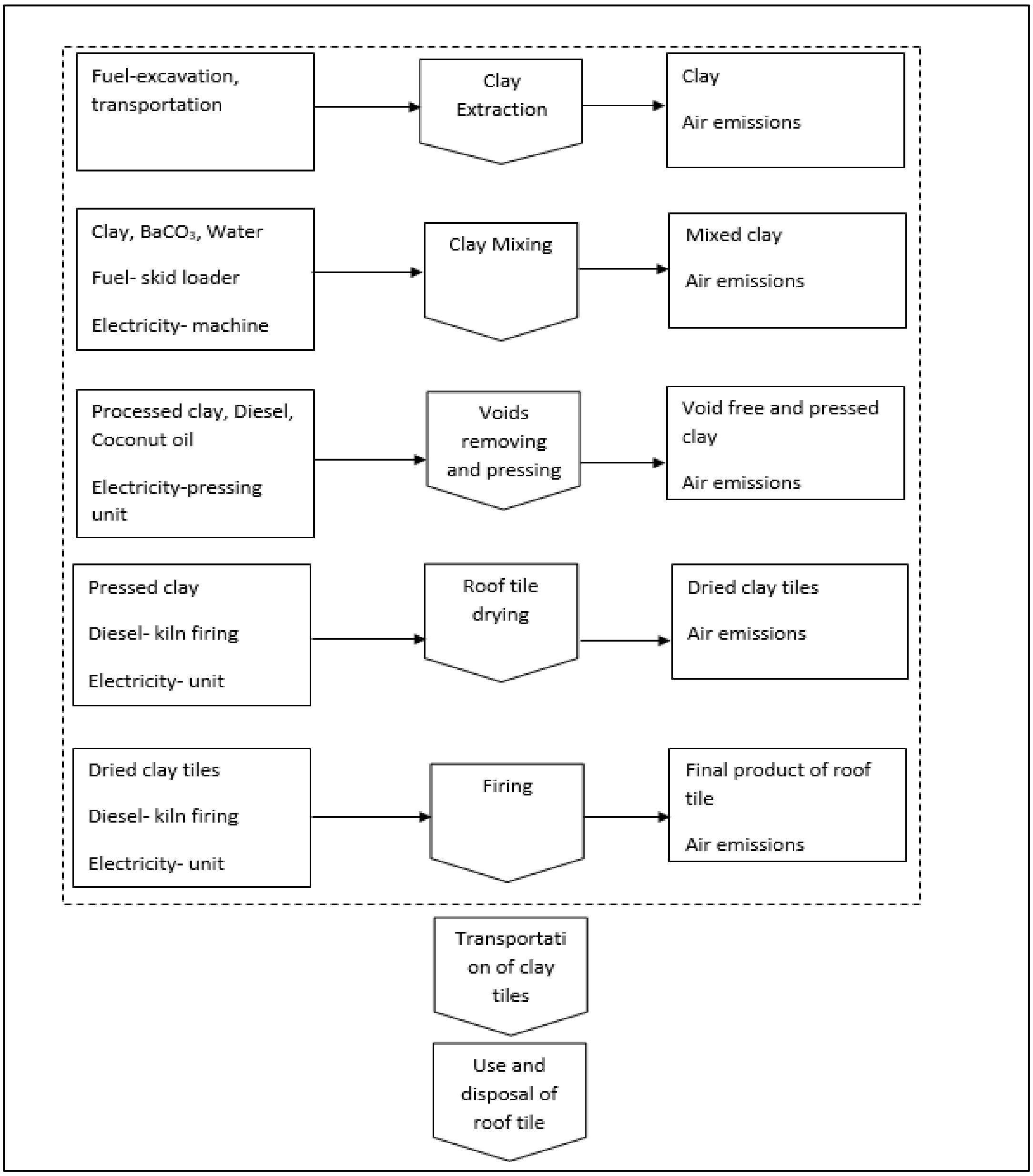

Figure 3: Identification of system boundary of clay tile manufacturing

Data was gathered in line with ISO 14040 section 5.3.2, 2006.,. During the Cradle-to-Gate phase of Clay roofing tiles, data-gathering sheets were created to address input materials and energies, and outputs.

2.3.2 Product system for ASA roofing sheets

Data was gathered in line with ISO 14040 section 5.3.2, 2006. During the Cradle-to-Gate phase of ASA roofing sheets, data-gathering sheets were created to address input materials and energies, and outputs.

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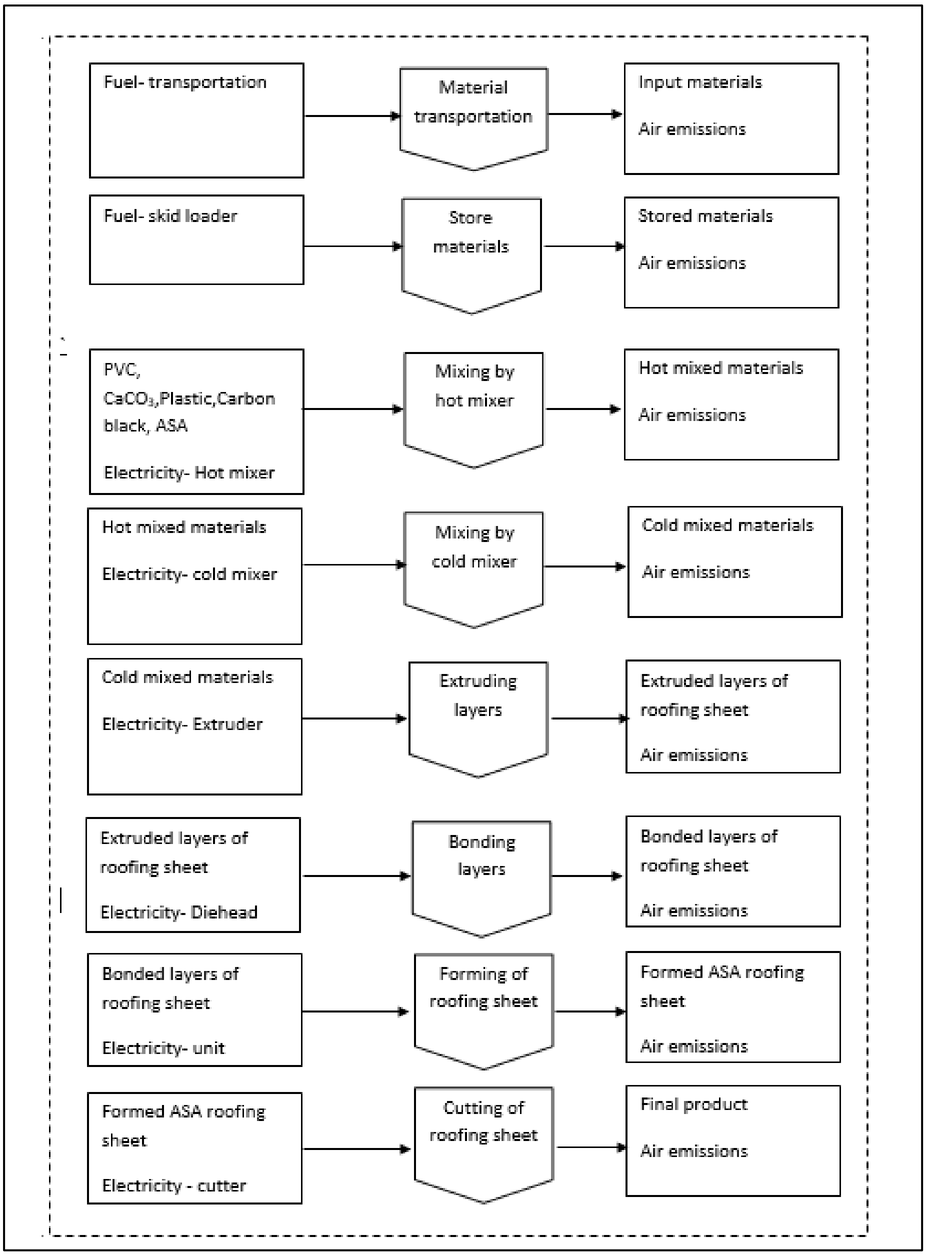

Figure 4: Identification of system boundary of ASA roofing sheet manufacturing

2.4. Impact assessment

The production of clay roof tiles and ASA roofing sheets was modeled using Open LCA software after the completion of the life cycle inventory data. The Ecoinvent database was used for the analysis. The Life Cycle Impact Assessment was conducted utilizing the two standard methodologies: ReCIPe midpoint and endpoint impact categories [1].

2.5 Limitations

The study was carried out only considering the 'Cradle to Gate' analysis of LCA for both roofing materials. Due to the unavailability of the overseas transportation analogy of Openlca software, the material transportation of ASA roofing sheet transportation from overseas was not considered.

3 RESULTS

3.1 Analysis of ReCIPe midpoint (H)

The 18 impact categories were compared for both roofing materials, as presented in Figure 5. Results were generated by considering the entire production process of two roofing materials**.**

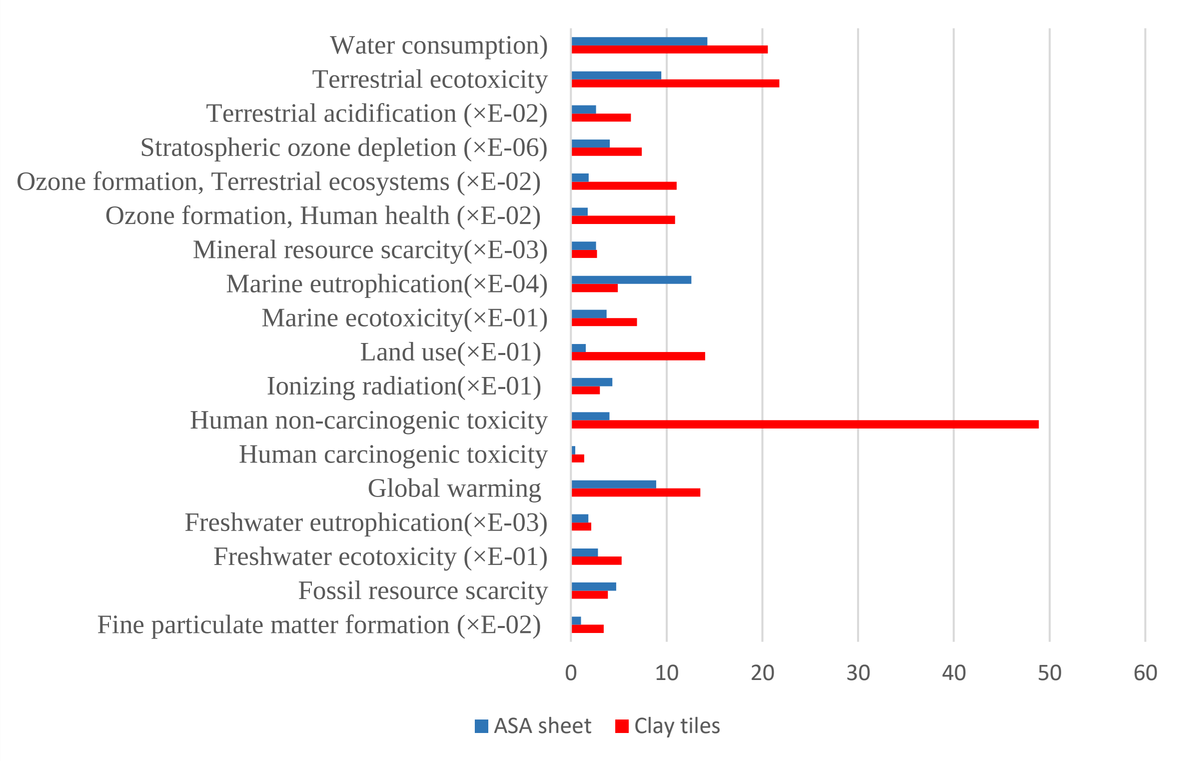

Figure 5: Comparison of Midpoint Impact Categories between the two roofing materials

Clay roofing tiles have the highest impact on Human non-carcinogenic toxicity, Terrestrial ecotoxicity and Water consumption impact categories while the ASA roofing materials have the highest impact on Water consumption, Terrestrial ecotoxicity and Global warming categories. Clay roofing tiles and ASA roofing sheets had a contribution of 13.51 kg CO_2-Eq and 8.90 kg CO_2-Eq contribution of total global warming potential considering all manufacturing stages, respectively. It can be seen that clay roofing tiles have more impact on the global warming potential category than ASA sheets. According to Figure 5, it can be seen that the human non-carcinogenic toxicity midpoint impact category of the Clay roofing tile has increased drastically in comparison to the ASA roofing sheet production. This is due to the usage of $BaCO_3$ in the production of clay roofing tiles because $BaCO_3$ is toxic to human health [6]. Referring to Figure 5, it can be seen that the fossil fuel scarcity of ASA roofing sheet is higher than clay roofing tile. This should be mainly due to the higher electricity consumption of the manufacturing process of ASA roofing sheets as 52% of the total electricity generation of Sri Lanka is from fossil fuel burning [7]. Referring to Figure 5, it can be seen that the Stratospheric Ozone depletion of the clay roofing tile is higher than the ASA roofing sheet. For the clay tile, it was 7.41E-10 kg CFC-11-Eq and for the ASA sheet, it was 4.06E-06 kg CFC-11-Eq per Fuand mixing materials by hot mixer was the hotspot phase of ASA sheet.

A past study conducted in Sri Lanka also had relatively similar results in global warming, acidification, eutrophication, and ozone depletion categories [1,2] and the FU for the study was the same but the hotspot analysis and LCIA methodology and software used were different from this study. For the comparison, a similar study done for clay roofing tiles, in Malaysian context had, 17 kg CO_2-Eq, 0.000462 kg N-Eq, 0.0695 kg SO_2-Eq, 4.82E-10 kg CFC-11-Eq for Global Warming, Marine eutrophication, Acidification, Ozone Depletion midpoint impact categories respectively [8]. As a percentage there was 6%-34% difference with the past study. Similar results can be seen in this study as well.

There are no past studies in the Sri Lankan context assessing the life cycle analysis of ASA roofing sheets using any kind of LCA software. However, globally some studies have researched the life cycle analysis of PVC roofing material. For ASA roofing sheet production, PVC has the highest contribution of input materials. Therefore, it is convenient to make a comparison between those studies and this study in the same significant impact categories. Also, the functional units of those studies were the same, and the 'Cradle to Gate' methodology had been used. Carlisle Sure-Flex PVC Membranes(2.32mm) [3], White SPPR PVC roofing membrane (1.21mm) [4] were the materials considered for comparison and for Global Warming(8.8, 5.2 kg CO_2-Eq), Marine eutrophication(0.146, 0.076 kg N-Eq), Acidification(0.052, 0.029 kg SO_2-Eq), Ozone Depletion(1.4E-06, 5.5E-07 kg CFC-11-Eq) midpoint impact categories were the results obtained for those materials respectively. It can be seen that the difference with ASA roofing sheet's results for Global warming midpoint impact category was at 1.1% and 41% for Carlisle Sure-Flex PVC Membranes and White SPPR PVC roofing membrane respectively.

3.2 Identification of hotspot base on midpoint impact categories

Referring to Figure 6, it can be observed that the hotspot is the firing phase of clay tile production for all the impact categories. According to past studies [1], the chamber firing phase produces the most greenhouse gas emissions, whereas this study also shows that the kiln firing of the clay tile production produces the most environmental emissions.

3.2.1 Hotspot analysis for clay roofing tiles

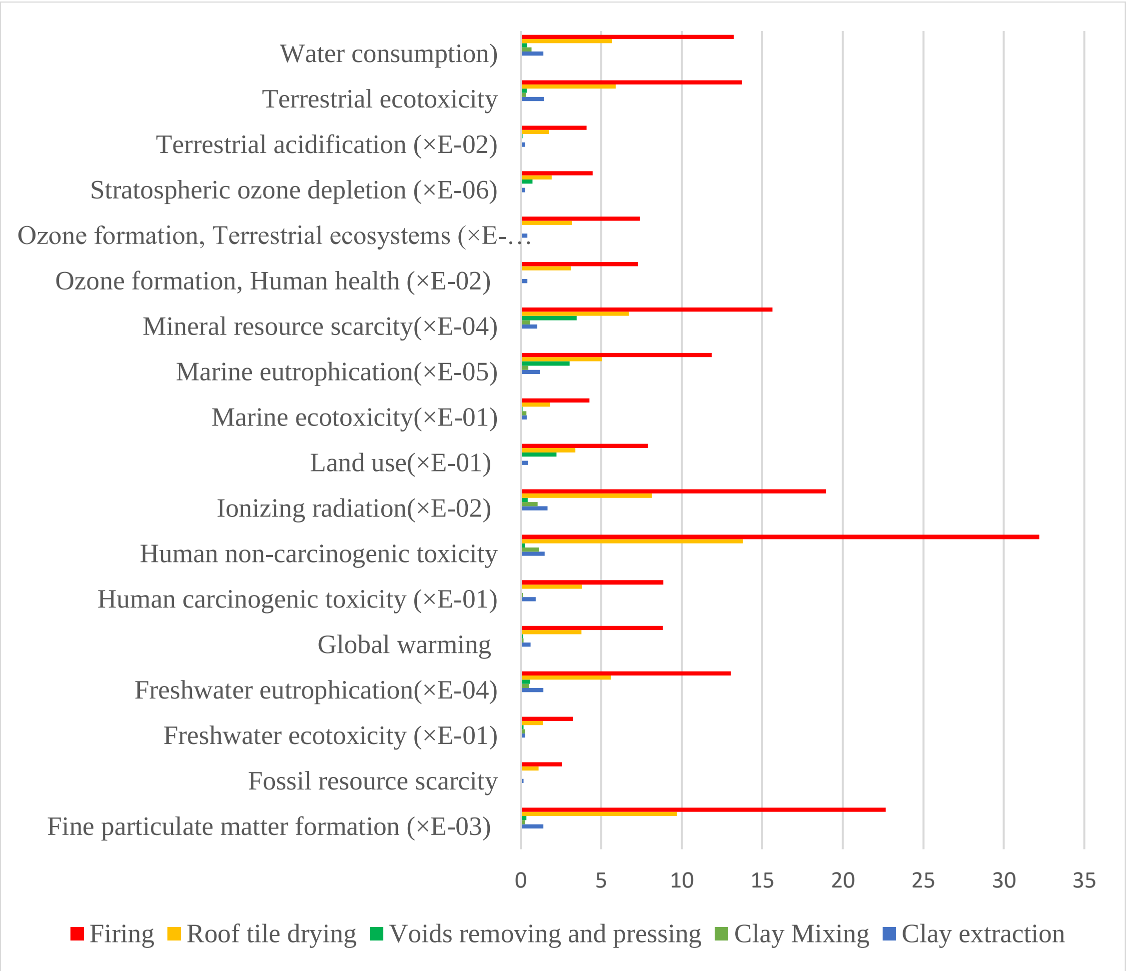

Figure 6: Hotspot analysis for Clay roofing tiles

3.2.2 Hotspot analysis for ASA roofing sheets

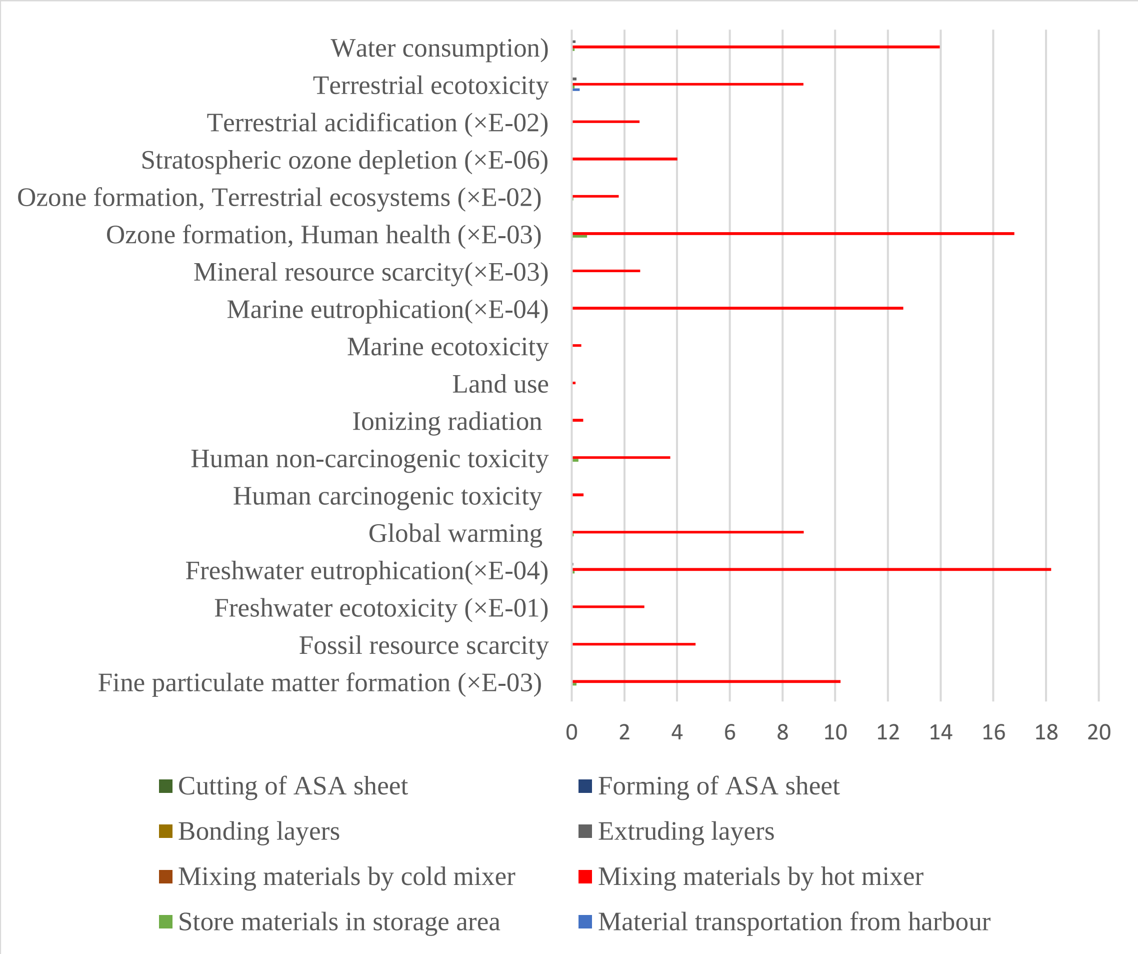

Figure 7: Hotspot analysis for ASA roofing sheets

Referring to Figure 7, it can be observed that the hotspot is the mixing materials by the hot mixer phase of ASA roofing sheet production.

3.3 Analysis of Recipe Endpoint (H, A)

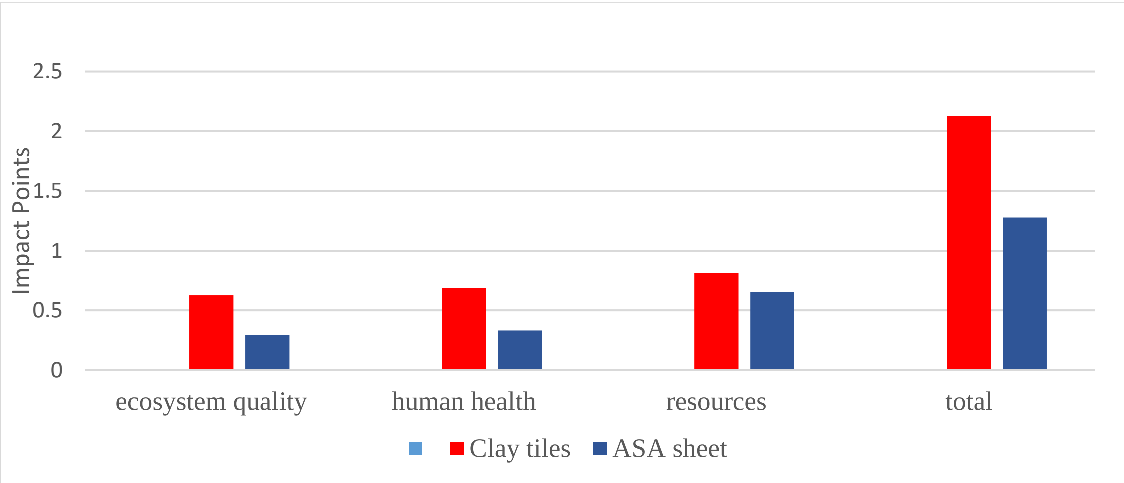

Figure 8: Comparison of endpoint categories for roofing materials

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According to Figure 8, clay tiles have resulted in 0.624781, 0.68797971 and 0.814012 impact points with respect to ecosystem equality, human health and resources. From all three endpoint categories, clay tiles have more impact on the environment than ASA sheets and also from total endpoint impacts, clay tiles have 2.1268 Impact points while ASA sheet has only 1.2761 Impact points. As a percentage, clay tiles have 39% more impact than ASA sheets indicating better sustainability performance.
A past study for LCA of Asbestos roofing sheets, conducted locally had results, for total endpoints as 2.95 Impact points [2]. Also, another past study for LCA of Calicut-Type clay tiles conducted locally had results, for total endpoint as 0.41 Impact points [1] while a study conducted in the Brazilian context showed the total endpoint resulting in 2.06 impact points [9]. It can be noted that this study also has approximately similar results for total endpoints compared to the Brazilian context than the locally conducted study for Calicut-type roofing tiles.

4 CONCLUSION

The main goal of this study was to compare two different non-conventional roofing materials to determine how much impact each one had on the environment. The effect on the endpoint categories was discovered after acquiring the quantitative impacts of the production of clay roof tiles and ASA roofing sheets using two modern manufacturing procedures. The clay roofing tile and ASA roofing sheet were examined based on the stated system boundary, Cradle to Gate life cycle of the product. Five important midpoint impact categories were evaluated across the complete manufacturing process in both factories. The production process of clay roofing manufacturing process produces, human-non-carcinogenic toxicity of 48.87209 kg 1.4-DCB, global warming of 13.50554 CO_2 eq, fossil resource scarcity of 3.876369 kg oil eq, stratospheric Ozone depletion of 7.41E-06kg CFC-11-Eq, Terrestrial acidification of 0.062769 kg SO_2-Eq while ASA roofing sheets produce, human-non-carcinogenic toxicity of 4.043057 kg 1.4-DCB, global warming of 8.902324 CO_2 eq, fossil resource scarcity of 4.730785 kg oil eq, stratospheric Ozone depletion of 4.06E-06 kg CFC-11-Eq, Terrestrial acidification of 0.026102kg SO_2. When assessing the results obtained from 'OpenLca' software from both midpoint and endpoint impact categories, it is evident that the most impactful roofing material production procedure belongs to clay roof tile production.
This is mainly due to the kiln firing process of the manufacturing procedure, and it can be identified as the environmental hotspot of the process. Also, mixing materials using a hot mixer was identified as the hotspot phase of ASA roofing sheet manufacturing procedure and this is due to the high material consumption of that phase compared with the entire procedure and high electricity consumption. When considering the evaluated endpoint environmental impacts of both roofing materials, it can be seen that the impacts on the ecosystem, human health, and resources, the clay roofing tile manufacturing process has acquired higher points than the ASA roofing sheet production process. Nevertheless, considering the impacts on resources, both roofing materials have shown approximately the same results. In conclusion, the results depict that the manufacturing process of clay roofing tiles impacts more in both midpoint and endpoint impact categories according to the ReCIPe method. This is mainly due to the identified hotspot phase, kiln firing of the manufacturing process and the high amount of diesel burning. This could be reduced by introducing alternative methods for the firing process.

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