IMPACT: International Journal of Research in
Engineering & Technology (IMPACT: IJRET)
ISSN(E): 2321-8843; ISSN(P): 2347-4599
Vol. 2, Issue 3, Mar 2014, 81-92

TOWARDS AN INTEGRATED TOOL TO ESTIMATE CARBON EMISSIONS FROM LIFE CYCLE ASSESSMENT OF BUILDING MATERIALS IN EGYPT

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ABSTRACT

Life cycle assessment (LCA) program developments were intended for the construction of life cycle inventory (LCI) database for refrigerators, computers, and general consumer products. But buildings are different from general consumer products for their long life span, and possess different characteristics from consumer goods. Examples of the various programs developed or commercialized for the performance of LCA are Be Cost, BOUSTED, ECOLOGIC, IDEA, PEMS, TEMIS, SIMAPRO, ECOPACK2000, TEAM, OfE, LIFEWAY, LCAiT, GaBi, KCL-ECO, and LCAiT each of them special country-specific, the paper introduce a brief on each program. From aforementioned, Egypt do not have tool to estimate carbon emissions from building LCA, thus the paper sheds light on Be Cost tool to take advantage from it, furthermore to be a guide in creating ECE-LCA Tool. Thus, the main aim of this paper is to develop a tool to estimate the life cycle carbon emissions (Global Warming Potential (GWP)) of the residential building materials in Egypt.

KEYWORDS: ECE-LCA Tool, Building Materials, Residential Building, Egypt

INTRODUCTION

Indoor environmental quality (IEQ) is an important element in building design due both to the large amount of time spent indoors and the influence of design factors on IEQ [1]. Life cycle assessment (LCA) is a useful tool for evaluating the environmental impacts of a system [1]. For example, LCA can be used to quantify greenhouse gases, energy and water usage, and emissions from a building's life cycle phases. [2]

W. Omar et al. [3] defined LCA is “a technique for assessing the environmental aspects and potential impacts associated with a product, by: (1) compiling an inventory of relevant inputs and outputs of a product system; (2) evaluating the potential environmental impacts; and (3) interpreting the results of the inventory analysis and impact assessment phases” [4] It outlines four phases to be performed which encompass: (1) goal and scope definition; (2) inventory analysis; (3) impact assessment; and (4) interpretation. Based on the different system scopes and theory, LCA can be classified as process LCA, input–output LCA and hybrid LCA. [5]

Process LCA (PLCA)

Process LCA is most preferred for the particular processes, products or manufacturing chains for which the physical flow of goods and services can be easily identified and traced [6]. *Nässén et al.* [7] found that process LCA induces systematic truncation errors due to the incomplete definition of system boundary. Almost 90% of specific energy consumption was from top-down analysis due to the truncation error defined during bottom-up approach.

Furthermore, the bottom-up approach underestimated the energy consumption for transportation, services, etc. During the production phase compared to the use phase [7]. The main reason is that the use phase is easily estimated by direct energy consumption. [8]

Input–Output LCA (I–O LCA)

The I–O LCA is calculated based on the flow of materials in an economy structure in order to determine the amount of primary energy required to produce a specific product or service. The I–O LCA uses the economic I–O tables of a national economic structure, thus, it must be for each country has its own I-O tables. It uses a top-down linear macroeconomic approach to describe the complex inter-industry relationship in terms of monetary transactions in industrial structure. [5] Furthermore, it is the best suited to systematically estimate the indirect effect of carbon emissions and improve the method of assessment in a LCA framework [9]. According to *Crawford et. al* [10], the use of I–O data improves the reliability of LCA by increasing completeness and reliability of life cycle inventories compared to the traditional inventory analysis. [10] An I–O table maps the flow of goods and services between sectors in an economic structure [11]. The flow of energy within an economic structure is possible to trace by assessing the input and output of monetary flows from the energy producing sectors and converting it to a physical energy value [12]. By using I–O LCA, all energy transactions within national economic structures are identified and captured. These can then be used to assess inputs and outputs of energy. [7]

Hybrid LCA (HLCA)

The principal aim of HLCA is to combine the advantages of the more accurate process LCA and the extended system boundary of the I–O LCA. [13] It combines balance among system boundary, specialization of model applicability as well as time and cost efficiency. With HLCA, both upstream and downstream processes of manufacturing products can be extended by considering both direct and indirect emissions. [14]

Moon et al. [15] mentioned, however, this method mainly adds I-O LCA-based CO2 emission data to the process LCA-based CO2 emission data based database, or reversely, adds process LCA-based CO2 emission data to I-O LCA-based CO2 emission data based database and combine them. The identifying system boundary by using methods of building LCA is given in Figure 1.

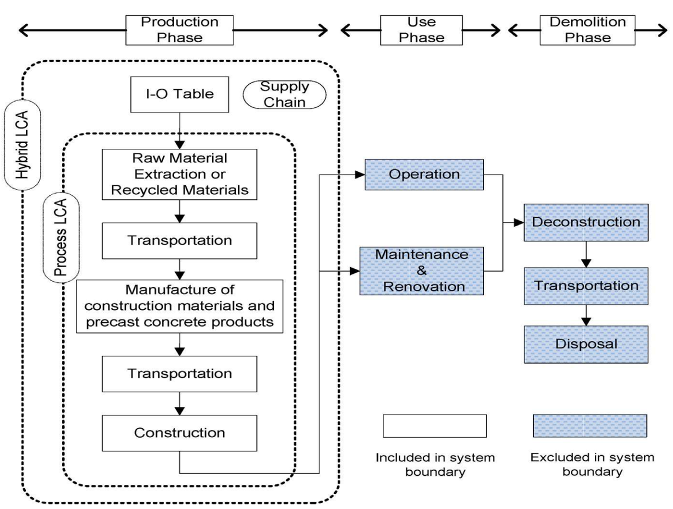

Figure 1: System Boundary for LCA in Building Construction Process, for Example [14]

Figure 2, shows that LCI databases around the world and clarifies based on the methods of process-based analysis, I/O based analysis or hybrid analysis. *N. Yokoo et al.* [16] summarized in his study that 42 databases and most of the databases are created based on the process based.

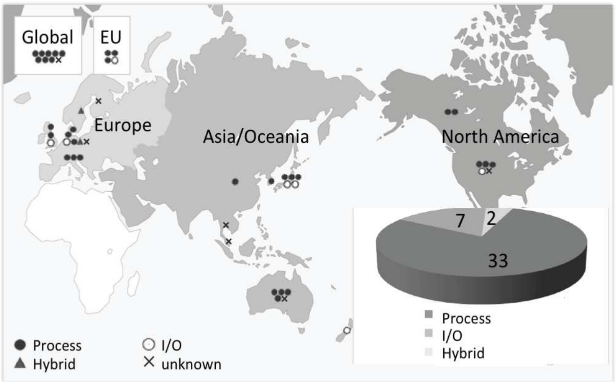

Figure 2: LCA Methods in the World [16]

From aforementioned, although the input-output tables are a detailed approach and can provide energy requirements by industry, it requires the existence of an energy input-output table, which does not exist for Egypt [17]. In addition, this approach does not provide straightforward price elasticities. Therefore, it would not be feasible to use it for the evaluation of life cycle impact assessment of buildings. And by extension, it would not be feasible to use the HLCA because it depends on the I-O LCA in Egypt.

INTERNATIONAL LITERATURE STUDIES OF BUILDING LIFE CYCLE ASSESSMENT

From the start of the 21st century, interest in LCA has been increasing rapidly, as can be seen in the next overview of case studies. Life cycle thinking is also growing in importance within European Policy as i.e., demonstrated by the Communication from the European Commission on Integrated Product Policy (IPP). [18] A direct result of the IPP is the development of the International Reference Life Cycle Data System Handbook (ILCD), a practical guide for LCA according to the current best practice published in 2010, complementary with the ISO 14040 [19] LCA has been used for environmental evaluation of buildings and building related industry and sector (including construction products, construction systems, buildings, and civil engineering constructions) through a very scattered literature. [32]

L.F. Cabeza et al. [20] summarized in a review paper with agreeing with *M. Buyle et al.* [21], shows that the case studies found in the literature are difficult to compare because of their specific properties like building type, climate, comfort requirements, local regulations, etc. A comparison can be seen in Table 1 in *L.F. Cabeza, et al.* [20] where most case studies considered in this review. Many important phases of LCA are compared that is the scope, the lifetime, the functional unit considered, the system boundaries, the location, and the building typology. *T. Ramesh et al.* [22] collected a literature survey on buildings' life cycle energy use was performed resulting in 73 case studies from 13 countries. Survey included both office and residential buildings. Data is collected for wood, steel, concrete and other structured buildings.

A. Sharma et al. [23] summed up in another form, the results of various case studies shows the effect of buildings on various environmental categories, i.e., GHG emissions, energy use, AP and EP. Commercial buildings were found to have more impact on environment as compared to the residential buildings. *M. Buyle et al.* [24] dealt with 38 case study and comparison between them about the impact methods of residential, office and commercial buildings and whole-building life cycle stages over the life span of buildings in the various countries of the world.

P. Yung et al. [25] shows that different authors have included different life cycle stages of 38 research works consisting of 206 cases, covering 16 countries, have been included. The majority of studies did not include either energy used in transportation or construction stage or both. The study comparison between the different construction materials such as; CW: cavity wall, RC: reinforced concrete, S: steel and T: timber.

From aforementioned, the international studies emphasizes the importance of building LCA in the world from the many views; construction materials, impact methods, building life span, used software and LCA stages.

It is clear from figure 3, the distribution of LCA studies in the world and Sweden has the largest number of studies because it has significant database of building LCA, and it is clear that Arab countries do not have any studies excluded only one study in Bahrain and neglect significantly from the continent of Africa and especially Egypt.

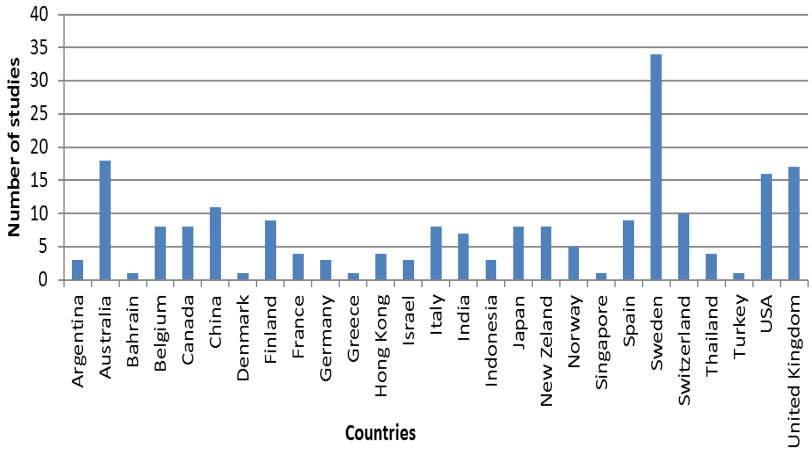

Figure 3: Summary of the Case Studies in the 27th Countries from the World (Collected by Author from 205 International Case Studies)

Finally, *L.F. Cabeza et al.* [20] summarize the literature studies until 2014 can be seen in figure 4, which found from America is LCA of the building industry or of buildings, while in Asia and Oceania most cases are LCEA. Europe presents similar amount of LCA and LCEA papers. Finally, only one LCCA of a building could be found.

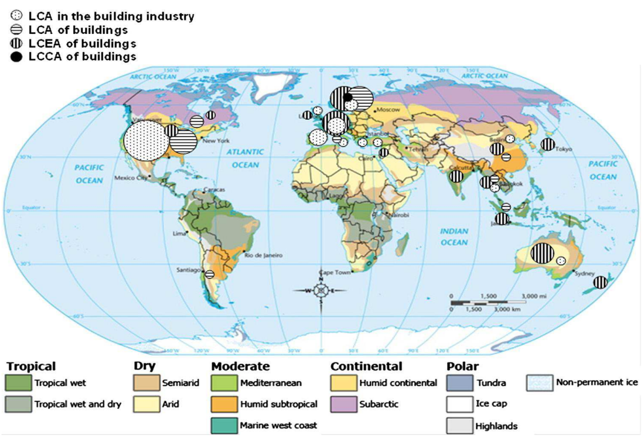

Figure 4: Summary of the Studies Organized by Areas of Assessment and Type of Study Carried Out (Size of Circles Represents the Amount of Studies Carried) [20]

INTERNATIONAL TOOLS OF BUILDING LIFE CYCLE ASSESSMENT

Examples of the various programs developed or commercialized for the performance of LCA are BOUSTED, ECOLOGIC, IDEA, PEMS, TEMIS, SIMAPRO, ECOPACK2000, TEAM, OfE, LIFEWAY, LCAiT, GaBi, KCL-ECO, and LCAiT. [26] These and others add up to approximately 20 programs already completed, and many more if we include those still in development. A perusal of the representative LCA Programs and their main components are as shown in Table 1. [27]

Some of the datasets listed in Table 1 are complete, or there are extensive efforts of people working on completing them, but due to the wide range of materials in the construction industry, and the variety of construction techniques, none of these tools and data sets are able to model or compute the environmental impacts of a whole building or construction, including all the life-cycle phases and production processes in detail. [1] The databases and tools listed vary according to study goal, users, application, data, and geographical location. Databases differ from one country or region to another according to many factors, including energy sources, supply assumptions, product specifications, manufacturing differences and complications in the economic activities. [28] Each of these factors can produce significant variations in the environmental impact assessment, for instance, (whether delivered or end use) energy supply assumptions can cause significant differences in the embodied energy calculations, as different countries have different energy sources. For example, France depends strongly on nuclear power, while the UK depends more on gas and electricity, and this fundamental difference in the energy sources affects the environmental impacts of production.

Johnson et al. [29] emphasized that there are specific calculation procedures for performing an LCA inventory analysis by hand, however these procedures have been mostly superseded by computer software. Programs such as SimaPro (www.pre.nl/simapro) and GaBi (www.gabi-software.com), both developed in Europe, allow users to create an inventory using information collected by the user or taken from databases included in the software. Typical databases include those developed by the software companies, as well as databases like Ecoinvent which have been compiled from years of data collected by research companies or governments.

Table 1: Some International Databases and Tools of Life-Cycle Assessment [1]

Database	Country	Function	Type	Level	Software	Website
Athena	Canada	Database + Tool	Academic	Whole building design decision	Eco Calculator	www.athenaSMI.ca
Bath data	UK	Database	Academic	Product comparison	No	people.bath.ac.uk/cj219/
BeCost (LCA-house)	Finland	Database	Academic	Whole building design decision	Web-based tool	http://virtual.vtt.fi/virtual/proj6/environ/ohjelmat_e.html
BEE	Finland	Tool	Academic	Whole building design decision	BEE 1.0	--------------------------
BEES	USA	Tool	Commercial	Whole building design decision	BEES	www.bfrl.nist.gov/oae/software/bees.html
BRE	UK	Database + Tool	Public	Whole building assessment	No	www.bre.co.uk
Boustead	UK	Database + Tool	Academic	Product comparison	Yes	www.boustead-consulting.co.uk
DBRI Database	Denmark	Database	Public		No	www.en.sbi.dk
Ecoinvent	SL	Database	Commercial	Product comparison	No	www.pre.nl/ecoinvent
ECO-it	NL	Tool	Commercial	Whole building design decision	ECO-it	www.pre.nl

Table 1: Contd.,

ECO methods	France	Tool	Commercial	Whole building design decision	Under development	www.ecomethods.com
Eco-Quantum	NL	Tool	Academic	Whole building design decision	Eco-Quantum	www.ecoquantum.nl
Envest	UK	Tool	Commercial	Whole building design decision	Envest	envestv2.bre.co.uk
Gabi	Germany	Database + Tool	Commercial	Product comparison	Gabi 4	www.gabi-software.com
IO-database	Denmark	Database	Academic	Product comparison	No	---------------------
IVAM	NL	Database	Commercial	Product comparison	No	www.ivam.uva.nl
KCL-ECO	Finland	Tool	Commercial	Product comparison	KCL-ECO 4.1	www.kcl.fi/eco
LCAiT	Sweden	Tool	Commercial	Product comparison	LCAiT	www.ekologik.cit.chalmers.se
LISA	Australia	Tool	Public	Whole building design decision	LISA	www.lisa.au.com
Optimize	Canada	Database + tool	---------	whole building design decision	Yes	----------------------
PEMS	UK	Tool	Public	Product comparison	Web	----------------------
SEDA	Australia	Tool	Public	Whole building assessment	SEDA	----------------------
Simapro	NL	Database + Tool	Commercial	Product comparison	Simapro 7	www.pre.nl
Spin	Sweden	Database	Public	Product comparison	No	http://195.215.251.229/Dotnetnuke/
TEAM	France	Database + Tool	Commercial	Product comparison	TEAM 3.0	www.ecobilan.com
Umberto	Germany	Database + Tool	Commercial	Product comparison	Umberto	www.umberto.de
US LCI	USA	Database	Public	Product	No	www.nrel.gov/lci

A major shortcoming is that most are centered on European information. LCA, while extremely popular in Europe, has not caught on perform more as quickly in North America, so users must of their own data collection or substitute European values where necessary.

Development Egyptian Tool to Estimate Carbon Emissions from LCA of Building Materials (ECE-LCA Tool)

From the previous tables which shown that Egypt do not have tool to estimate carbon emissions from building LCA, ECE-LCA must include a building's life cycle, and be devised to permit input and output of Egyptian LCI database for the respective stages of this life cycle. Furthermore, it is necessary to allow comparison between alternatives, and to show the results of analyses in a quantitative format of CO2 emissions. The research will study BeCost tool to take advantage from it, furthermore to be a guide in creating ECE-LCA Tool. ECE-LCA Tool should have these input to developed; Type of usage, Location, Structure, Building dimension, Total area and volume of building, Height of area, Life span of building. Be-Cost is a www-based tool for life cycle assessment of building structures and for the whole building, Figure 5. [30] The program includes:

- Environmental profiles, costs and maintenance costs of building materials produced in Finland.
- The structures for designing outdoor walls, indoor walls, roofs, floors, etc.
- Material quantity calculations

- Environmental profile calculation for designed structure.
- Result as plot of environmental profile (emissions), energy- and raw-material use, and cost impact for the structure and whole building.

Be-Cost is an easy to use program - the user should first define the building by making relevant choices, by choosing the structure and materials, by giving the volumes in m2 and by choosing the service life of the building.

This can be used for different purposes:

- To examine the ecological effect of building choices related to materials used and service life of the whole building (designer and constructors use);
- Verifying environmental characteristics' fulfillment, if such has been demanded (designer use);
- For owners to examine their building's environmental profiles (owner use);
- Checking the effect of care, maintenance and repairing actions on the environment;
- Comparing environmental profiles of structures having the same functional units;
- Comparing environmental impacts of produced- and competing materials in certain structure or building (use of building material producer).

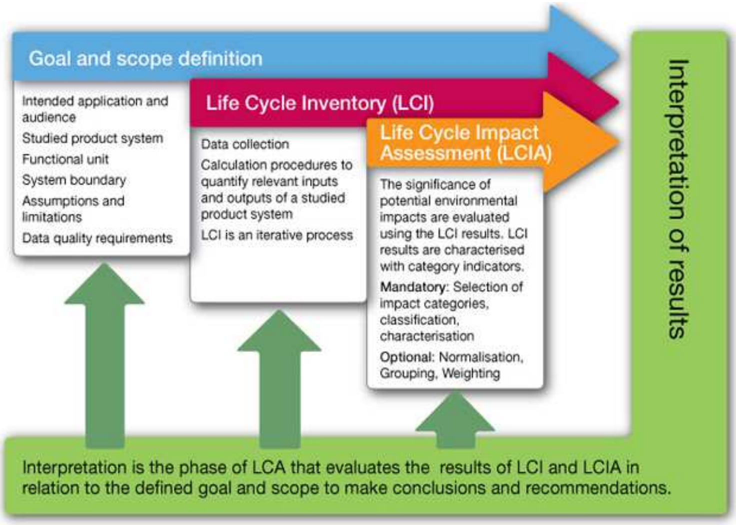

Figure 5: Development of Life-Cycle Assessment Framework in Finland [31]

In order to accomplish the research objectives, a research methodology is set consisting of the following stages:

Stage One: Developing of Egyptian National LCI Database (ENLCI) involves the collection and quantitative data on the inputs and outputs of material, energy and waste flows associated with a product over its entire life cycle so that its whole-life environmental impacts can be determined.

This stage will be done by doing survey field in the Egyptian agencies of Energy and Environmental studies and finding some questionnaire to the architectural engineers, owner of buildings, customers of buildings and factories which manufacture the mainly construction material in Egypt.

An LCA comprises three steps: [32]

- Compiling an inventory of relevant energy and material inputs and environmental releases (outputs) associated with a defined system. Releases can be solid wastes or emissions to air or water.
- Evaluating the potential impacts associated with these inputs and releases, e.g. the global warming impact from CO2 emissions.
- Interpreting the results to help make informed decisions.

Stage Two: Applying the Data in ECE-LCA Tool: The collection data from the first stage will be the input data of the new Egyptian tool as a web-based tool, in figure 6 the suggested framework of ECE-LCA tool to calculate in the end of the process the carbon emissions from Egyptian building which will be the output data of the tool.

Stage Three: Verification and Validation of the Egyptian Tool: Applying the tool after finish the modeling in the exciting building in Egypt as a case study.

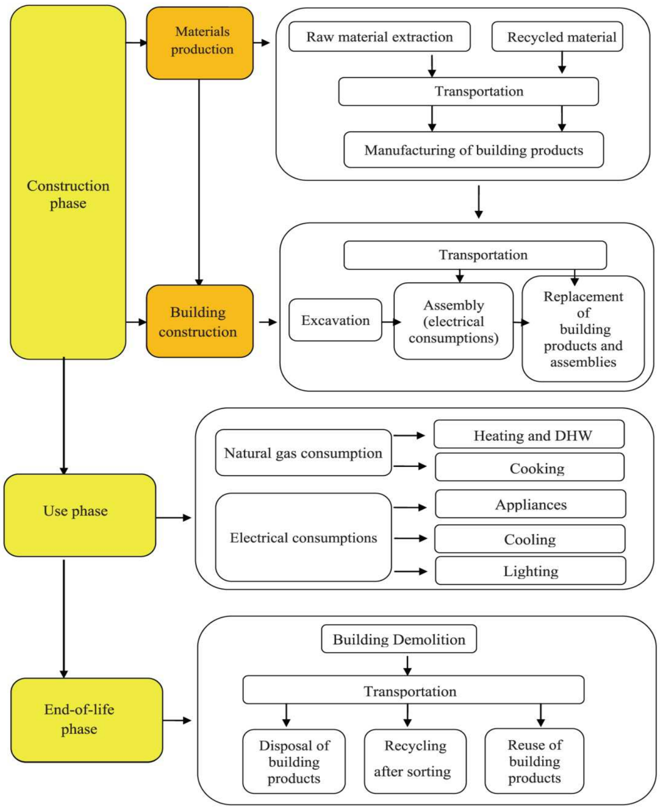

Figure 6: Suggested Framework of ECE-LCA Tool: All LCA Stages

CONCLUSIONS

Life cycle assessment has become an important tool for determining the environmental impact of materials and products. It is also useful in analyzing the impact a structure has over the course of its life cycle. The International Organization of Standardization's 14040 series specifies how to perform a formal life cycle assessment in which the materials, construction, use, and demolition of a building are quantified into embodied energy and carbon dioxide (CO2) equivalents, along with representation of resource consumption and released emissions. These results are useful to architects, structural engineers, contractors, and owners interested in predicting environmental impacts throughout a building's life.

LCA can be classified as process LCA, input–output LCA and hybrid LCA. Although the input-output tables are a detailed approach, it requires the existence of an energy input-output table, which does not exist for Egypt. Thus it would not be feasible to use the HLCA because it depends on the I-O LCA in Egypt.

The review can summarize that to calculate the CO2 emissions and energy consumption from building material in Egypt from LCA view is more difficult because Egypt does not has tool/program to estimate carbon emissions from building LCA, ECE-LCA must include a building's life cycle, and be devised to permit input and output of Egyptian LCI database for the respective stages of this life cycle. The results from this review study can be used to standardize the study of Life Cycle Assessment concept in Egypt because it has a lack of LCA studies and to put the bedrock of Egyptian tool framework ECE-LCA to build environment more cleanly from air emissions.

ACKNOWLEDGEMENTS

The first author would like to thank Egyptian Ministry of Higher Education (MoHE) for providing him the financial support (PhD scholarship) for this research as well as the Egypt Japan University of Science and Technology (E-JUST) for offering the facility and tools needed to conduct this work.

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