Life Cycle Assessment in Ceramic Floor Tile Industry in Sri Lanka

S. Kamalakkannan, R.L. Peiris and A.K. Kulatunga
Department of Manufacturing & Industrial Engineering
Faculty of Engineering
University of Peradeniya
siva.kamalakkannan@gmail.com, rajithalakshanpeiris@gmail.com, aselakk@pdn.ac.lk

Abstract

Tiles industry is the prime ceramic product which widely uses in Sri Lanka. Wall tiles, Floor tiles, and Roof tiles are the major products of tile industry outlet. In Sri Lankan building construction applications, ceramic floor tiles show a significant contribution when compared with other floor development materials. The present world is more concerned about environmental awareness with continuous growth unsustainable manufacturing practices. Therefore, many manufacturers are trying to create more and more eco-friendly processes and products by minimizing the effects of their activities on the environment. Although, as a developing country, the environmental performance of the tiles manufacturing sector and improvement of the product quality and performance are key factors to improve the sustainability. In order to go for a green future, it is needed to identify the environmental hotspots generates by the manufacturing sector. the product life cycle assessment (LCA) is an effective tool in the identification of environmental hotspots. In addition to that, it is required to model different life cycle scenarios for the improvement of Life Cycle Management (LCM). Therefore, this research focuses on conducting LCA towards eco-design in floor tile industry by using scenario analysis. Through this study, local floor tile industry can be driven to improve its overall sustainability of the floor tile manufacturing sector.

Keywords
Life cycle assessment, Life cycle management

1. Introduction

All over the world Environmental awareness of the manufacturing sectors is considerable in the present time because of unsustainable manufacturing practices such as excessive raw material consumption, resource consumption, energy usages, inadequate waste disposals, Unregulated production processes, Adverse emission discharges in the midst of the production environment. Therefore, many manufacturing sectors are going towards the green manufacturing environment to have a higher level of appreciation by the society than other competitors in the market. Moreover, green Label is to direct manufacturers to review and account for the environmental impact of their products at each stage of the product's life cycle, from preproduction to disposal and it will increase the demand and eco-friendly image among competitors and global markets. Therefore, recently most of the manufacturers expect to adapt to the Eco-labels and environmental product declaration (EPD). In fact, recently manufacturing of construction material is growing rapidly as its applications and needs dominate the whole world. But, most of the construction is predominantly focused on a profitable pursuit. Therefore, it is indispensable to concern about the sustainability of construction materials. In that respect, the ceramic tile industry also plays an important role in the context. Because ceramic tile is one of the essential consumer substance in Sri Lanka. When considering at ceramic industry it is produced as major products such as wall tiles, floor tiles, and roof tiles. Nevertheless, the floor tile is one of the important product among them which is widely used for building construction applications all in Sri Lankan. However, Ceramic tile is produced using completely natural resources such as clay, feldspar, silica sand and dolomite which is directly extracted from the ambiance. Further, energy consumption of the all ceramic tile industries are intensive such as liquefied natural gas, electricity which is a threat to the environment. In addition, auxiliary material applications such as packaging material, glazing and printing ink materials, raw material transportation from a significant distance and fired tiles and glazed tiles wastages, which predominantly goes to landfill, are acted as a burden to the green environment. Therefore, there is a need to commit the environment and recognize that sustainability is important to the sustainable built environment. Thus, it is required to assess the environmental performances of the floor tile product which helps to optimize the consumption of resources and energies, reduce the environmental impacts and also improve the productivity and quality of a product. In order to improve the environmental performances of the floor tile manufacturing sector, it is significant to consider the entire life cycle of the product which assists to identify the environmental hotspots available in whatever the stages or phases of the product life cycle. With the intention of identifying the environmental hotspot of manufacturing sectors, the comprehensive LCA is used as an easy way to identify a tool for environmental issues. The previous LCA studies for local manufacturing context in Sri Lanka were considered as general LCA. Even though, none of the researches have not been conducted the LCA before on ceramic floor tiles in Sri Lanka. Therefore, this paper is very beneficial for understanding the environmental potentials of ceramic floor tile industry. In addition to that, this research has been carried out further analysis towards the eco-design which includes scenario analysis. Through the scenario analysis, the process or places which has the possibility to reduce the energy and resources consumptions can be identified. The reason for this scenario analysis is to compare performances when making changes in the process or products during the phases. Some of the previous studies have been conducted LCA to facilitate the assessment of scenario analysis (Caputo et al. 2014, Cooper et al. 2012, Niero et al. 2014, Ostad et al. 2011, Zimmermann et al. 2013). And some more studies have been carried out in this particular ceramic tiles sector. In order to improve the environmental performance, the researcher has been conducted the LCA in floor and wall ceramic tiles for the cradle to grave phase in Sri Lanka (Edirisinghe et al. 2013). Also, Environmental LCA has been carried out in the ceramic sector including cradle to grave (Maria et al. 2010). In pursuit of comparing the performance between tile and vinyl, the entire environmental LCA, LCC, social LCA have been assessed in Sri Lanka (Yasantha et al. 2009, Yasantha et al. 2006). Moreover, to quantify the environmental and economic impact of ceramic tile from cradle to gate, a cost combined life cycle assessment has been conducted (Ye et al. 2018). Furthermore, none of the research has been done a comprehensive LCA for ceramic floor tile from raw material collection to gate by the way of scenario analysis in Sri Lanka. Therefore, the author believes that this paper help to identify the environmental hotspot which is sorely harmful to the environment and directs the appropriate route to enhance the sustainability of the ceramic floor tile industry in Sri Lanka.

2. Methodology

With the intention of enhancing the sustainability of ceramic floor tile industry, the methodology has been pursued with the life cycle approach which is incorporating the scenario analysis. In order to identify the environmental hotspot, the prominent Life Cycle Assessment tool has been used which is established by ISO 14040 and 14044. With the purpose of calculating the impact values, the reputed software SimaPro (Ph.D. version), which is connected with the global impact database has been used. Subsequently, scenario analysis of global warming potential was calculated before and after 1% of error in inputs of 1m^2 ceramic floor tile which defined as a functional unit (FU) of this study. In conclusion, by interpreting the result the environmental hotspot was identified.

2.1 Goal and Scope definition

In order to conduct the study, Ceramic floor tile manufacturing was selected for this study.

Table 1. LCA system definitions.

Definition	Description
Goals	• Identify the environmental impacts and hotspot. • Scenario analysis
Scope	Raw material collection to Gate
Functional unit	1 m^2 of Ceramic floor tile
Life cycle level-based boundary	• Life cycles of infrastructure and capitals were neglected. • Non-material emissions (Ex: Noise) were neglected.

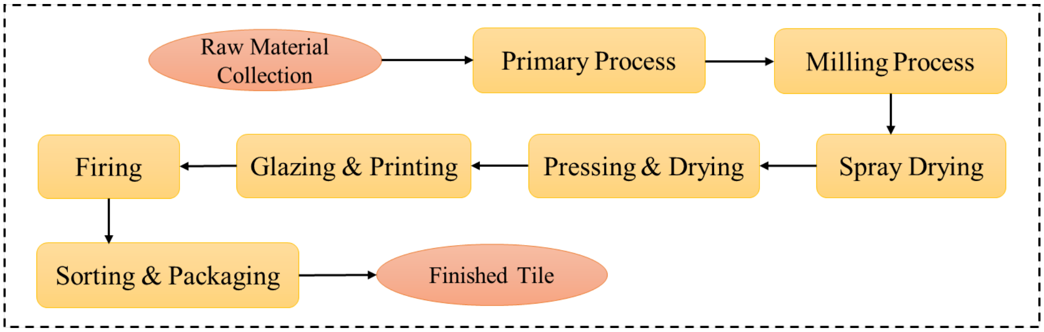

Figure 1. Scope-based boundary

2.1 Life cycle inventory (LCI)

In the Life cycle inventory phase of LCA, all relevant inputs and outputs of a product or process such as energy, raw materials, solid wastages and further releases for the selected life cycle of a product. In order to assess the comparative environmental impact, LCI must be developed and organized according to processes or whatever requirements. Through the site visits and direct contact with technical officers, the LCI data were generated and analyzed in relation to the functional unit. The summarized LCI data which consist of raw materials, electricity, LP gas, wastages and other resources for the functional unit (1 m^2 Ceramic floor tile) of each section wise process is shown in Figure 2. Furthermore, in this research, the back life cycles of resources and country-specific computerized model in SimaPro were constructed (Peiris et al. 2017).

Table 2. Summarized life cycle inventory data for one square meter (FU: 1 m^2) of finished ceramic floor tile

Inputs	Unit	Amount	Product	Unit	Weight	Outputs	Unit	Amount
			Ball Clay	kg/FU	6.71			
			Silica Sand	kg/FU	3.58			
			Dolomite	kg/FU	0.89			
			Feldspar	kg/FU	11.18			
			Total	kg/FU	22.36			
Electricity - Crushing & Primary	kWh/FU	0.01	**Primary Process**					
			Raw Material	kg/FU	22.36			
Water - Added to ball mills	L/FU	6.10	**Milling Process**					
Electricity - Ball Mills	kWh/FU	0.96						
			Slip Liquid	kg/FU	28.14			
LP Gas - Spray Drying	kg/FU	0.90	**Spray Drying**			Evaporated Water	L/FU	4.73
Electricity - Spray Drying	kWh/FU	0.14						
Water - Dust Separator	L/FU	1.80						
			Powder	kg/FU	23.42			
Electricity - Drying	kWh/FU	1.34	**Pressing & Drying**			Evaporated Water	L/FU	1.26
LP Gas - Drying	kg/FU	0.41						
			Dried Tiles	kg/FU	22.15			
Electricity - Glazing	kWh/FU	0.23	**Glazing & Printing**			Rejected glazed tile	kg/FU	0.67
Electricity - Glaze Making	kWh/FU	0.27						
Englobe & Glaze Liquid mixture	kg/FU	6.80						
Printing Ink	g/FU	11.71						
			Glazed Tiles	kg/FU	21.23			
Electricity - Kilns	kWh/FU	1.29	**Firing**			Rejected fired tiles	kg/FU	0.64
LP Gas - Firing	kg/FU	1.44						
			Fired Tiles	kg/FU	20.60			
Electricity - Sorting, Packaging	kWh/FU	0.64						

Polythene - Packaging	m/FU	0.74	**Sorting & Packaging**			
Diesel - Forklifts	ml/FU	11.12				
			Finished Tile	**kg/FU**	**20.60**	
				m^2/FU	**1**	

Table .2. shows a life cycle inventory data of each unit process wise for one square meter of ceramic floor tile which is defined as a functional unit of this study. LCI data was collected by site visits, recorded data, direct measurements, and direct contact with technical officers. According to the LCI data availability that the unit process and functional unit calculations were defined and calculated. Inputs show a contribution of energies and other resources for each unit process relevant to the functional unit. Further, the main material flow and waste stream were also presented. This summarized LCI data has been used to model and assess the environmental potential through the SimaPro software.

2.1 Life cycle impact assessment (LCIA)

The Life cycle impact assessment (LCIA) phase of LCA is the evaluation of environmental impacts in different impact categories based on different methods such as IPCC GWP, ReCiPe, Eco-indicator99 etc. In order to calculate the environmental impacts, the reputed software SimaPro (Ph.D. version) has been used. Evaluated impact categories such as human health, resources, Ecosystem quality etc. have been defined by impact methods. A Life cycle impact assessment endeavors the vulnerability of environment by the manufacturing processes.

2.1 Interpretation

The purpose of interpretation of LCA is intended to provide a comprehensive and consistent presentation of the LCI and LCIA results of LCA based on the goal and scope definition. Through the interpretation, the following elements can be addressed: Identifying significant issues, Evaluation, and Limitations and recommendations. In order to identify improvements and eco-design possibilities on processes or whatever places, this interpreted result will act as a decision support system.

3. Results and Discussion

In order to assess the environmental performance by using SimaPro (PhD version) tool, there are several impact assessment methods such as IPCC 2013 GWP, Eco-indicator 99, ReCiPe and etc. which consist many different sets of impact categories such as climate change, ozone depletion, human toxicity and etc. are available based on different country, regions, rest of world, global and etc. Further, the above mentioned impact assessment methods have been facilitating to investigate the environmental performance in two stages which are problem-oriented (Mid-point) method and damage-oriented (End-point) method. This study has been assessed by using IPCC 2013 GWP and ReCiPe methods.

3.1 IPCC 2013 GWP Method

For the purpose of identifying the climate change, the IPCC 2013 GWP method was generated by the Intergovernmental Panel on Climate Change (IPCC). The Global warming potential (GWP) is a measure of how much heat a greenhouse gas traps in the atmosphere up to a specific time horizon, relative to carbon dioxide (CO_2eq). Further, the GWP is calculated over a specific time frame which is 20, 100, and 500 years. In this study, the characterization model for mid-point assessment was used to assess the global warming potential (GWP) of greenhouse gases (GHGs) over 100 years.

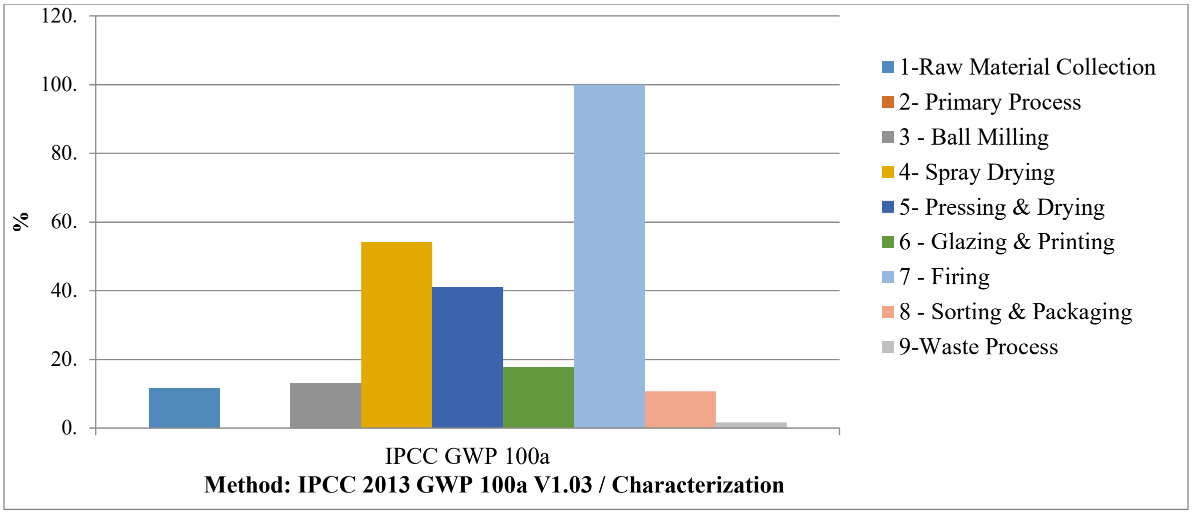

Figure 2. Section wise Contributors to the Global Warming Potential

Figure 2. illustrates the section wise contributors to the GWP for ceramic floor tile manufacturing processes. The graphs are qualitative, which means they are compared to one another. All values were evaluated with respect to the maximum impact, which was set as 100%. It can be seen that the firing process has the most significant potential impact (5.86 kg CO_2eq) on global warming. Further, the spray drying has been occupied the second most contributor (3.17 kg CO_2eq) to the environmental impact. The firing plays a major role due to LP gas combustion process because liquefied petroleum gas (LP-gas) consists of propane, propylene, butane, and butylene which is used to produce a heat in industries and it is produced Greenhouse gasses (GHG) such as Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions during LPG combustion process. However, this fossil fuel combustion processes rapidly increasing the level of GHG emissions in the atmosphere, causing global warming and climate changes.

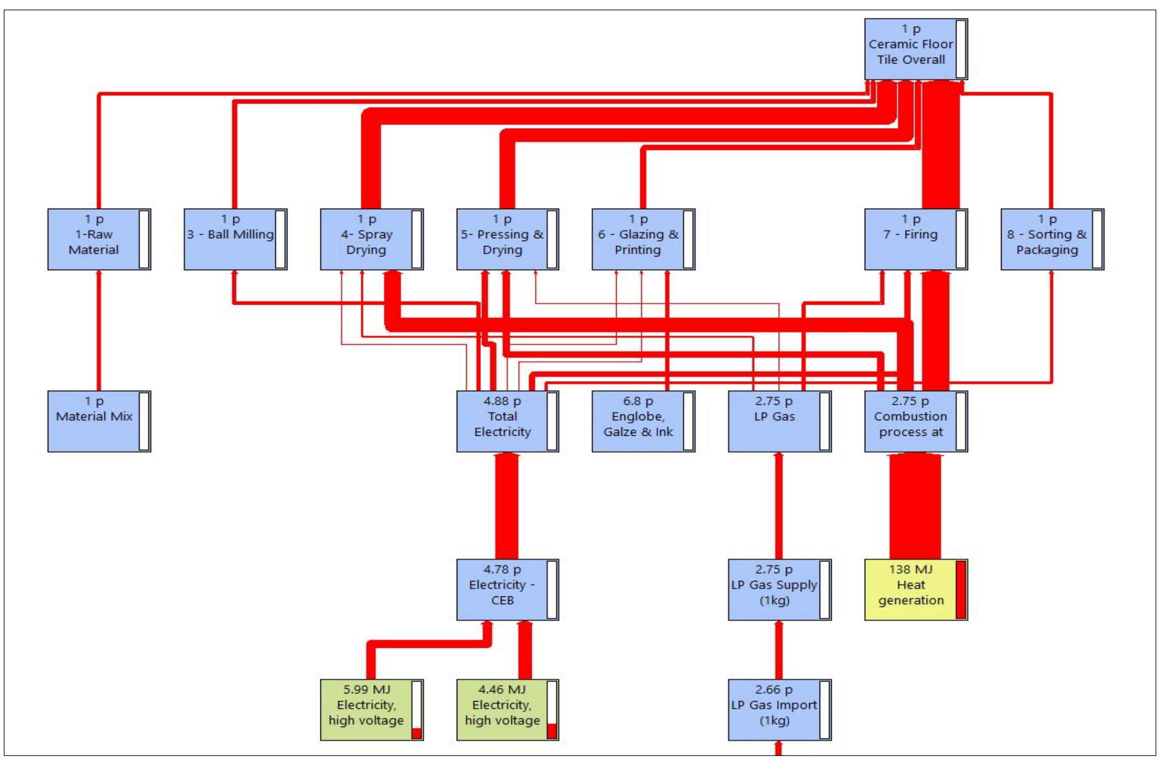

Figure 3. The section wise GWP impact network diagram

Figure 3. represents the global warming potential impact for overall tile manufacturing in network impact assessment approach with 4.2% cut-off. This network diagram shows the exact places where the impacts are generated and how the impact of auxiliary life cycle places and respective impact values are integrated from roots of energy and resources life cycle to factory outlet gate. Further, the weight of the impact is represented by the thickness of the life cycle path which is shown in red lines. The network diagram emphasize that LP gas combustion proses play a major role in causing environmental impact rather than others. However, the LP gas supply is not badly affected and the second major GWP contributor to the tile manufacturing is electricity generation process.

3.2 ReCiPe Method

ReCiPe is an impact assessment method used in LCA which calculates the environmental impact in two different streams: midpoint level (Problem-oriented) and end pint level (Damage oriented). The midpoint indicators focus on single environmental problems such as climate change, ozone depletion, human toxicity etc. But the endpoint indicators show the impact on three higher aggregation level such as resource, human health, and ecosystems.

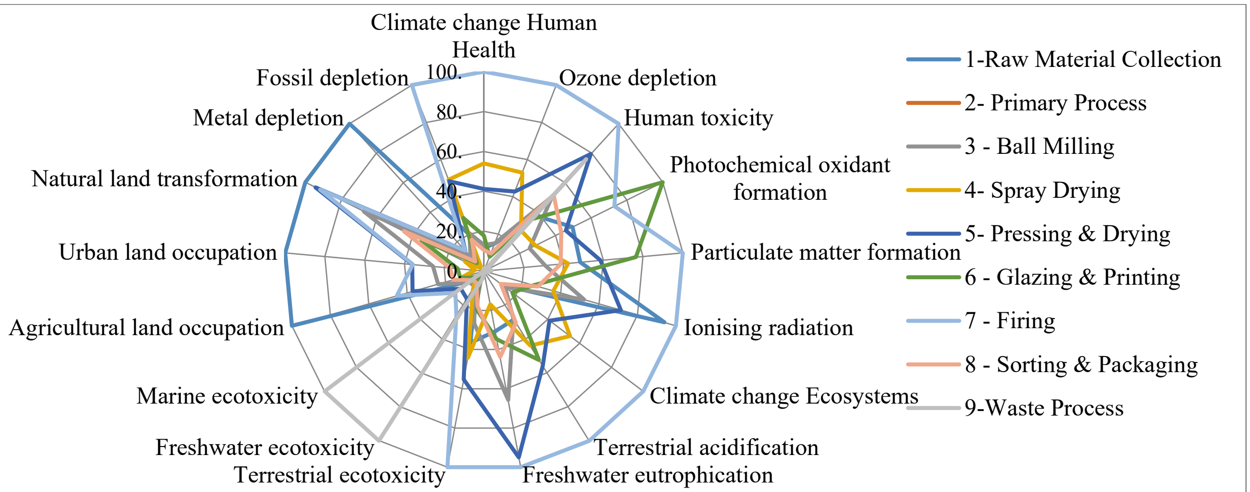

Figure 4. The section wise midpoint characterization model with regard to the ReCiPe impact method

Figure 4. shows a section wise comparison of impact categories under ReCiPe impact method in the tile manufacturing sector for midpoint characterization. It is witnessed from Figure.3 that the impact categories such as climate change human health, ozone depletion, human toxicity, climate change ecosystem, natural land transformation and some of the others are mostly affected by the firing process because of the LP gas usage. As mentioned above, the combustion of LP gas creates a very dangerous effect on the environment through different impact categories. Thereafter, ball milling process is the major contributor to the impact categories which are marine Ecotoxicity and freshwater Eco toxicity due to the electricity consumption and glazing, and printing process plays a major role in photochemical oxidant formation impact categories.

Figure 5. depicts the ReCiPe single score damage assessment within the manufacturing processes. Weighting involves multiplying the normalized results of each of the impact categories with a weighting factor that expresses the relative importance of the impact category. All the weighted results have the same unit and can be added up to create one single score for the environmental impact of a product or process. It is evident from the single score impact result, the major contributor to the environmental impact in all three endpoint impact categories is the firing process. Further, the resource category is affected significantly by the firing process among these three categories.

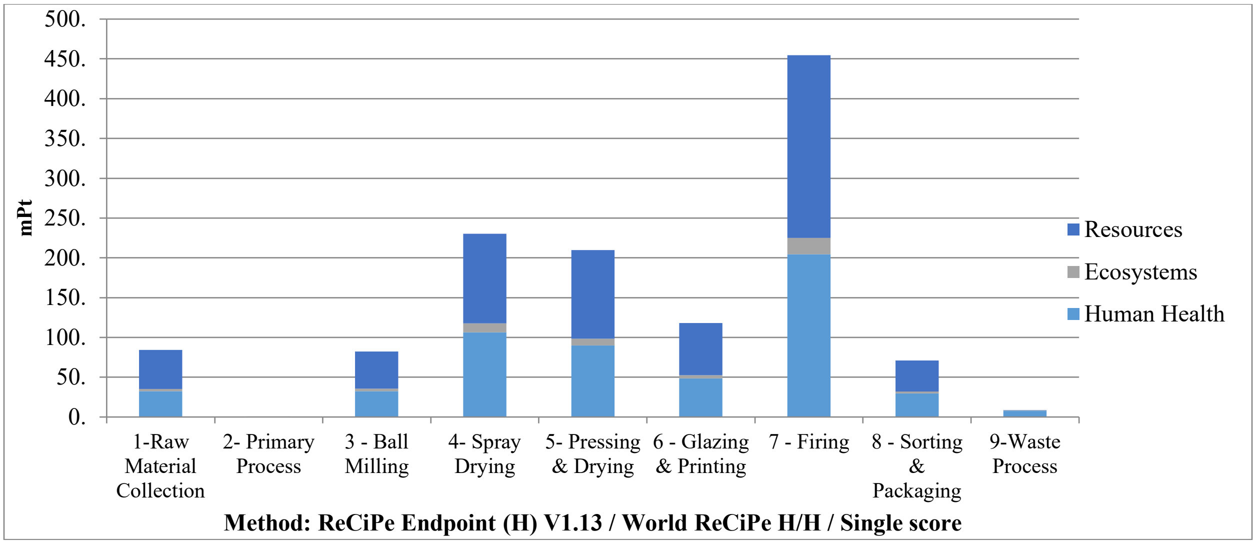

Figure 5. The section wise endpoint single score model with regard to the ReCiPe impact method

Table 3. Scenario analysis of global warming potential before and after 1% of error in inputs

Impact Category	Unit	State	Raw Material	Primary Process	Ball Milling	Spray Drying	Pressing& Drying	Glazing& Printing	Firing	Sorting& Packaging	Waste process
IPCC GWP 100a	Kg CO_2eq	Actual	0.684	0.0076	0.772	3.17	2.41	1.04	5.86	0.622	0.0949
		+1% Error	0.691	0.0077	0.779	3.20	2.43	1.05	5.92	0.629	0.0958

Table .3. shows a scenario analysis of global warming potential before and after 1% of error in inputs of 1m^2 ceramic floor tile which is defined as a functional unit (FU) of this study. The actual GWP value for the overall ceramic industry for FU was calculated by SimaPro 14.661 kg CO_2eq. Thereafter, GWP value was calculated after increase the inputs of all unit processes by 1% of existing inputs, the GWP value is 14.803 kg CO_2eq. Therefore, it is evident from the table value that the total increment of GWP by 1% of error for FU is 0.142 kg CO_2eq. Thus, from this scenario analysis, the way how the impact can be controlled by optimizing energy and resource consumption by 1% of its inputs is cleared.

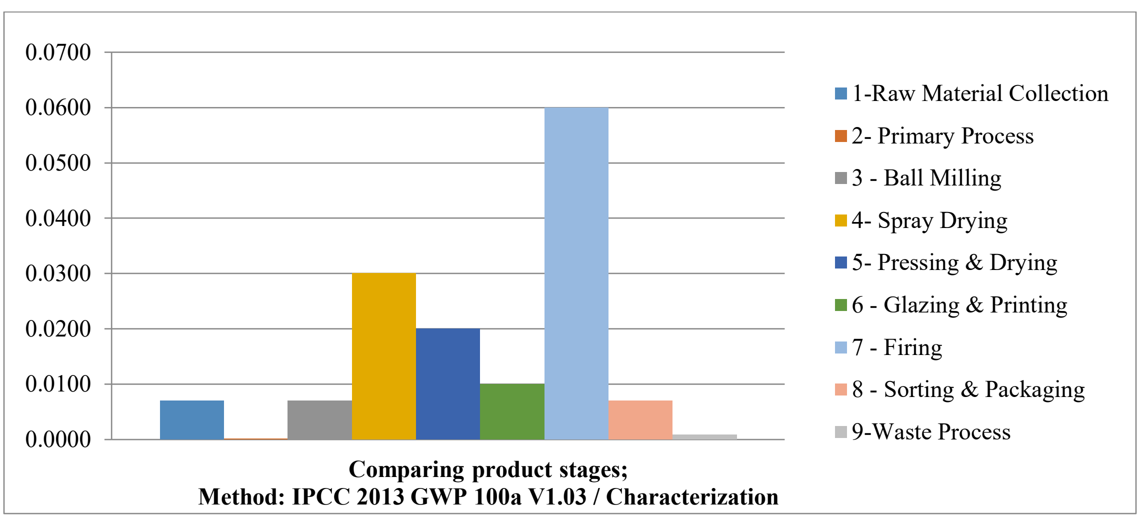

Figure 6. Section wise increment of global warming potential by 1% of error in inputs

Figure 6. shows a section wise increment of global warming potential by 1% of error in inputs. It can be seen that the firing process has the most significant potential impact (0.06 kg CO_2eq) on global warming by 1% of error in input. Afterward, spray drying is the second highest discharging process (0.03 kg CO_2eq) to the environment. This figure clearly states that the firing process plays a vital role in environmental impact due to the LPG combustion process.

4. Conclusions

Global warming is the biggest threat to the world in this current period. This is due to the illegitimate manufacturing practices and enterprises as well as excessive resources and energy utilities. Therefore, such a comprehensive LCA can bring hidden environmental hotspot to the surface which is acting as a major role in environmental impact. In that respect, the environmental hotspot was identified through this study by referring ISO 14040 and 14044 principles which provide a guideline for LCA. According to the IPCC GWP impact assessment method, the firing process was identified as the environmental hotspot which is discharging high amount of emission (5.86 kg CO_2eq) among the ceramic floor tile processes because the LP gas combustion processes rapidly increase the level of GHG emissions in the atmosphere and cause global warming and climate changes. As well as, when concentrating on the ReCiPe impact method, firing process acts as a major contributor to the environmental impact in all three endpoint impact categories such as resource, ecosystem and human health. Particularly, the resource category is affected significantly by the firing process among these three categories. Furthermore, the scenario analysis shows that the firing process discharges a significant amount of impact (0.06 kg CO_2eq) and overall factory emits 0.142 kg CO_2eq to the environment from the production of 1 m^2 floor tile by an increment of 1% of error in input. Therefore, it shows that a small amount of input reduction can also be avoided the environmental impact significantly. On the other hand, a minor error in the LCI may direct to identify incorrect environmental hotspot. Therefore, the accuracy and reliability of LCI is very essential. In such cases, the parametric modeling would be the best solution to compare the performance when making changes in the product or process frequently and it is very beneficial to identify the eco-design possibilities during the design stage. In essence, it is evident from this entire life cycle impact assessment results that the firing process is the stringent hotspot to the environment. Therefore, in order to enhance the sustainability of Sri Lankan ceramic floor tile industry, it is essential to ensure the eco-design possibility to the firing process as it causes serious problems towards the green world.

References

Caputo, J., ‘Incorporating Uncertainty into a Life Cycle Assessment (LCA) Model of Short-Rotation Willow Biomass (Salix spp.) Crops’, *Bioenergy Research*, 7(1), pp. 48–59. doi: 10.1007/s12155-013-9347-y, 2014.

Cooper, J. S., Noon, M., and Kahn, E., ‘Parameterization in Life Cycle Assessment inventory data: Review of current use and the representation of uncertainty’, *International Journal of Life Cycle Assessment*, 17(6), pp. 689–695. doi: 10.1007/s11367-012-0411-1, 2012.

Edirisinghe, J., Life Cycle Assessment of a Ceramic Tile Produced in Sri Lanka, *ARPN Journal of Science and Technology,* vol. 3., pp.1060–1070, 2013.

María D. Bovea, Elena Díaz-Albo, Antonio Gallardo, Francisco J. Colomer, Julio Serrano, Environmental performance of ceramic tiles: Improvement proposals, *Materials and Design* 31 pp.35–41, 2010.

Niero, M., ‘How can a life cycle inventory parametric model streamline life cycle assessment in the wooden pallet sector?’, *International Journal of Life Cycle Assessment*, 19(4), pp. 901–918. doi: 10.1007/s11367-014-0705-6, 2014.

Ostad-Ahmad-Ghorabi, H. and Collado-Ruiz, D. ‘Tool for the environmental assessment of cranes based on parameterization’, *International Journal of Life Cycle Assessment*, 16(5), pp. 392–400. doi: 10.1007/s11367-011-0280-z, 2011.

Peiris, R.L., Kulatunka, A.K., Jindasa, K.B.S.N. Life Cycle assessment of semi-conventional roof tile manufacturing in Sri Lanka,*8th International Conference on Structural Engineering and Construction Management*, ICSECM2017-162,54-63. 2017.

Yasantha Abeysundara, U.G., Sandhya Babel, Mongkut Piantanakulchai, A matrix for selecting sustainable floor coverings for buildings in Sri Lanka, *Journal of Cleaner Production,* 17, pp.231–238, 2009.

Yasantha Abeysundara, U.G., Sandhya Babel, Alice Sharp, life cycle perspective on building floor coverings in Sri Lanka, *5th Australian Conference on Life Cycle Assessment,* 2006.

Ye, L., Hong, J., Ma, X., Qi, C., Yang, D., Life cycle environmental and economic assessment of ceramic tile production: A case study in China, *Journal of Cleaner Production*, doi: 10.1016/j.jclepro.2018.04.112, 2018.

Zimmermann, T. 'Parameterized tool for site specific LCAs of wind energy converters', *International Journal of Life Cycle Assessment,* 18(1), pp. 49–60. doi: 10.1007/s11367-012-0467-y, 2013.

Biographies

Kamalakkannan.S is currently a fulltime Research Assistant at Faculty of Engineering University of Peradeniya. Mr. Kamalakkannan holds a Bachelor of Science degree in Manufacturing and Industrial Engineering from the University of Peradeniya. He has carried out a project regarding design and fabrication of impact resistance testing instrument for ceramic floor tiles. Furthermore, he worked with BOEHM + LECKNER MULTI MOULDS (PVT) LTD and SINGER (SRILANKA) PLC where he supported the engineering departments.

Rajitha L. Peiris is a mechanical and manufacturing engineer and graduated from faculty of engineering, University of Ruhuna. Currently, he has been working as a research assistant in faculty of engineering, University of Peradeniya and reading for M.Phil in the field of sustainable manufacturing. He has contributed around for 8 publications. His research strengths are specialized in Life cycle assessment (LCA), Ecological design, sustainability decision support systems, Machine design, and manufacturing technology.

A. K. Kulatunga is a senior lecturer in the Department of Manufacturing & Industrial Engineering at the Faculty of Engineering, University of Peradeniya, Sri Lanka. He earned Bachelors in Production Engineering from University of Peradeniya, Sri Lanka, and Ph.D. in Mechanical/ Industrial Engineering from University of Technology, Sydney, Australia and gLink Erasmus Mundus Research Fellowship at University of Bremen Germany. He has published several books/book chapters, and more than seventy journal and conference papers. Dr. Kulatunga has served in many local and international forums which include the ministry of Environment Sri Lanka, UNEP LCA initiative, UNIDO-NCPC projects. His research interests include lean and sustainable manufacturing, Industrial Engineering. He is the country representative for IEOM in Sri Lanka. He also holds memberships at IIE, IEEE, ERSCP, and IESL.