DEVELOPING A SIMPLE LIFE CYCLE ASSESSMENT (LCA) TOOL TO ASSESS CLIMATE ADAPTIVE BUILDINGS

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Abstract:
Climate change adaptations already identified as a key priority globally. Sustainable building practices like climate adaptive buildings and green buildings are immerged more prominently supporting climate adaptation strategies. A quantitative assessment through scientifically accepted LCA method supports to justify the environmental investments in these new constructions models. Introducing a simple LCA tool assessing the global warming potential calculating through greenhouse house gas emission per selected functional unit supports to find the environmental savings or degradations. Scope can be select to cover both constructing & use phases. LCA outputs will further reinforce the sustainable building initiatives both ecologically and economically.

Keywords: *life cycle assessment, climate adaptive buildings, green buildings, climate change adaptation, climate change mitigation*

1. Introduction

Frequent natural disasters and changes in the environment indicate the climate change is not a myth. Most of the Asian nations are in the mostly climate vulnerable region. Climate change adaptation and mitigation practices already considered as a timely priority in the national strategies by majority of the nations. Countries are also in the process of either developing climate resilient national policies or reviewing the existing ones in order to improve more. These cover mitigation practices more lean towards developed - high greenhouse gas (GHG) emitting nations and adaptation actions for the climate vulnerable countries. Mostly the mitigation practices are implemented jointly through industrial and private partnerships while adaptations commonly lead by government intervention. Adaptive capacity varies between countries depending on social structure, culture, economic capacity, geography and level of environmental degradation. (UNFCCC, 2007)

2. Background Problem

Building climate resilience into new property will avoid unnecessary climate-related damages and costs, as the impacts of climate change begin to be felt more intensely. (Torbay Council, 2010) One of the major impacts of climate change - sea level rise is likely to have adverse impacts on: buildings and tourism. (UNFCCC, 2007). More focus to constructions were given under adaptation strategies; including buildings, dams and other flood management initiatives, since their higher vulnerability in disaster conditions. Millions of people could become homeless in the Asia-Pacific region by 2070 due to rising sea levels, with Bangladesh, India, Vietnam, China and Pacific islands most at risk. (Perry, 2006) New building construction requires considering wetter winters, drier summers, extreme rainfall events, rising sea levels, intensification of the urban heat island effect and higher wind speeds depend on the location. These impacts are changed not only the building architecture also the material consumption. Green building is a solution to mitigate challenges cause by climate change. (United Nations Economic Commission for Europe, 2009) Similarly green buildings are supported climate adaptations, consideration of structure to be adaptive to anticipated climate change. Some buildings are already being developed so that they will be able to resilient to future climate change extreme events. The European Commission has also identified the future market opportunity for climate adaptive buildings (Dalton & John, 2008). Analysis of environmental benefits and losses of climate adaptive building efforts will help to find the macro picture rather than stick to the green building or climate adaptive building concepts alone. Also it will justify more on investing on climate adaptive buildings which is still in the starting level of developing nations.

3. Research objectives and Scope

The objective of the research is developing a simple LCA tool as a strong justification method for decision makers and related stakeholders on rationalizing the newly constructing buildings in climate adaptive or green building architectural concepts considering the GHG aspect which directly supports the climate change impacts. Research outcomes could make more transparent evaluation of buildings and harmonize the climate adaptive buildings and green buildings a way forward GHG reducing and sustainable consumption and material focused constructional methods. Through this research spatial planners and building architects will be mostly benefited in order to make designs environmentally biased and reducing impacts which simultaneously reduces the cost (both capital and recurrent). Local government bodies will also interested to quantitatively justify the environmental positive (towards carbon neutral and beyond) benefits of these buildings in the scope of climate change mitigation and adaptation. The final data will be more important for the environmental economists, in order to economically justifying the environmental impacts which the most is commonly considered as burdens

4. Research methodology

Throughout the study ISO 14040:2006 standard – 'Environmental management -- Life cycle assessment -- Principles and framework' was selected as the LCA standard which also the research methodology. United Nations defined "Life Cycle Assessment (LCA) is an analytical tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle. LCA provides an adequate instrument for environmental decision support. A reliable LCA performance is crucial for a life cycle economy. The International Organization for Standardization (ISO) completed a whole series of Life Cycle Assessment standards in 2002, the 14040 series." (ATIS Exploratory Group on Green, 2010) This ISO 14040:2006 standard which is the most commonly accepted and practiced internationally, describes the principles and framework for life cycle assessment (LCA) which includes: defining of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements (ISO, 2006). Standard was initially introduced in 1997 and reviewed 1998, 2000.and finally by 2006. However defining of a specific 'scope' is critical in these studies, due to variable of building parameters are mostly depended on the geographical location, purpose and based on socio cultural influences.

5. Research framework

The research framework is split in to three steps, in order to study more deeply and align with the selected methodology ISO 14040: 2006. LCA objectives, goal and the scope are covered in the step one while life cycle inventory and analysis (LCI) covered under second step. The third step is the life cycle impact assessment (LCIA) while the lifecycle interpretation pillar is embedded to each of these steps in order to elaborative delivered.

5.1.1 Step 01

LCA objective is also similarly defined aligning to the research objective which is 'developing a simple LCA tool as a supportive method for decision makers and related stakeholders on justifying the newly constructing buildings in climate adaptive or green building architectural concepts considering GHG emissions as the impact category'. The goal of the LCA is, construct and propose a simple LCA tool for the above purpose. The LCA tool will be introduced to measure the environmental impact of climate adaptive or green buildings for considering two scenarios; selecting traditional buildings as the baseline study. This tool will help to compare two scenarios; baselines study and improved climate adaptive or green building. From a single building to a housing scheme can be selected as the study area for the LCA study.

LCA scope was defined as 'material to use' type which life cycle focused on both constructional and used phase impacts. Environmental impacts of material transportation from the generated point to building are also within the LCA scope. 'Use phase' environmental impacts will be more focused due to access to actual data collection possibilities and also varied due to climate change impacts (in long run). In this research, the environmental impacts due to disposal or recycling of the building after the lifetime will not be considered, mainly due to it is still not in the national implementation agenda of developing (more climate vulnerable) countries. Hence this will be a typical LCA framework to 'cradle to use' in general LCA for products. Selection of the specific scope 'from material to use' phase will support to assess both environmental impacts on adaptation phase and mitigate actions.

Life cycle impacts can be categorized under few LCA functionalities as United States Environmental Protection Authority (USEPA) reported in their Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI, 2007 version). They are: primary energy, acidification potential, eutrophication potential, global warming potential, human health respiratory effects potential, ozone depletion potential, weighted raw resource use and photochemical smog potential. In order to align with the goal and objective of this LCA study 'global warming potential' was selected which is indicated as anthropogenic GHG emission per unit time and unit area as the functional unit. All the computations, comparisons and interpretations is based on this functional unit. This indicator is introduced as 'BuiLCA-CC' in order to represent buildings – LCA – climate change and defined as below equation (1). Unit of this indicator is derived as '$kgCO_2e/m^2$'. The system boundary of the product life cycle shall exclude the GHG emissions associated with: human energy inputs to processes and/or preprocessing (BSI, 2009) however an uncertainty may influence the final figures which require certain statistical control during primary data acquiring (LCI) and calculation and interpretation (LCIA) phase. Once calculated BuiLCA-CC for a building, it will also support the climate change evaluation schemes for buildings.

$$\text{BuiLCA-CC} = (\text{Construct phase GHG} + \text{Use phase GHG}) / \text{area of the building} \qquad (1)$$

Use phase GHG will only consider for one year which the backward latest from the calculating time.

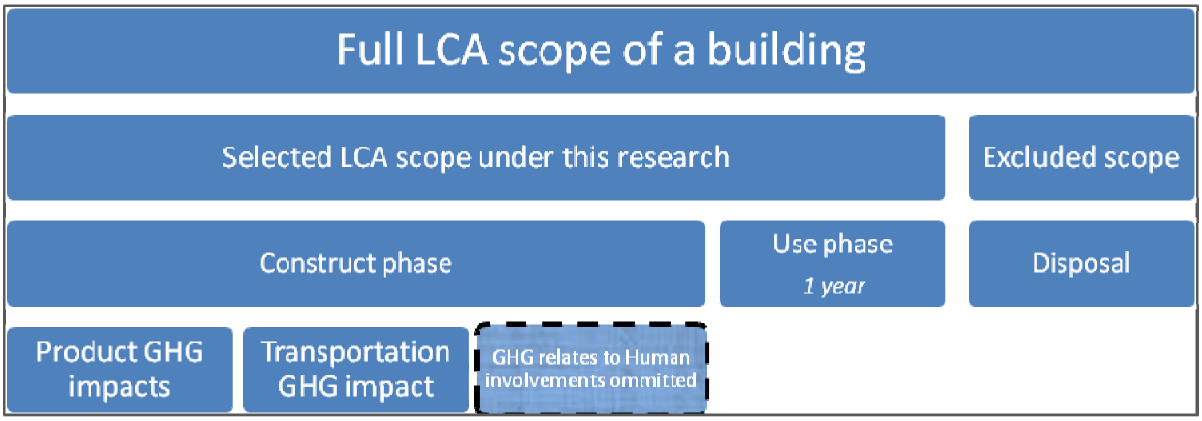

Figure 1: Scope of the LCA tool

Climate change vulnerability extremely differs with geography, climate patterns and the social status of a location. For an effective LCA comparison, considering all above facts are critical. Especially for the 'use phase' an emphasis should be given to select the similar socio-economical status. The LCA tool (initially) will not have the facility to compare geographic, socio, economic and other variations. For the baseline study a housing complex or a representative house can be selected from the location where focused climate adaptive or green building complex is located (which is the best) or from a similar geographical region. The tool will be selected under 'single family residential category' to be more focused on the integrated community based adaptation impacts. The building life expectancy also required to similar for a LCA comparison in order to make a one to one comparison.

5.1.2 Step 02

The life cycle inventory and analysis process is covered under this step. The life cycle inventory preparation process was again split in to two pillars in order to minimize the complexity of the study. The first part of the LCI is fully focused on the construct phase which consist of GHG emission from materials and material transporting phase and the second part is to focus on 'use phase' impacts. The inventory preparation and calculations will be done accordingly to the following tables. LCI preparation is recommended annual basis in order to have more rationalized values. The data acquisition is highly important in the LCI phase which is always necessary to use actual data other than an extreme difficulty to find. Following two tables Table 1 to Table 4 are shown the proposed data sources. For the construct phase GHG calculations 'bill of material record' is a critical data source. Generally this set of data is only available for buildings constructed by professional contractors.

Table 1: LCI – Construct phase - Product related GHG calculation

Parameter	Material	Specific product GHG emission	Used quantity	Product phase GHG for material
	i	a_i	q_i	P_i
Unit	NA	$kgCO_2e$ /ton $product_i$	ton	$kgCO_2e$
Information source	Bill of material record	LCA or PCF (product carbon foot printing) data bases	Bill of material record	Calculation $P_i = a_i \times q_i$

Initially the cement, steel, timber, sand, tile, paint and metal were selected for the LCA tool, keeping the provision to expand once researching in more complex cases. In some cases instead of cement, sand and metal, 'supplied concrete' can be directly used upon the application on site. The below table elaborate the calculation of GHG in material transportation phase. This covers the transportation related GHG from the supplier to building location.

Table 2: LCI – Construct phase – Material transport related GHG calculation

Parameter	Material	Used quantity	Average loaded weight per trip	Round the trip distance	Specific GHG emission for the used vehicle	Transport phase GHG emission
	i	q_i	w_i	d_i	v_i	T_i
Units	NA	ton	ton/trip	km/trip	$kgCO_2e$/km	$kgCO_2e$
Information source	Bill of material record	Bill of material record	Actual or estimated	Actual or estimated	LCA or Carbon foot printing data bases	Calculation $T_i = (q_i / w_i) \times d_i \times v_i$

Calculation of construction phase GHG is equal to summation of Product phase GHG ($\sum P_i$) for material and Transport phase ($\sum T_i$) GHG emission with unit $kgCO_2e$.

$$\text{Construct phase GHG} = \sum (P_i + T_i) \qquad (2)$$

LCI calculating GHG foot printing for 'use phase' was also focused under Step 02. Main GHG source of the 'use phase' is from energy consumption. The raw (primary) data required are electrical energy consumption (in kWh), use natural gas (in m^3), liquid petrol gas (LPG) (in liter) and other sources. The thermal energy which consider is for building heating purpose only and not used for cooking since the thermal requirement for cooking significantly depend on societal structure and economical background. Following two tables describe the use phase energy related GHG LCI – data requirements and calculations separately.

Table 3: LCI – Use phase – Thermal energy related GHG calculation

Parameter	Energy source	Used quantity	Lower calorific value	Fuel specific carbon factors	GHG emission for thermal fuel
	i	u_i	c_i	f_i	TE_i
Unit	NA	ton	GJ/ton	$kgCO_2e$ /GJ	$kgCO_2e$
Information source	Primary data	Primary data	Intergovernmental Panel on Climate Change (IPCC) 'lower calorific values	IPCC default 'fuel specific carbon factors'	Calculation $TE_i = u_i \times c_i \times f_i$

Electrical energy usage related GHG emission is calculated as per the below table. However availability of accurate and updated secondary data is important in this calculation process.

Table 4: LCI – Use phase – Electrical energy related GHG calculation

Parameter	Utilized electrical energy	Grid carbon factor	GHG emission for thermal fuel
	e_i	G	EE_i
Unit	kWh	$kgCO_2e$ /MWh	$kgCO_2e$
Information source	Primary data	Whichever the latest from the local electrical supplying body, national reports or latest United Nations Framework for Climate Change Convention (UNFCCC – CDM) reports. In cases none of the above sources are available IPCC (2007)	Calculation $EE_i = e_i \times g$

Calculation of use phase GHG is equal to summation of GHG emission from thermal energy ($\sum TE_i$) and from electrical energy utilization ($\sum EE_i$) with unit $kgCO_2e$.

$$\text{Use phase GHG} = \sum (TE_i) + \sum (EE_i) \qquad (3)$$

In order to calculate the functional unit measuring the area of the selected house or building is critical. Building area is measured in SI unit m^2. Calculation of the area the building required a similar approach to both scenarios in order to compare in one to one basis. For this parameter measuring the area of the living space of the house (including bed rooms, visitors' area, wash rooms and kitchen) is required. It is also possible to extend to other parts of the house depend on the architect design however it is further require to be a similar approach in both scenarios. The final data for both scenarios will be presented in the unit's $kgCO_2e/m^2$ per year as the functional unit of the study as per the equation (1).

5.1.3 Step 03

This step covers the LCIA phase. The final two sets of data will be available in 'one to one' comparison mode in order to assess scenario wise emission both in absolute and specific GHG emission. These two figures are used to assess the environmental soundness of both scenarios. Absolute emission figures can also used to compare the GHG emission reductions or increasing during annually. The climate adaptive constructional investments and the return can also be assessed in both building scenarios using the BuiLCA-CC indicator. Since the indicator is based on two main GHG streams: constructional and use phases, it provides the facility of sector level analysis.

6. Verification of Results

Used equations during the LCI process are only derived using fundamental theories. Since validating of such equations might not require necessarily. The data which use to feed to this model require certain validation steps. Especially the functional unit of this study is entirely depended on the constructional, transportation and use phase inputs which require a statistical data validation before input to LCI. Also before using of 'use phase' annual figures it require to introduce a control limit with a co-efficient of variation interval to remove outliers to justify the effort of calculating such parameters. During LCI phase the use of secondary data is also high in this study, mainly due to find the constructional phase GHG emissions. Accessing latest and reliable data sources and selecting the exact product related emission is also important in this exercise which enhances the data validation process.

7. Conclusion and proposed future work

Introducing and developing a LCA tool to assess the climate adaptive buildings is definitely supporting to justify the investments in quantified environmental factors. These findings will diminish the resilient to invest on climate adaptation strategies in building sector which is an important requirement currently. BuiLCA-CC can also use as an indicator for environmental competitions as an unbiased estimator to assess the environmental friendliness with respect to 'global warming impact'. The model will be useful for the green building architects to improve their future models more ‘carbon friendly’ similarly to justify if more capital expenses require on green building constructions, through recurrent carbon (ie environmental) savings derived through global carbon costing models.

The research can be further expanded in two different axes. While increasing the number of functional units and integrated eco indicator for green building can be introduced. This will support on applying certification schemes like LEEDS (Leadership in energy and environmental design). The other aspect is to link with an environmental cost benefit analysis model and justifying the adaptation cost by showing the GHG saving during impact stages and disaster reduction. GHG emission can be quantified in economical terms using developed models like "the model of the Eco-costs / Value Ratio" which is identified as a future addition to this tool.

For developing countries the findings will be further important on justifying the green building costs with respect to environmental savings benefited from mitigation aspects by using latest climate change models and selected building adaptation strategies.

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