Sustainability Metrics: Life Cycle Assessment for Current Building Infrastructure

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ABSTRACT

The embodied energy in building materials constitutes a large part of the total energy required for any building. In working to make buildings more energy efficient this needs to be considered. Integrating considerations about life cycle assessment for buildings and materials is one promising way to reduce the amount of energy consumption being used within the building sector and the environmental impacts associated with that energy. Life-cycle assessment is a decision-making support tool which provides an account of the materials and energy used in a product and assesses the related environmental impact. In this paper LCA is reviewed from a buildings perspective. The aim of this paper is to review Life Cycle Assessment (LCA) as a means of evaluating the environmental impact of buildings.A life cycle assessment (LCA) model can be utilized to help evaluate the embodied energy in building materials in comparison to the buildings operational energy. This thesis takes into consideration the potential life cycle reductions in energy and CO2 emissions that can be made through an energy retrofit of an existing building verses demolition and replacement.

KEYWORDS: Embodied energy, Life Cycle Assessment, Environmental impacts.

I. INTRODUCTION

In recent years, building and construction sector has been found to be responsible for a large part of the environmental impact of human activities. The impacts which caused by construction and operation of buildings are many. One of the most significant effects is the climate change caused by consuming energy in these processes. As the use of fossil fuel has increased, climate change has emerged as an immediate problem since the relation between greenhouse gases and their influences on global temperature was discovered. Greenhouse gas emissions are hypothesized to contribute to a warmer climate, which can increase the melting of glaciers. In addition, emissions disturb hydrological cycles, resulted in variable climate change with extreme wind effects and flooding. One consequence might be the displacement of population along with enormous economical effects.

LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) involves evaluating the environmental impacts of a product, process, or activity holistically, by looking at the entire life cycle of the product or process from raw materials extraction through disposal. LCA is an important tool used in environmental management and green design efforts. Selection of product design, materials, processes, reuse or recycling strategies, and final disposal options requires careful examination of energy and resource consumption as well as environmental impacts associated with each design alternative.

The definition of LCA by SETAC is: “A process to evaluate the environmental burdens associated with product, processes or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and released to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment include the entire lifecycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution; use, reuse, maintenance; recycling and final disposal.”

ISO 14040 defines LCA as: ―A technique for assessing the environmental aspects and potential impacts associated with a product, by: compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts; and interpreting the results of the inventory analysis and impact assessment phases. LCA is often employed as an analytical decision support tool.

II. LCA METHODOLOGY

International Standards Organization ISO 14040 (1997) series on LCA was released in Geneva as a development of the ISO 14000 Environmental Management Standards. The series provide principles, framework, and methodological standards for conducting LCA studies. The four steps of the LCA which are:

- ISO 14040 Environmental management, LCA, Principles and framework (1997).
- ISO 14041 Environmental management, LCA, Goal definition and inventory analysis (1998).
- ISO 14042 Environmental management, LCA, Life-cycle impact assessment (2000).
- ISO 14043 Environmental management, LCA, Life-cycle interpretation (2000).

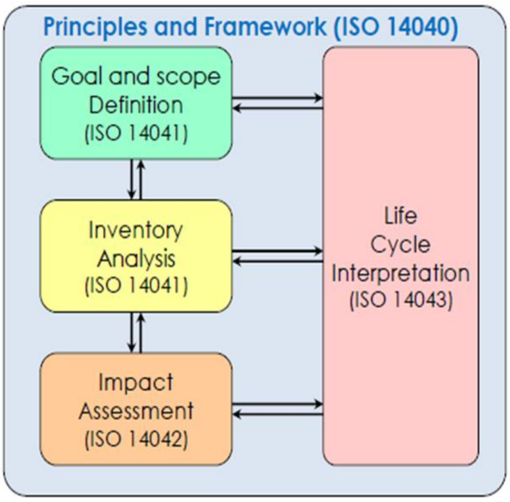

Figure 1: Phases of LCA methodology

GOAL AND SCOPE DEFINITION

The first part of an LCA study consists of defining the goal of the study and its scope. The goal of the study includes the reason for carrying out the study as well as the intended application of the results and the intended audience. In the scope of an LCA the following items are considered and described:

• The function of the system.

• The functional unit.

• The system boundaries.

• Type of impact assessment methodology and interpretation to be performed.

• Data requirements and quality.

• Assumptions and limitations.

A functional unit of a 'm² usable floor area' is chosen. This alternative would make the calculations of the building easier. The unit is also widely used in other studies and is utilized to easily compare and draw conclusions between cases. Nevertheless, the functional unit 'm² usable floor area' is chosen, the usable floor area is defined as the floor areas in the building, staircases, cellar and attic if any. In order to replicate the findings of the study, the conclusion determines the environmental impacts per m2 usable floor area of the case study buildings. This will give a rough estimate that can be used by practitioners in determining these impacts for similar building types.

The scope describes the depth of the study and show that the purpose can be fulfilled with the actual extent of the limitations. The functional unit is a measure of the function of the studied system and it provides a reference to which the inputs and outputs can be related. This enables comparison of two essential different systems. The system boundaries determine which unit processes to be included in the LCA study. Defining system boundaries is partly based on a subjective choice, made during the scope phase when the boundaries are initially set. The following boundaries can be considered:

• Boundaries between the technological system and nature. A life cycle usually begins at the extraction point of raw materials and energy carriers from nature. Final stages normally include waste generation and/or heat production.

• Geographical area. Geography plays a crucial role in most LCA studies, e.g. infrastructures, such as electricity production, waste management and transport systems, vary from one region to another.

• Time horizon. Boundaries must be set not only in space, but also in time. Basically LCAs are carried out to evaluate present impacts and predict future scenarios. Limitations to time boundaries are given by technologies involved, pollutants lifespan, etc.

LIFE CYCLE INVENTORY ANALYSIS (LCI)

LCI comprises all stages dealing with data retrieval and management. Data are validated and related to the functional unit in order to allow the aggregation of results. LCI also involves the calculations to quantify material and energy inputs and outputs of a building system. A detailed description of raw materials and energy inputs are used at all points and the emissions, effluent and solid waste outputs. Examples of output are resource depletion (e.g. material and energy), pollutant emissions and discharges of chemical or physical load (e.g. substances, heat, or noise).

The data collection is the most resource consuming part of the LCA. Reuse of data from other studies can simplify the work but this must be made with great care so that the data is representative. The data quality aspect is therefore also crucial.

Athena Impact Estimator is an LCA tool for building analysis developed by the Athena Institute of Merrickville in Ontario, Canada. This program allows full building modeling and includes many assumptions about ‘standard’ building practices. Data used are industry averages adjusted to regional conditions. This data is based mostly on information from the US Life Cycle Inventory Database (2011). The Athena program was developed in Canada and has the capability of placing the project in various Canadian cities and few cities in the United States, such as Los Angeles, Atlanta, Pittsburgh, Orlando, as well as a national U.S. average. When the location is specified, the program will adjust calculations to the appropriate power grid, resources, and average travel distances for the area.

The inventory analysis involves data collection and calculations to quantify material and energy inputs and outputs of the building cases. Identification and quantification of material and energy flows (inputs and outputs) of the buildings are primarily derived from the floor plans, specifications sheets, and bill of materials provided by the architect. Some data can be collected through on-site measurements and inquiries to sub-contractor. Inventory is completed using ATHENA 4.1 (2010) life-cycle calculation program. A complete list of materials is compiled based on the outcome from the modeling program. Material placement burdens are subdivided into material production, transportation in each life cycle phase.

LIFE CYCLE IMPACT ASSESSMENT (LCIA)

LCIA evaluates the significance of potential environmental impacts based on the LCI results, relating the identified inputs and outputs to environmental impacts. It involves selection of impact categories, category indicators and characterization models. Impact categories are selected and defined with respect to the goal and scope of the LCA. ISO 14040 suggests that LCIA includes the following steps (the first 3 are mandatory, the others are optional):

1- Classification (assignment of LCI results): The environmental loads are classified according to the impact categories. (Some environmental loads belong to more than one impact category.)

2- Characterization (calculation of category indicator results): The category indicator is modeled for the different environmental loads that caused by certain pollutants e.g. the Global Warming Potential is caused by CO_2 and CH_4.

3- Valuation: Expressing category indicators relative to a standard (e.g. ton of CO_2 equivalent).

4- Grouping: Sorting and possibly ranking of the impact categories.

5- Weighting: Expressing the subjective importance of an impact category. Categories are often sorted by theme or damage category.

6- Data Quality Analysis: Understanding the reliability of the indicator results.

The classification, or assigning of inventory data to impact categories, and the characterization, or modeling of inventory data within the impact categories (ISO 1997), to be performed using the ATHENA 4.1 life-cycle calculation program (2010) which is used to model the buildings. The study also compares the environmental impacts of different building assembly systems (foundation, structure, walls, floors, roofs) so that the significant environmental impact could be identified within these systems.

a. ENVIRONMENTAL IMPACT CATEGORIES

• GWP is also called Greenhouse Effect or Carbon Footprint. This effect represents an average increase in earth temperature due to the burning of fossil fuels and other forms of energy resulting in higher atmospheric concentrations of gases such as carbon dioxide, methane, and nitrous oxide. The occurring short-wave radiation from the sun comes into contact with the earth's surface and is partly absorbed and partly reflected as infrared radiation. The reflected part is absorbed by greenhouse gases in the troposphere and is re-radiated in all directions, including back to earth. Hence, the quantity of heat the earth can give away to the space is accordingly reduced and the (mean) temperature of the layers of the atmospheric envelope (that are close to the ground) tends to increase accordingly. Greenhouse gases that are considered to be caused or increased are carbon dioxide, methane and CFCs. Figure ….shows the main processes of the greenhouse effect. An analysis of the greenhouse effect should consider the possible long term global effects. For other gases than CO2, GWP is calculated in carbon dioxide equivalents (kg CO2-eq.). This means that the greenhouse potential of an emission is given in relation to CO2. Since the residence time of the gases in the atmosphere is incorporated into the calculation; a time range for the assessment must also be specified. A period of 100 years is customary for GWP.

• Resources use, reported in kilograms (kg), addresses the resource extraction activities associated with the manufacturing of each building material. As stated in the Athena IE software, the values reported for this impact category are the sum of the weighted resource requirements for all products used in each of the building cases.

• ODP is also called "Ozone Hole", which is the depletion of the stratospheric ozone layer. The ozone of the stratosphere absorbs a large portion of the hard UV sun rays. Depending on climatic conditions, the catalytic action of Chlorofluorocarbons CFC compounds degrades ozone down to oxygen. Some of these gases have a very long residence time in the stratosphere and may cause the ozone molecules to be destroyed even many years after their emission. Reduced concentration of the ozone (hole in the ozone layer) causes an increased transmission of UV sun rays with negative consequences for plants, animal and human beings (for instance increased skin cancer hazard, DNA damage, etc). The ozone depletion potential is expressed in terms of mass equivalence of Trichlorofluoromethane (CCl3F = CFC-11), which is the measure used to assess the importance of the effect produced by the various gases.

• Particulate Matter (PM) of various sizes PM10 and PM2.5 (with aerodynamic diameters of 10 or 2.5 microns or less, respectively) have a considerable impact on human health. The US EPA (2002) has identified "particulates" (from diesel fuel combustion) as the number one cause of human health deterioration due to its impact on the human respiratory system – asthma, bronchitis, acute pulmonary disease, etc. These include PM10 (inhalable particles) and its fractions PM2.5 (fine particles). It should be mentioned that particulates are an important environmental output of construction products production and need to be traced and addressed. The equivalent PM2.5 basis is the measure of this impact indicator.

• POCP always referred to as "Summer Smog" which is the production of ground level ozone. It is the result of reactions that take place between nitrogen oxides (NOx) and volatile organic compounds (VOC) exposed to UV radiation. Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog. While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NOx). The smog potential is expressed on a mass of equivalent NOx basis that represents these air emissions from industry and transportation that are trapped at ground level.

• EP is also called "Over-fertilization". The term "eutrophic" means well-nourished, thus, "eutrophication" refers to natural or artificial addition of nutrients to bodies of water and to the effects of the added nutrients. When the effects are undesirable, eutrophication is considered a form of pollution." (National Academy of Sciences, 1969). The process happens when a body of water acquires a high concentration of nutrients, especially phosphates and nitrates. These typically promote excessive growth of algae. As the algae die and decompose, high levels of organic matter and the decomposing organisms deplete the water of available oxygen, causing the death of other organisms, such as fish. Eutrophication is a natural, slow-aging process for a water body, but human activity greatly speeds up the process. The calculated result of EP is expressed on an equivalent mass in kg of nitrogen (N+) ion basis.

- Acidification, also named as “acid rain”, comprises processes that increase the acidity (hydrogen ion concentration, H+) of water, air, and soil systems. Acid rain generally reduces the alkalinity of lakes. Acid deposition also has deleterious (corrosive) effects on buildings, monuments, and historical artifacts. The acidification of soils and waters occurs through the transformation of air pollutants into acids. This leads to a decrease in the pH-value of rainwater and fog from 5.6 to 4 and even below forming “acid rain” that can pollute forests, lakes and rivers, as well as buildings. The most important substances contributing to AP is SO2 (sulfur dioxide) and NOx (nitrogen oxides) and their respective acids (H2SO4 und HNO3) produce relevant contributions. These are released into the atmosphere when fossil fuels such as oil and coal are combusted. This damages ecosystems, whereby forest dieback is the most well-known impact. Acid rain generally reduces the alkalinity of lakes. Acidification has direct and indirect damaging effects (such as nutrients being washed out of soils or an increased solubility of metals into soils). But even buildings and building materials can be damaged. Examples include metals and natural stones which are corroded or disintegrated at an increased rate. The resulting acidification characterization factors are expressed in hydrogen (H+) mole equivalent deposition per kilogram of emission.

- FFC is also referred to as primary energy consumption or fuel depletion. It is usually given in mega-joule. This impact category is the total energy used to transform and transport raw materials into products during the manufacturing and construction phases. This includes inherent energy contained in raw materials in addition to indirect energy use associated with processing, converting, and delivering energy. This impact essentially characterizes the gain from the energy sources such as natural gas, crude oil, lignite, coal and uranium. Natural gas and crude oil will be used both for energy production and as material constituents e.g. in plastics. Coal will primarily be used for energy production. Uranium will only be used for electricity production in nuclear power stations. It is important that the end energy use (e.g. 1 kWh of electricity) and the primary energy used are not miscalculated with each other; otherwise the efficiency for production or supply of the end energy will not be accounted for.

INTERPRETATION OF RESULTS

The aim of the interpretation phase is to evaluate findings and to reach conclusions and recommendations in accordance with the defined goal and scope of the study. Results from the LCI and LCIA are combined together and reported in order to give a complete account of the study. The life cycle interpretation of an LCA or an LCI comprises 3 main elements:

1. Identification of the significant issues based on the results of the LCI and LCIA phases of a LCA.

2. Evaluation of results, which considers completeness, sensitivity and consistency checks.

3. Conclusions and recommendations.

III. CONCLUSION

Life-cycle assessment of buildings is less advanced than in other industries, but researchers are working to enhance the possibilities of adopting LCA as a decision making support tool within the design stage. It is clear that LCA is well explained, and its methodologies are well established and accessible to users, but there are still many impediments to its use for buildings, and these set the research agenda for the future.

The main problem is the building, whose production process is complicated, and whose life span is long with future phases based on assumptions. There is little standardization within the building sector, so there is a clear lack of data inventory. Researchers are working hard to overcome this problem, but the nature of the building industry makes it difficult to have an international dataset available for all users, which can make the life-cycle assessment studies comparable. There should be an internationally accepted framework, protocol, and conversion tools based on different factors, to enable the comparison between one LCA study and another. The currently available datasets are typically not transparent, and most of them are based on local and simple materials but not components or composites. There is a need to produce accurate local datasets with the possibility to convert their results to an internationally comparable form.

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