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Inventory of life cycle CO_2 emission of selected building materials of Bangladesh

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ABSTRACT: Bangladesh is a developing country. The construction sector of Bangladesh has seen massive boom in last few decades and is responsible for greenhouse gases contribution. The aim of the study is to develop inventory of life cycle CO_2 emission equations for seven most widely used construction materials of Bangladesh namely brick, cement, sand, steel; both from billet and scrap, stone chips, timber and concrete. The system boundaries have been both cradle to gate and cradle to grave. Locally used units have been used in developing these empirical equations. The stages considered have been raw materials extraction, processing, transportation, construction of building, demolition and disposal. Operational CO_2 emission of the building has not been taken into consideration. The developed equations will help the local civil engineers to assess and compare the environmental impact of building projects in different locations of Bangladesh and also help to identify sustainable building material for Bangladesh.

1 INTRODUCTION

The construction industry is responsible for a large and growing share of global emissions and a major contributor of green house gas emissions. It is responsible for 40% of the greenhouse gas emission (Fernandez 2008). It has a tremendous impact on the environment and natural resources. Building envelopes consume a large amount of materials related to raw and processed construction materials such as cement, glass, steel, brick, timber etc. It also consumes great amount of traditional building materials namely bricks, tiles, ash, sand, stone, etc. If the carbon footprint of these materials is known then initiatives can be taken to reduce it. It has been suggested recently that CO_2 emissions may be a more meaningful single indicator of overall global environmental impact. A carbon footprint of a material is “the total set of greenhouse gas (GHG) emissions” caused by that material. It is a subset of the ecological footprint and of the more comprehensive Life Cycle Assessment (LCA) (Bernstein et al. 2007). In many cases it is feasible to calculate CO_2 emissions from energy data, though again this tends to be country-specific, depending on the energy mix and industrial base of the region and chemical releases of CO_2. Nevertheless, this study is an attempt to develop empirical equations of life cycle CO_2 emission from building materials. It has been structured for seven most common and widely used construction materials of Bangladesh. They are brick, cement, sand, stone chips as coarse aggregates, steel; both from billet and scrap, timber and concrete.

2 METHODOLOGY

Oppenheim & Treloar (Oppenheim et al.1995) discussed that in both Australia and overseas the field of embodied energy and CO_2 emission analysis is generally still only of academic interest. There is little interest in the market place for undertaking of these calculations and the design changes that would follow from the results produced. Additionally, no country yet has embodied energy regulations. Accurate knowledge is hard to find, and it is rare to find calculations done during the design process. For this study, data has been collected from the secondary resources of public domain, including journal articles, life cycle assessments, books, websites, conference papers, field data etc. All the information has been collected and used considering perspective of Bangladesh. Cradle to gate has been the most common boundary condition but for some material study has been also continued for cradle to grave. For some recyclable materials like steel; both from billet and scrap total life cycle emission term has been used other than the boundary condition cradle to grave. Uncertainty is unfortunately a part of CO_2 analysis and even the most reliable data carries a natural level of uncertainty.

2.1 *Emission data selection criteria*

Due to the difficulties that have been experienced in selecting emission values, the criteria needed to be flexible but maintain an ideal set of conditions. Six criteria have been applied for the selection of CO_2 emission values for individual materials. This ensures the consistency of the data. They are given below:

Compliance with approved methodologies: Preference has been given to data sources that complied with accepted methodologies and manufacturing procedure. For example, about 90% of the brick fields use manual molding, drying procedures. In this case, mechanical operations have not been considered.

System boundaries: The system boundary has been adopted mainly as 'cradle to gate', but in case of some materials 'cradle to grave' has been considered. Construction phase and demolition phase has been taken into consideration. Steel is recycled as raw material after use in building. In this case, the term 'total life cycle emission' has been used other than cradle to gate or cradle to grave. For component materials like sand, aggregate and cement which will be finally incorporated into concrete, cradle to gate emissions has been considered.

Origin of data: Ideally the data used and the equations developed would have been restricted to that emanating from Bangladesh. In case of some materials it has not been feasible due to lack of available data and study. Data of CO_2 emission from manufacturing process, construction equipments etc from foreign sources has been considered only if the same procedures are followed in Bangladesh.

Age of data sources: Preference has been given to modern sources of data. Historical changes in fuel mix and carbon coefficients associated with electricity generation give rise to greater uncertainty in the CO_2 emission values.

Operating CO_2 emission: In this study, operating CO_2 emission of building material, thermal conductivity and diffusivity has not been considered. No of times the material has been recycled do not have any significant impact on CO_2 emission calculation.

Carbon dioxide emission factors: Petro chemicals as fuels have been considered for number of manufacturing process of materials. In that cases the fuel consumption has been converted to CO_2 emission values by using CO_2 emission factors. Emission factors have been used from unit conversion fact sheet by MIT (2007) (http://web.mit.edu/mit_energy) and Guidance for Voluntary, Corporate Greenhouse Gas Reporting: Data by New Zealand (Fuel combustion emission factors 2008). In addition to these selection criteria the data primarily focused on construction materials.

The total life cycle of the materials has been considered from perspective of Bangladesh. For example; aggregates are mainly imported from neighboring countries and mainly processed in Bangladesh though very small amount can be quarried. So, equations have been developed for both cases. The carbon dioxide coefficients selected for the study has been representative of typical materials employed in the Bangladeshi market. In order to ensure that this data have been representative of typical products, taking timber as an example; the consumption of most common types of timber was applied to estimate a single 'representative' value that can be used in the absence of more detailed knowledge of the specific type of timber.

2.2 *Mode of material transport*

In most of the previous researches of life cycle CO_2 emission of construction materials, the boundary conditions were cradle to site. This was based on the assumption that in many cases transport from the factory gate to construction site would be negligible (Cole et al.1996). Whilst this may be true for many materials but this is not exclusively the case. In the case of materials which have very low carbon dioxide emissions from their processing such as sand and aggregate, emission from transportation is likely to be significant. For these reasons the ideal boundaries have been modified to cradle to gate from the previous cradle to site. This decision will also encourage the user to be transport specific to their case in hand.

In this study two types of transportation has been considered. They are –

- Shipment of materials (for slag, steel billets)
- Transportation by road of raw materials and products within the country.

Emission from fuel consumption data has been used from the chart of Swedish Network for Transport and the Environment (Maersk Line 2007) which gives emission of carbon dioxide directly for mode of transportation. In case of shipment distance in nautical miles (http://www.searates.com/reference/portdistance/) has been converted into miles to calculate emission from shipment. Bangladesh imports raw materials from a number of countries. In this case among the countries Bangladesh regularly imports raw materials; maximum and minimum distance have been selected considering local market survey to give representative values.

2.3 *Functional unit*

Empirical equations have been developed which required input values in desired unit. Material must be represented on their functional unit basis. For example, cement is represented in tons, sand in kg, bricks in single unit etc. The manufacture of 1 kg of product requires raw materials more than 1 kg. The quantity of waste, volume decrease, shrinkage etc has been considered in this study. The impacts of maintenance on life cycle emission of materials have not been considered. Highly fabricated and intricate items require manufacturing operations that are beyond the boundaries of the study.

3 INVENTORY OF CO_2 EMISSION OF MATERIALS

3.1 *Brick Profile*

In aggregate starved Bangladesh, fired clay bricks form a significant portion of the materials used in the construction industry. Brick making is considered to be the largest contributor to green house gas emissions in Bangladesh in the order of 3.0 million tones of CO_2 emissions annually (World Green Building Council 2006).Currently, the brick making sector in Bangladesh uses four types of technologies: Fixed Chimney Kilns (FCK), Bull's Trench Kilns (BTK), Zigzag Kilns, and traditional Hoffman Kilns. Prior to 2004, of the kilns in Bangladesh used the BTK design, a relatively primitive design that is over 150 years old. After promulgation of the Brick Burning (Control) Act in 2004, almost all of the BTKs have been converted to FCKs (UNFCC 2008).

Table 1: Current market share of technologies in the brick making sector

Kiln type	Number	Percentage of total	Annual brick production billions	Percentage of total production
FCK	3,138	76	6,276	75.9
BTK	797	19	1.59	19.3
Zigzag	198	5	0.40	4.79
Total	4,133	100	8.27	100

Source: Improving Kiln Efficiency for the Brick Making Industry - PDF B Phase (UNDP-GEF-BGD/04/014)

As fixed chimney kilns are majority, FCK kiln has been considered for emission calculation from kilns in this study. Stages considered for brick have been - clay extraction, clay delivery to brick plant, mixing and shaping, drying and burning, transportation, installation in site, recycling as brick chips and reuse. For drying and burning of bricks, emission data of FCK kiln has been used (UNFCC 2008). Equations have been developed for a single brick as functional unit and both the boundary conditions i.e. cradle to gate and cradle to grave. In all calculations standard brick dimension (9.5″x 4.5″x 2.75″) given by Public works department (PWD) Bangladesh has been considered.

Similar studies on life cycle CO_2 emission from single brick done in Australia (Grant 2010) showed that the emission is 700 g CO_2 and 620 g CO_2 in the study done by university of bath (Hammond et al. 2008). In both these studies the whole process was mechanized and in cradle to gate emission calculation operation CO_2 emission from the building was also considered. In case of Bangladesh, most of the bricks are still hand molded. Mechanical equipment is almost always used in clay preparation. Almost all the operations are manual, ranging from bringing the clay to the pug mill, to the molding and drying ground, to the kiln and from the kiln to the warehouse. Brick production in Bangladesh is labor intensive.

Cradle to gate emission = $380.25+0.21d_{b1}$ (g CO_2 / single brick) (1a)

Cradle to grave emission = $380.25+0.21 (d_{b1}+d_{b2})$ (g CO_2 / single brick) (1b)

Where, d_{b1}= distance in km from brick field to construction site; d_{b2}= distance in km from construction site to brick chips processing site.

3.2 *Cement Profile*

A cement production plant consists of the following three processes: raw material process, clinker burning process and finish grinding process. The raw material process and the clinker burning process are each classified into the wet process and the dry process. These processes are selected with consideration given to properties of raw materials, costs of fuel, conditions of location and others. For the wet process, plant construction cost is rather low and high-quality products are manufactured easily. On the other hand, the dry process consumes less energy and its running cost is lower. Ninety percent or more of fuel is consumed for clinker burning. About 40% of electric power is consumed for finish grinding, and a little fewer than 30% each is consumed by the raw material process and the clinker burning process. The raw material grinding process consumes a large volume of power for the mill and fan. Bangladesh imports clinker and slag; so the raw materials shipment has been considered other than extraction and quarrying. Most of the cement plant in Bangladesh is grinding plants and production process starts from grinding, so the development of CO_2 emission equation starts from raw material grinding. Grinding is a mechanical process and same for all countries. The emission data of Tec Eco cement (www.tececo.com) has been used for raw grinding, kiln process, chemical releases and re-carbonation. Study of Tec eco cement showed that for every 1% slag emission reduces 8.4 CO_2/ton of cement.

According to University of bath, CO_2 emission from Portland cement was found to be 830 kg CO_2/ton; whereas CO_2 emission from cement with 26% fly ash was 620 kg CO_2/ton and 50% fly ash was 420 kg CO_2/ton (Hammond et al. 2008). Hence, stages considered for cement were raw grinding, kiln process, chemical releases, emission due to shipment of slag, less re-carbonation and transportation within country. Three most popular cement types have been considered for their different composition. As the grinding and kiln process are similar worldwide, the emission data of Tec Eco cement (www.tececo.com) was used for CEM-I, CEM-IIA and CEM-IIB. Life cycle CO_2 emission equations were developed for one tone of cement with cradle to gate boundary condition.

Cradle to Gate Emission

CEM- I = $870 + 50\ d_c$, (kg CO_2/ton) (2a)

CEM-IIA = $700 + 50\ d_c$, (kg CO_2/ton) (2b)

CEM-IIB = $580 + 50\ d_c$, (kg CO_2/ton) (2c)

Where d_c = total distance in km from cement factory to market and market to construction site.

3.3 *Steel Profile*

Bangladesh imports 70% billets and other raw materials of steel production from foreign countries (www.secbd.org/Prospectus_BSRMS.pdf) as scrap ship import had been decreased. Sources of steel products include Australia, Belgium, Canada, China, France, Germany, Greece, Hong Kong, India, Indonesia, Italy, Japan, Malaysia, Mexico, Netherlands, North Korea, Poland, Russia, Saudi Arabia, Singapore, South Korea, Turkey, UK and the USA. But the major sources are India and South Korea. Considering both the sources emission equations are developed.

3.3.1 From Billet

In developing life cycle CO_2 emission equation, the major stages considered are Shipment of billet, rerolling process (scrap melting and rerolling) (Das et al. 1997), erection considering use of crane and welding, and transportation. As steel has recycling potential along with the term cradle to gate, total life cycle CO_2 emission was used. For cradle to gate criteria stages considered have been shipment of billet and rerolling process. Separate equations of minimum and maximum values are given for minimum and maximum shipment distance respectively. Here, distance from Bangladesh to India has been considered as the minimum distance and distance from Bangladesh to South Korea has been considered to be maximum distance. Equations have been developed for one ton of steel billet.

Cradle to gate (min) = $750 + 0.05\, d_{st1}$ (kg CO_2/ton) (3a)

Cradle to gate (max) = $800 + 0.05\, d_{st1}$ (kg CO_2/ton) (3b)

Where d_{st1}= total distance in km from port to rerolling mills and rerolling mills to market.

As the steel elements such as bean, column etc are taken to the construction site emission of CO_2 occur during erection, crane operation and welding of the steel elements. At the end of the operational period of the structure the steel elements are again taken to the rerolling mill for recycling and the system continues. Hence, considering all the stages starting from shipment of the billets and neglecting emission during the useful life of the building life cycle CO_2 emission was calculated.

Total life cycle emission (min) = $750 + 0.05\,(d_{st1}+d_{st2}) + 8.1h + 1.03L + 0.04A$ (kg CO_2/ton) (3c)

Total life cycle emission (max) = $800 + 0.05\,(d_{st1}+d_{st2}) + 8.1h + 1.03L + 0.04A$ (kg CO_2/ton) (3d)

Where d_{st2}= distance in km from market to construction site; A= total area of weld for connection in square meter; h= hoisting height of the crane in meter for one ton of steel element transfer; L= derricking length of the crane in meter for one ton of steel element transfer.

3.3.2 *From Scrap*

The history of ship breaking is as nearly old as ship building. At present ship-breaking is conducted by 20 Ship breaking yards in an area of about 8 km^2 starting from a point near Baro Awlia under police station, Sitakundu of Chittagong (Rahman et al.1999). All the yards are located on the beach of the Bay of Bengal. There are 20 Ship breaking yards at present in Kattoly-Kumira ship breaking areas (Rahman et al.1999). Generally 95% of a ships body is made of mild steel (M.S.), 2% of stainless steel and 3% of miscellaneous metals, such as brass, aluminium, copper, gun metal and other alloys which are important factors of ship breaking. No sound technical system is used to recover valuable stores, spares, metals and other items from the ships.

Thus, the main stages considered for steel produced from scrap are cutting procedure of ship in ship breaking, rerolling process i.e. scrap melting and rerolling, use of crane and welding in erection of steel member in building and transportation of steel into rerolling mill and construction site. As steel has recycling potential along with the term cradle to gate, total life cycle CO_2 emission has been used. For cradle to gate criteria, stages considered have been ship breaking and rerolling process.

Cradle to gate = $920 + 0.05\, d_{st1}$ (kg CO_2/ton) (3e)

Total life cycle emission = $920 + 0.05\,(d_{st1}+d_{st2}) + 8.1h + 1.03L + 0.04A$ (kg CO_2/ton) (3f)

Where, d_{st1}= total distance in km port to rerolling mills and rerolling mills to market; d_{st2}= distance in km from market to construction site; h= hoisting height of the crane in meter for one ton of steel element transfer; L= derricking length of the crane in meter for one ton of steel element transfer; A= area of weld for connection of one ton of steel in square meter.

3.4 *Sand Profile*

Sand is loose material formed of quartz grains such as that of the beaches or dunes. Sand grains are mostly siliceous; sometimes calcareous or of volcanic origin. Bangladesh is quite rich in terms of sand and silt deposits. Extraction of sand keeps the river channels clear for the free flow of water. Thus, the stages considered for life cycle CO_2 emission of sand are extraction by dredging, sand screening, transportation to construction site or market. For calculation of CO_2 emission form sand extraction and screening the mechanical capacity of dredger and sand screening machine available in Bangladesh has been considered. According to Bangladesh Inland Water transport authority (BIWTA), some 180 liters of fuel oil are needed for a single hour of dredging. This fuel consumption capacity of the dredger and the mechanical capacity of the screener were converted into CO_2 emission with the conversion factors (http://web.mit.edu/mit_energy). The boundary condition for sand was cradle to gate.

$$\text{Cradle to gate emission} = 0.05+50\, d_{st1}, \qquad (g\ CO_2/kg) \tag{4}$$

Where d_s= total distance in km from sand processing unit to market and from market to construction site.

3.5 *Aggregate Profile*

Sandstones and granites are the main two types of aggregates mainly used in Bangladesh. Granite is an intrusive igneous rock which is widely distributed throughout Earth's crust at a range of depths up to 31 miles (50 km). Many variations of granite appear on the commercial market with white, gray, pink, and red being the most common primary colors. Sandstone is a very common rock in the geological group-formations of Bangladesh. Sandstone is often used as building material as blocks in the construction of large buildings.

Very small percentage of aggregates is quarried in Bangladesh. Stages considered are mining and processing of aggregates, transport to market and construction site. Most of aggregate manufacturing units are processing units. Equations have been developed for two different life cycles, one starting from mining and the other starting from processing for both sandstone and granite. Total life cycle emission of aggregates has been calculated in two distinct phases. First phase starting from extraction or processing to transportation to market, prior to use in building where the second phase starting from the segregation of aggregates from concrete after their effective life used in building; also considering reuse and disposal in landfill. As crushing is considered in life cycle of concrete so it has not been included in life cycle of aggregates. Blasting is the common procedure for mining. Hence the research data of SISTech (Crishna et al.2010) regarding carbon emissions at each stage in the extraction, processing have been used in developing equation.

Cradle to Gate:

$$\text{Granite (only processing)} = 70 + 50\, d_a, \qquad (g\ CO_2/kg) \tag{5a}$$

$$\text{Granite (mining + processing)} = 90 + 50\, d_a, \qquad (g\ CO_2/kg) \tag{5b}$$

$$\text{Sandstone (only processing)} = 55 + 50\, d_a, \qquad (g\ CO_2/kg) \tag{5c}$$

$$\text{Sandstone (mining + processing)} = 65+ 50\, d_a, \qquad (g\ CO_2/kg) \tag{5d}$$

Hence, considering transportation to disposal site the cradle to grave equations can be developed.

Life Cycle CO_2 Emission:

$$\text{Granite (only processing)} =70 + 50\, (da + d_{ad}), \qquad (g\ CO_2/kg) \tag{5e}$$

$$\text{Granite (mining + processing)} = 90 + 50\, (d_a+ d_{ad}), \qquad (g\ CO_2/kg) \tag{5f}$$

$$\text{Sandstone (only processing)} = 55 + 50\, (d_a + d_{ad}), \qquad (g\ CO_2/kg) \tag{5g}$$

$$\text{Sandstone (mining + processing)} = 65+ 50\, (d_a + d_{ad}), \qquad (g\ CO_2/kg) \tag{5h}$$

Where, d_a = total distance in km from processing unit to market and from market to construction site; d_{ad} = distance in km from construction site to disposal site.

3.6 *Timber profile*

Timber denotes structural wood. A study (Page 2006) showed that embodied CO_2 emissions of timber were two to three times lower than for the steel or concrete building. Timber is considered as an important structural member with less carbon footprint. The main source of timber in Bangladesh is Sundarban. In developing equation of life cycle CO_2 emission of timber, stages considered are felling of tree with chain saw, transportation from forest to wood processing unit, wood processing in saw mill, demolition and transportation. Equations have been developed considering trees with log diameter 10-12 inch. Diesel fuel was considered as the fuel used in saw mill. As timber has recycling potential it can be used number of times. After the demolition of the building where timber was incorporated for the first time it can be used for land filling or it may be burnt for cooking depending on the condition of the timber. Considering burning of timber as the demolition criteria cradle to grave equation was developed.

$$\text{Cradle to Gate Emission} = 0.12\,\frac{t}{v} + (0.280+0.05\, d_{t1}); \qquad (kg\ CO_2/cft) \tag{6a}$$

$$\text{Cradle to Grave Emission} = 0.12\frac{t}{v} + 3.45+0.05(d_{t1}+d_{t2}); \qquad (kg\ CO_2/cft) \tag{6b}$$

Where, t = no of trees cut; d_{t1}= distance in km from wood to saw mill; d_{t2}= distance in km from sawmill to construction site; V= volume of timber cut in cubic feet.

3.7 *Concrete profile*

Concrete is an artificial material obtained by mixing together cementing material, coarse aggregate, fine aggregate and water. In this study stone chips have been considered as coarse aggregate, CEM-IIA has been considered as cement and CO_2 emission equations has been developed for three different mixing ratios. The ratios are 1:2:4 with water cement ratio (w/c) 0.5, 1:3:6 with water cement ratio 0.65 and 1:1.5:3 with water cement ratio 0.45. The concrete mixes have been designed by absolute volume basis (Singh et al.2005) and emission equations have been developed for one cubic feet of concrete. The cradle to gate CO_2 emission equations of the component materials such as cement, sand and stone chips have been considered to develop the equations of concrete. Emission of CO_2 in mixing of materials and casting of concrete; considering use of vibrator is termed as cradle to gate emission. In this study, the use phase of concrete in the effective life of the building is not considered. After demolition of the building, concrete aggregate collected from demolition site is put into a crushing machine. After crushing they can be used in land filling. Hence, the demolition of the concrete is considered and CO_2 emission from the first stage to demolition can be termed as cradle to grave CO_2 emission.

Cradle to Gate Emission

For ratio 1:2:4 and w/c 0.5 = $8980 + 440d_c + 0.59d_s + 0.99d_a$, g/cft (7a)

For ratio 1:1.5:3 and w/c 0.45 = $10700 + 542d_c + 0.58d_s + 0.92d_a$, g/cft (7b)

For ratio 1:3:6 and w/c 0.65 = $6790 + 304d_c + 0.61d_s + 1.10d_a$, g/cft (7c)

Cradle to Grave Emission

For ratio 1:2:4 and w/c 0.5 = $9020 + 440d_c + 0.59d_s + 0.99d_a$, g/cft (7d)

For ratio 1:1.5:3 and w/c 0.45 = $107400 + 542d_c + 0.58d_s + 0.92d_a$, g/cft (7e)

For ratio 1:3:6 and w/c 0.65 = $6830 + 304d_c + 0.61d_s + 1.10d_a$, g/cft (7f)

Where, d_c = distance in km from cement factory to market and market to construction site; d_s= distance in km from processing unit to market; d_a= distance in km from processing unit to market.

4 CONCLUSION

In this study, life cycle CO_2 emission equations have been developed for seven most widely used materials of construction industry of Bangladesh. For brick, timber and concrete; cradle to grave emission equations have been developed. For stone chips, cement and sand cradle to gate criteria has been considered. Emission due to concrete crushing has been considered in life cycle of concrete. For recyclable materials such as steel, the term ‘total life cycle emission’ has been used. Equations of concrete have been developed for three different mix ratios which will help not only to determine CO_2 emission from different mix ratios but also to compare their CO_2 emission potential.

Life cycle CO_2 emission of the materials cannot be compared without giving the inputs required by these empirical equations. Material production procedures practiced in Bangladesh has been taken into consideration in developing these empirical equations and locally used units have been considered. The stages considered have been raw materials extraction, processing, transportation, construction of building, demolition and disposal. Different construction materials are obtained from different sources and locations. Transportation of materials has a major contribution in total CO_2 emission. The study of CO_2 emission will be incomplete without calculating the travel distance of the materials to the market, construction site and disposal site. Transportation of the materials between different consecutive stages of the life cycle has been the main input variable in all the equations except that developed for timber.

With these equations it may be possible to calculate the total life cycle emission of a building project constructed in a particular location. It may help local Civil Engineers to assess the environmental impact by comparing alternative building systems of Bangladesh. It may be possible to identify sustainable materials, considering CO_2 emissions of individual building materials.

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