Global warming potential of English brick manufacturing in Sri Lanka: A cradle to gate analysis

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Abstract—Clay bricks are one of the most commonly used walling materials in Sri Lanka. The brick manufacturing process poses a notable impact on the environment. Clay excavation leads to resource depletion while diesel fuel utilized for excavation and clay transportation pollutes the air. Additionally, tree cutting for wood fuel contributes to deforestation whilst wood burning promotes air pollution. Thus, this research aimed to quantify the global warming potential due to English brick manufacturing using cradle to gate Life Cycle Assessment (LCA) approach. The functional unit used was one-meter square of the brick wall area. Data collection, analysis and interpretation of results were done by the ISO 14044/14040 standards. Primary life cycle inventory data was gathered via brick kiln owners and workers. The LCA assembly was modelled using the 'OpenLCA' software. Three product systems were defined according to the brick bond types and wall thicknesses. The global warming potential related to brick production was assessed using the 'GWP 100a' method. Clay excavation, clay transportation and wood chamber firing emerged as emission hotspots. The study revealed that the global warming potential of 225mm brick wall and 115mm brick wall as 11.9 and 5.9 kg CO_2-eq/m^2, respectively. Through this study, local clay brick industry can be driven to improve the overall sustainability of the brick manufacturing sector.

***Keywords* — Clay industry, Environmental impact, Life Cycle Assessment (LCA)**

I. Introduction

The construction sector has emerged as one of the most crucial industries in the world, held accountable for massive environmental impacts. Construction material production incurs a large amount of environmental costs. Clay bricks are the most commonly used walling material in small-scale building construction within Sri Lanka. Sri Lankan brick industry dates back to the arrival of Rev: Mahinda Thero [1]. Since then, the brick industry has been spreading into many parts of Sri Lanka such as Kurunegala, Deduruoya, Polonnaruwa, Hikkaduwa, Rathnapura, Galle, Kandy, Kaluthara [2], and significantly in Dankotuwa and Puttalam districts [3]. Annually 800 million bricks are being produced in Sri Lanka [4] for construction.

Resource depletion due to martial consumption, energy consumption and waste disposal are some of the key problems associated with brick production. Clay and biomass are the main resources used in brick production in Sri Lanka whereas India, Sudan, Uganda, and Bangladesh [5] utilize coal and biomass mix energy as fuel for brick kilns. Tree cutting for wood is directly impacting deforestation while fire wood-burning furthers air pollution creating adverse social, health and economic issues. In present, the world is in search for economical and sustainable approaches for all products and services. The brick industry makes commendable efforts to develop various alternative eco-friendly bricks using improved techniques to enhance environmental sustainability. Environmental Life Cycle Assessment can be considered as one of the most feasible and successful methodologies to study the sustainability of products or services by identifying the relevant hotspots.

Much research [6] [7] [8] has been done regarding the structural performance and dimension variation of bricks but LCA studies on local brick manufacturing and associated sustainability assessment can be considered scarce.The objective of the present study was to conduct a cradle to gate Life Cycle Assessment to estimate the global warming potential of clay (English) bricks manufactured in Sri Lanka considering varying functional units.

II. Materials and Methodology

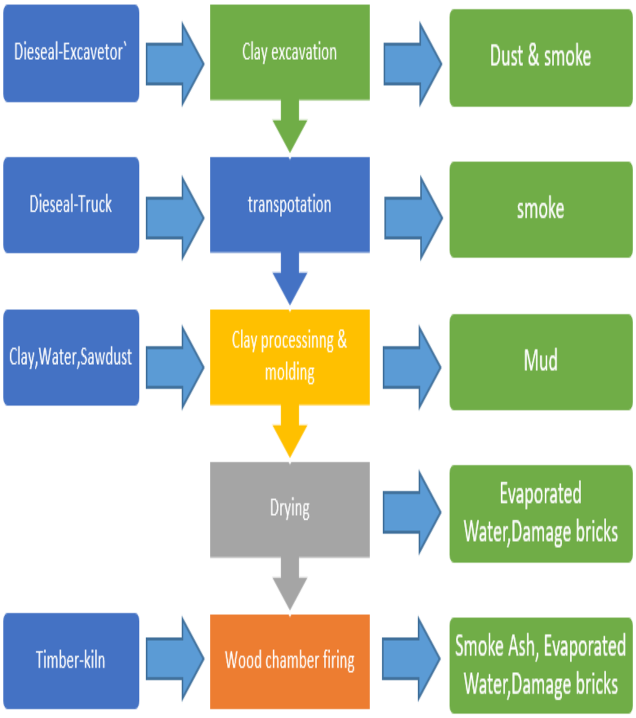

Fig. 1. Process flow diagram of brick production with system boundaries

A. Study site

The site visits were completed in two rounds. A random selection process was carried out to carefully choose ten brick kiln locations prioritizing the Dankotuwa area as most of the clay brick industry is distributed around the Ma Oya valley. These chosen brick kilns were visited to gather the basic required details. The process flow of brick manufacturing was thereby identified as demonstrated in Fig. 1.

B. Goal and Scope Definition

1) Goal –

- To study the GWP due to brick manufacturing according to the functional unit related to three product scenarios as per the Fig 2.
- To identify the hotspots in the process.

2) Scope –

- Cradle to gate

3) Boundary conditions –

- Only English ricks were considered.
- Life cycles of buildings and machinery were neglected.
- Non-material pollutions (noise) were neglected.
- Data other than the LCI were obtained from existing databases.

4) Functional unit –

- One-meter square of wall area according to the brick bond type as per the Fig. 2. Cement, Sand and water requirement for mortar mix were neglected.

C. Life Cycle Impact Assessment.

The 'OpenLCA' software was utilized for the LCA analysis. 'GWP 100a' impact assessment method was the most commonly used reliable method to assess the global warming potential of the average life span of 100 years of brick due to the brick production process. The cradle to gate life cycle analysis was conducted as per the ISO14040 and ISO14044 standards [10],[11].

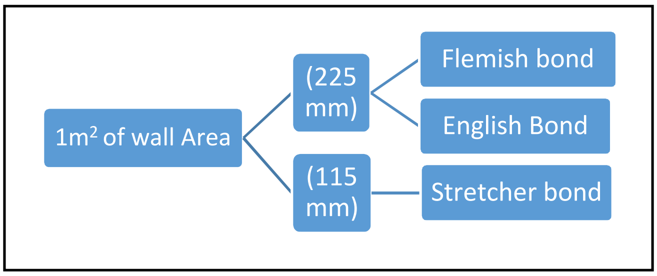

Fig. 2. Fig. 2 Functional unit corresponding to each scenario

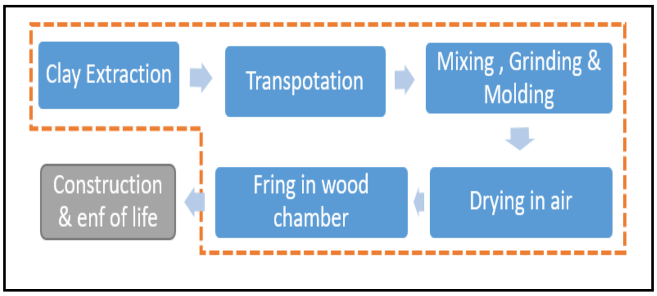

Fig. 3. Fig. 3 LCI Flow Chart

D. Unit processes

1) Clay excavation.

Clay mining is usually carried out by utilizing heavy machinery such as excavators. The LCA inventory indicated diesel as the main input for the excavation process. It should be noted that all other life cycle inputs related to the excavator were neglected. All the emissions related to diesel-burning were gathered from the 'Agri-footprint' database. Other remaining information was collected as per "TABLE I" directly from the excavator operators.

2) Clay transportation

While tipper trucks were used mainly for clay transportation, the diesel quantities expended for transportation activities was obtained as LCI input. Other life cycle inputs of the tipper truck were neglected. But two-way traveling was included with the empty return. Emission-related data for the diesel-burning processes were obtained from the 'ecoinvent' databases. Data on the tipper trucks such as fuel efficiency, travel times and distances were gathered as per "TABLE II" via direct interviews and encounters with the excavator drivers and other involved personnel.

3) Clay processing & Molding

The brick molding was done by skilled workers manually. Therefore, it can be noted that the clay processing and molding unit processes did not require any form of power from electricity or fuel. Following this, the casted bricks were stored layer by layer. In order to remove the stickiness between bricks, the workers applied a layer of sawdust on the freshly casted bricks.

4) Drying

The molded fresh clay bricks were kept for a minimum time period of 7 days to dry by airing. A special brick stacking technique was followed by the workers for ease and to speed up the drying process. No inputs were added to the LCI for this unit process. However, the output of the LCI for this unit process comprised of values which accounted for bricks that were broken or damaged due to mishandling during stacking and moving, while additionally the water inside the brick which was removed as water vapor during the airing process was also considered. This water quantity was measured by taking the weight difference between the fresh bricks and dried bricks.

5) Wood chamber firing

This can be considered to be the most crucial unit process for the LCI. In this stage, dried bricks were stacked as a 'tunnel kiln'

TABLE I. CLAY EXCAVATION DATA

Description	Value	Unit
Net Power of the CAT 320 excavator	162	hp
Excavation and loading duration for 100 ft3 of clay	20	min
Fuel consumption per hour	5	l/h
Total diesel consumption for excavation and loading of 100 ft3 (2.83 m3) clay	1.65	l

TABLE II. CLAY TRANSPORTATION DATA

Description	Value	Unit
Truck engine capacity	4500	CC
Tipper truck capacity	100	Ft^3
Average clay hauling distance	15	km
Average fuel consumption	7	l/km

Following the arrangement of the brick kilns, the wood was inserted. Normally, firewood was purchased from timber sellers who usually gather different wood from different areas and timber mills. The softwood category is considered the optimum choice for kilns. The firing process was considered to take approximately two days. Next the kiln is allowed to cool down naturally, which generally takes up to one week. In this unit process inputs were firewood and outputs were ash, smoke and damaged bricks normally, 1-2% of bricks were considered to be damaged during stacking and loading.

The main objective of the first round was to select the most suitable kiln for this LCA study. After summarizing all the collected data, an analysis process was carried out where a list of different criteria was documented to be checked and compared with regards to each studied kiln, to finally choose the best option satisfying all concerned criteria. All collected data from each brick kiln was graphed in accordance to the criteria listed as follows. Total wood consumption Vs Brick Kiln, Dimensions of the brick Vs Brick Kiln, Average clay hauling distance Vs Brick Kiln, Total brick production from (100 ft^3) a lorry cube of clay Vs Brick Kiln. The trend lines were drawn accordingly and appropriately. Finally the brick kiln that best met all four criteria considered was chosen for this LCA study.

After finalizing the selection of the most appropriate brick kiln, it was visited again and the above-identified inventory data for the LCI was collected through a form of a questionnaire which was distributed amongst the kiln owners and site workers. For the LCI, the brick quantity was taken according to the FU. In order to calculate the brick quantity, a 1 m^2 of the continuous wall with a 10 mm thick mortar bed was assumed. However, bedding maotar was not considered for the calculation. The brick amount was calculated as shown in Equations “(1)”to “(3)”;

Stretcher bond (115 mm) = 59.26 Bricks (1)

Flemish bond (225 mm) = 118.40 Bricks (2)

English Bond (225 mm) = 118.52 Bricks (3)

E. Sample calculation for English bond wall

This section describes the data selection & calculation for the inventory table as the sample calculation for English bond. The other two scenarios (Flemish and Strecher bonds) also can be calculated accordingly. All the LCI input sample calculations are shown in The “TABLE III, TABLE IV, TABLE V, TABLE VI” & outputs are “TABLE VIII, TABLE IX, TABLE X, TABLE XI”.

TABLE III. CLAY EXTRACTION & LOADING FUEL CALCULATION FOR ENGLISH BOND WALL

Description	Value	Unit
Total diesel consumption for excavation and loading of 100 ft3 clay	1.65	l
No of bricks produced by the 100 ft3	1100	Nos
Diesel requirement for brick	1.65/1100 =0.0015	l
No of Bricks in 1m2 English bond wall	**118.52**	**Nos**
Total diesel requirement for FU	**118.52*0.0015 =0.178**	**l/FU**

TABLE IV. CLAY TRANSPORTATION FUEL CALCULATION FOR ENGLISH BOND WALL

Description	Value	Unit
Average fuel consumption	7	l/km
Total diesel consumption for 100 ft3	2.14	l
No of bricks produced by the 100 ft3	1100	Nos
Diesel requirement for brick	1.65/1100 =0.001945	l
No of Bricks in 1m^2 English bond wall	118.52	Nos
Total diesel requirement for FU	**118.52*0.001945= 0.231**	**l/FU**

TABLE V. CLAY VOLUME, WATER VOLUME & SAWDUST QUANTITY CALCULATION FOR ENGLISH BOND WALL

Description	Value	Unit
Tipper truck volume	2.83	m^3
No of bricks produced by the 2.83 m3	1100	Nos
Clay requirement for brick	2.83/1100 =0.002573	m^3
No of Bricks in 1m^2 English bond wall	118.52	Nos
Total clay requirement for FU	118.52* 0.002573= 0.305	m^3/FU
Water requirement for 1000 bricks	800	l
Water requirement for brick	800/1000 =0.8	l
No of Bricks in 1m^2 English bond wall	118.52	Nos
Total water requirement for FU	118.52* 0.8= 94.816	l/FU
Sawdust requirement for 1000 bricks	250	kg
Sawdust requirement for brick	250/1000 =0.25	kg
No of Bricks in 1m^2 English bond wall	118.52	Nos
Total sawdust requirement for FU	118.52* 0.25= 29.63	kg/FU

TABLE VI. WOOD FUEL CALCULATION FOR ENGLISH BOND WALL

Description	Value	Unit
wood requirement for 10 000 bricks	3.822	m^3
Wood requirement for brick	0.00382	m^3
No of Bricks in 1m^2 English bond wall	118.52	Nos
Total wood requirement for FU	**118.52* 0.0057= 0.045**	**m^3/FU**

- Clay extraction & loading

No outputs are there in this inventory table. Smoke due to the diesel-burning was automatically calculated within the software by using the data in the database.

- Clay transportation

No outputs are there in this inventory table. Smoke due to the diesel-burning was automatically calculated within the software by using the data in the database.

- Clay *processing & molding*

No outputs due to the clay processing and molding was considered. The only waste considered is the mud which is repetitively used for processing.

- Drying in air

During the drying process, bricks lose their weight by evaporating the water as water vapor into the atmosphere. This was calculated by taking the weight difference of fresh clay brick and dried clay brick.

TABLE VII. EVAPORATED WATER (DRYING IN THE AIR) VOLUME CALCULATION FOR ENGLISH BOND WALL

Description	Value	Unit
Average fresh weight of brick	2.1	kg
Average air-dried weight of brick	1.89	kg
Average evaporated water from the brick	0.21	kg
No of Bricks in 1m^2 English bond wall	118.52	Nos
Total evaporate water for FU	**118.52*0.21= 24.88**	**kg /FU**

TABLE VIII. DAMAGED BRICKS (DRYING IN AIR) QUANTITY CALCULATION FOR ENGLISH BOND WALL

Description	Value	Unit
Average wastage of damaged bricks	1	%
No of Bricks in 1m^2 English bond wall	118.52	Nos
Total Damaged bricks for FU	**118.52*1%= 1.185**	**No/FU**

TABLE IX. EVAPORATED WATER (WOOD CHAMBER FIRING) VOLUME CALCULATION FOR ENGLISH BOND WALL

Description	Value	Unit
Average air-dried weight of brick	1.89	kg
Average weight of final brick	1.78	kg
Average evaporated water from the brick	0.11	kg
No of Bricks in 1m^2 English bond wall	118.52	Nos
Total evaporate water for FU	**118.52*0.11= 13.037**	**kg /FU**

TABLE X. DAMAGED BRICKS (WOOD CHAMBER FIRING) QUANTITY CALCULATION FOR ENGLISH BOND WALL

Description	Value	Unit
Average wastage of damaged bricks	0.75	%
No of Bricks in 1m^2 English bond wall	118.52	Nos
Total Damaged bricks for FU	**118.52*0.75%= 0.889**	**No/FU**

TABLE XI. WOODASH GENERATION CALCULATION FOR ENGLISH BOND WALL

Description	Value	Unit
Average ash volume for 10 000 bricks	0.75	m^3
Wood requirement for brick	0.000075	m^3
No of Bricks in 1m^2 English bond wall	118.52	Nos
Total wood requirement for FU	**118.52*0.000075 = 0.009**	**m^3 /FU**

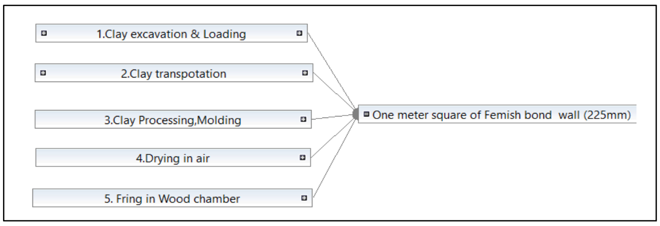

Fig. 4. Flemish bond (225 mm) Software assembly

During airing, mishandling of the bricks can result in damage and rejection of bricks. Although at this stage, damaged bricks can be crushed and reused, it can only be done at the expense of a lengthy process which can incur additional costs. At present, there is no reuse process in plance and the crushed bricks erode through weathering as a pile of clay. In average, 100 bricks were rejected for every 10 000 bricks. It is nearly 1% of the casted bricks.

- *Wood chamber firing*

When the firing process is carried out in the chamber, bricks are considered to emit water vapor into the air. It was calculated by the average weight difference of the air-dried brick and the final brick.

Mishandling of bricks at this stage can result in the damaging and rejection of bricks. At this point, it is impossible to reuse the damaged bricks as they are burnt. As an average number 75 bricks were rejected from every 10 000 bricks. It is nearly 0.75% of the casted bricks.

Ash is generated as a byproduct of wood-burning. Generally, the ash production can be quantified as 0.75 m^3 of ash for 3.822 m^3 (5 Yard^3). 5 Yard^3 of wood are used to burn 10 000 bricks.

F. Life cycle inventory (LCI)

Life cycle inventory was prepared according to the defined goals, scope & functional units. All required LCI data was collected by conducting a field survey while interacting directly with the brick kiln owners and workers. Table I summarizes inputs and outputs according to the unit processes as given in Fig. 1. Clay, wood, and water are the main raw materials while diesel was used in excavation and transportation-related equipment and machinery.

G. Life cycle impact assessment (LCIA)

The unit processes flow was created utilizing the 'Open LCA' software while the 'IPCC GWP 100a' was used as the analysis method.'IPCC GWP 100a' method was developed by the 'Intergovernmental Panel on climate change, for the quantification of the Global warming potential for 100 years. Using existing databases and LCI data in TABLE XII, three product systems were assembled according to the functional unit. Fig.4 represents the life cycle assembly for the Flemish bond (225 mm) which is similar to the two other product scenarios prepared.

III. RESULTS

A. Relative Results

Fig. 5 shows the relative indicator results of the respective project variants. For each indicator, the maximum result is set to 100% and the results of the other variants are displayed in relation to this resuls.

B. IPCC GWP 100a

Summary of IPCC GWP 100a results are shown in TABLE XIII. Global warming potential due to 1 m^2 English bond wall (225mm) is 11.9800 kg CO_2 eq, 1m^2 Flemish bond wall (225mm) is 11.9686 kg CO_2 eq, 1m^2 stretcher bond wall (115mm 5.9903. kg CO_2 eq. and other than the functional unit 100 bricks emit 1.0108 kg CO_2 eq.

Fig.6 shows the contribution of the unit processes for the GWP 100a. Accordingly, the main three hotspots were identified as clay excavation, clay transportation and wood

TABLE XII. LIFE CYCLE INVENTORY BY FIELD SURVEY

Process	Inputs					Outputs				
	Activity	Amount				Activity	Amount			
		Unit	Stretch er bond	Flemish bond	English Bond		Unit	Stretcher bond	Flemish bond	English Bond
Clay extraction & loading	Diesel-Excavator	l/FU	0.089	0.178	0.178					
Clay transportation	Diesel-Lorry	l/FU	0.115	0.230	0.231					
Clay processing & molding	clay	m^3/FU	0.152	0.305	0.305					
	water	l/FU	47.408	94.720	94.816					
	Sawdust	kg/FU	14.815	29.600	29.630					
Drying						Evaporated Water	l/FU	12.445	24.864	24.889
						Damaged Bricks	kg/FU	0.593	1.184	1.185
Wood chamber firing	wood	m^3/FU	0.0226	0.045	0.045	Evaporated Water	l/FU	6.519	13.024	13.037
						Damaged Bricks	kg/FU	0.444	0.888	0.889

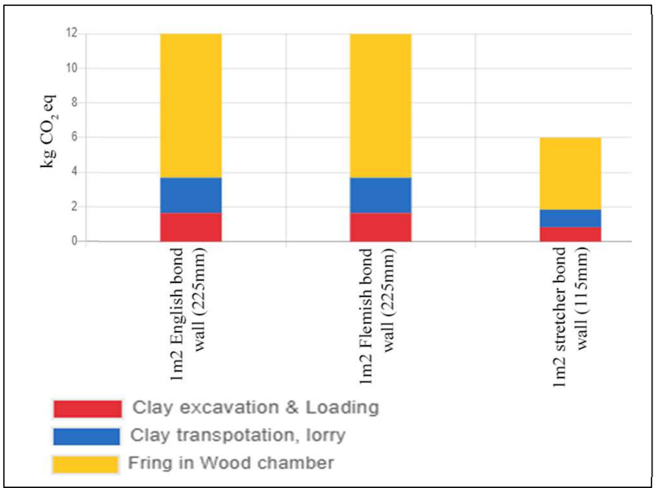

Fig. 5. Relative GWP of brick walls

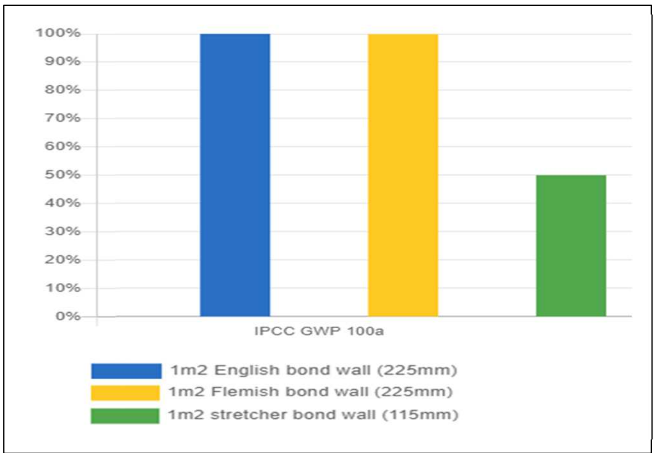

Fig. 6. Relative Results of the case study

TABLE XIII. IPCC GWP 100A RESULT SUMMARY

Indicator	$1m^2$ English bond wall (225mm)	$1m^2$ Flemish bond wall (225mm)	$1m^2$ stretcher bond wall (115mm)	Making of 100 Bricks	Unit
IPCC GWP 100a	11.9800	11.9686	5.9903	1.0108	kg CO_2 eq

chamber frying. More than 70% of GWP was accounted by the wood chamber of brick burning.

IV. DISCUSSION & CONCLUSION

A. Interpretation & Discussion.

a) IPCC GWP 100a Method

Three different brick wall patterns were studied under the given functional unit. "IPCC 2013 GWP" method was developed to identify climate change due to global warming potential. GWP describes the amount of greenhouse gas trapped in the atmosphere up to a specific time limit, equivalent to Carbon dioxide mass. This method was prepared by the Intergovernmental Panel on climate change (IPCC). '100' represents the specific period of the study in years (note that 20 years and 500 years' methods are available). With regards to this research, only GWP for 100 years was assessed.50 year average life were cosiderd normally in construction design, but most of the Buildings retain around 50-70 years since GWP 100a were selected.

GWP contribution of three different brick wall types other than the standard wall types and thicknesses. Within the considered five unit processes, firing in the wood chamber contributed to 48% of the GWP. It contains greenhouse gas emissions due to the wood fuel burning while the other two hotspot unit processes were majorly contributed by burning diesel as a transport and loading fuel. The required wood quantity slightly varied depending on the moisture content and the wood type. Generally, five cubic yards of wood fuel was demanded the burning of 10 000 bricks. Carbon dioxide, carbon monoxide, and nitrous oxide are the key gasses emitted due to wood-burning.

Trees are the net carbon sink for the atmosphere. During the lifetime of a tree, a considerably large amount of CO_2 is absorbed from the atmosphere. Furthermore, the end impact of wood-burning is considered as emittance of CO_2 to the environment because the net amount of carbon dioxide emission is the difference between the emission and absorption of CO_2 throughout the considered process. However, it should be noted that in this research CO_2 assimilated by the trees was neglected.

The results of the present study is comparable with the past studies. In a local study conducted [12] on conventional bricks, it was found that a single brick emits 0.113549 kg CO_2.

In comparison, this research founded that per brick emits 0.1957806 kg CO_2 Furthermore, a Brazilian study [13] indicated that the life cycle carbon emissions inventory for brick masonry is 11.88 kg CO_2 per m^2. In comparison, this research founded that per meter square of wall area generally emits 11.6 kg CO_2. Most of the LCA's neglect the CO_2 assimilation process and conducted as a seperete study becsuse it process takes few years to take accurate result.

B. Conclusion

The GWP of 1 m^2 of English bond wall (225mm) and 1m^2 of the Flemish bond wall (225mm) were found to be 11.9800 kg CO_2 eq, 11.9686 kg CO_2 eq. English bond wall being only 0.11% less than the Flemish bond wall. Stretcher bond (115mm), wall impacts were found to be less than 50.03% of the Flemish bond wall.

This LCA assembly contains the five-unit processes, however, in most cases, only the main three hotspots are emphasized on. The other two omitted unit processes, mixing, molding and air drying processes did not involve any kind of energy sources or chemicals as they were all manual activities.Clay excavation, clay transportation and wood chamber firing emerged as CO_2 emission hotspots. Wood chamber firing contributes 68.20% GWP, clay transportation contributes 17.83% GWP and Clay excavation contributes 13.97 GWP.

When comparing diesel fuel usage in Clay excavation and clay transportation, it can be identified that wood fuel comparatively incurs large damage than diesel fuel in brick industry.although at the expense of deforestation which causes a significant reduction in the natural air cleaning process. Therefore, it can be recommended that a suitable and effective solution for this issue is the utilization of timber residue from timber mills. This will aid the reduction of the drastic adverse impacts both wood fuel and diesel fuel usage causes.

ACKNOWLEDGMENT

we would like to express my grateful gratitude to the brick kiln owners, and their staff for the providing necessary information for my research.

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