State of the Art Study - How is Environmental Performance Measured for Buildings/Constructions?

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Abstract Several studies have used life cycle assessments to measure the impacts of energy consumption in different building stocks in a quantitative way. The use of LCA as the assessing tool has become commonly used in this respect. Today, greenhouse gas emissions from buildings are mostly linked to energy consumption during its operation period. Through increasingly stringent energy requirements and other changes, energy use for the operation is likely to decrease over time. On the basis of a literature reviews, it is carried out an assessment with the focus on explaining the methodological platforms the different studies are based on, and thereby explaining why the results vary and / or may not be comparable.

1 Introduction

For more than a decade Life Cycle Assessment (LCA) has been developed as a tool for assessing environmental aspects of different building products and constructions during its lifetime. However, we see a lot of LCA and EPDs of building materials which to a great extent have been limited to the environmental impacts associated with the building materials or products – cradle to gate. On the other hand as the energy for operation decreases as passive or low energy houses are built, the relative contribution to the total emissions in an LCA-perspective from building materials will increase.

Today, greenhouse gas emissions from buildings are mostly linked to energy consumption during its operation period. Through increasingly stringent energy requirements and other changes, energy use for the operation is likely to decrease over time. If so, this means that the energy consumed during production, transportation and construction of the building to a larger extent can be relatively more important in a life cycle assessment.

The Norwegian Ministry of Local Government and Regional Development has in this connection commissioned Ostfold Research to conduct a literature study, which will provide an overview and assessment of existing literature / research reports that describe various building materials' global warming potential and how this translates into a life cycle perspective (LCA – Life Cycle Assessment), and thereby describe the knowledge platform these assessments are based on. Moreover, it entails a description of the factors which affect the climate and environmental impacts, including the parts of the life cycle that are important.

2 The review study

The literature study was carried out through searches in scientific databases (Springer Link, Science Direct, Google Scholar, EPD Norway's database of environmental product declarations). The literature search is limited to studies that are based on LCA as a methodology for calculating the climate impacts associated with buildings and building materials.

Further, on the basis of the literature reviews, it is carried out an assessment with the focus on explaining the methodological platforms the different studies are based on, and thereby explaining why the results vary and / or may not be comparable. To illustrate this, this assessment is based on two statements that are strong in the public debate about the environmental impacts of building materials and buildings throughout their lifetimes; 1) Climate impacts of today's buildings are linked to the operational phase and 2) In low energy buildings the production phase becomes as important as the operational phase.

The methodological foundations that are used in the different studies are further applied in relation to the two statements.

3 Results

There are several LCA-studies that compare building materials, such as wood against concrete or steel. Many of the studies exclude phases or activities throughout the life cycle of the building [1]. The argumentation of the exclusion is not always clear, however some argue that "energy for heating is equal for both building systems" [2], [3]. This is clearly a weakness when comparing building systems based on different building materials.

Although numerous studies concludes that "the LCA shows that energy use during use phase is most important", it is simultaneously concluded that a building based on one particular building material is better than the other, without discussing if there are significant differences between the systems.

The different approaches of performing LCAs and of excluding certain life cycle phases or activities, affects the results in two main directions; a) what life cycle phases that has the largest impact and b) the influence of material choice on the results.

Haapio and Viitaniemi [4] have performed a literature review on different calculation tools for environmental evaluations based on LCA of entire buildings. The study shows that LCA results are dependent on the tool used, and that a comparison between results from different tools is impossible.

3.1 Are climate impacts of today's buildings linked to the operational phase?

One important result from the LCA analyses is that energy use for operation contributes to 70-90 percent of the total during the lifespan. This is a general conclusion and assertion that is verified whether analysing heavy or light constructions [1], [5]-[11].

Several factors are influencing the relative importance between production of building materials and operation phase. They can be divided in three categories - LCA methodology, localization and building technical aspects.

Geographical and climate conditions with respect to the localisation of the buildings, how they are designed, fitting in the terrain and how they are used will influence the total energy use and embodied energy. On the other hand these factors are not highlighted in the literature; it is mainly LCA methodological aspects that are focused.

3.1.1 Data

The selection of data is of vital importance for the results. First of all, an LCA can be approached methodologically from two different perspectives: bottom-up, based on Process Life Cycle Assessment (PLCA) or top-down, based on Input-Output Life cycle Assessment (IOLCA) analysis. A combination is hybrid approaches, which link process information collected in physical life-cycle inventories with monetary flows in economic models.

In the building sector PLCAs have been the most usual approach. This approach is calculating emissions from the inputs by its masses, which represents challenges for several reasons. Firstly, the construction sector does not have a tradition to evaluate their projects on mass basis, only in economical terms. Thus, one does not have key figures or experienced based calculations to lean on. Secondly, in a feasibility phase one doesn't know which materials will be chosen. And last but not least, there are not environmental data available for all building materials and components.

The combination of LCA and input-output models has shown value as a complementary tool to traditional inventory methods in LCA. The reason is bipartial. Firstly, the total embodied energy is not included when using PLCA. Input-Output Life Cycle Assessments for typical US industries indicate that on average up to 75% of total emissions were overlooked when only looking upon the industries direct emissions and not include services etc. [12].

Secondly, in a feasibility phase one does not know which materials will be chosen and the construction sector does not have a tradition to evaluate their projects on mass basis, only in economical terms. Especially in US one see the approach of IOLCA and Hybrid LCA utilized when analysing a construction project to overcome the lack of data and to include embodied emissions [3], [13]-[15].

3.1.2 Electricity model

When considering greenhouse gas emissions, the choice of energy model is essential, including the assumption of what energy carriers are generating the electricity consumed in the building. The assumption considerably affects the relative difference in impact from each life cycle phase. Reviews of variation in greenhouse gas emissions for different electricity models used in Norwegian calculations differ from 0 - 1.400 kg CO2-eqv/kWh [16].
This implies that the choice of electricity model may overturn the conclusion that the use phase is the most important phase when it comes to greenhouse gas emissions, as for cumulative energy demand. This proves the importance of

considering more environmental indicators than greenhouse gas emissions to obtain a holistic information basis.

3.1.3 Definition of user phase or operation

The perception and understanding of the term operation is not unambiguous. Figur 1 shows a typical environmental profile as a result of an LCA [9]. The phases and terms are in accordance with the MOMD-term – Management, Operation, Maintenance and Development and in addition End of life is included.

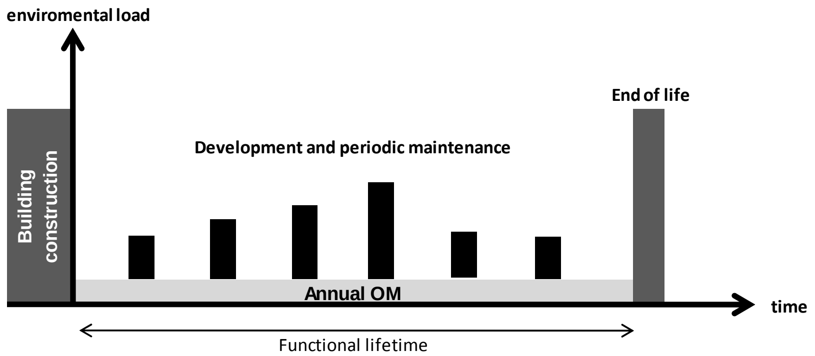

Fig. 1 Life cycle phases of a building [9].

Some studies are defining operation as use of energy for heating and cooling [17]. Other includes lighting, use of technical equipments and appliances in addition [18]. In the first case one can question whether lighting and use of technical equipments are explicitly included since it is hard to address the total energy used to different purposes. Other operation related activities like e.g. cleaning and inspection technical equipments are a part of daily operation of the building, but seldom included in LCAs. At the same time will design and choice of materials and equipments affect the need for and type of e.g. cleaning [15].

It is a challenge for the credibility of LCA results that the phases maintenance, replacement and development are excluded from the analysis. With that the total environmental performance through the life span of the building is under estimated. And the results from those studies are not presenting in real terms what life cycle phases are important and for what conditions they are important [7], [17]. Thus, design focused upon adaptability and use pattern is of more important than the building materials and products itself [15], [19]-[22].

The average rental period for office buildings in Norway is 7 years. Every seventh year the building is undertaken an extensive rebuilding due to new renters needs and requirements [15]. How extensive the rebuilding processes will be, is depending on the building's degree of adaptability.

This review study found no LCAs simulating consequences different use patterns have on the total energy use or other environmental aspects. This is interesting due to the fact that use pattern affect the energy use vitally. Comparison of five two-person households living in exactly equal houses in the same area shows that the variation between lowest and highest energy use for heating was 4.000-14.600 kWh/yr [23].

3.1.4 Factor of time

Estimated time, for which the LCA is undertaken, is of vital importance for the results due to a relatively long service life [19], [24]-[25]. The choice of service life period (SLP) influence the climate impact vitally and the range in SLP is found to be 20 - 100 years in the literature. SLP is defines as the period where no changes of the building occur.

With the exception of service life predictions the factor of time has not been dealt with in LCA until now [25]. Changes over time, being changes in the building and changes in technology, are not mentioned. If SLP will last during the whole life of the building, then there is no need for high adaptability, e.g. an opera building. But, in those cases where SLP is short e.g. hospitals or private houses were changes occur due to new technology or changes in household and use pattern the different those aspects should be included in an LCA. So far mainly static factors such as energy for operation and maintenance are taken into account in LCAs [25]. Aspects related to adaptability; re-design, changes in use pattern and functionality are often neglected in LCAs. Adaptable buildings give lower refurbishments cost and then total low life cycle costs [26].

On the other hand LCAs are often based on technical service life for products given by producers. Then this will again be basis for defining scenarios for maintenance, repair, replacement etc. to be included in the LCA. This often leads to prediction of use phase activities which not reflect real life. Studies of SLP in practice, shows that the real SLP differ considerably from the SLP given by producers [27]-[28]. The building product itself can satisfy the given requirements, but it may be other factors that define how and when changes occur, e.g. design and colour trends influence the need for paining and not necessarily the need for maintenance the set the frequency for panting.

3.1.5 Transport

Several studies conclude when doing LCA of buildings for planning purposes, especially regional planning, one should include transport activities related to use of the building. Transport may contribute to as high as 50 percent of the total energy use [29][33]. Transport of construction workers are not insignificant and are excluded in most studies [34]. On the other hand, LCA standards do not require transport of users (or workers) as a consequence of localisation to be included in LCAs.

3.2 Will the production phase become as important as the operational phase for low energy building?

A building material's impact on en entire buildings total energy use throughout the use phase has large influence on the results, as shown in earlier chapters. As the buildings become more and more energy efficient, the importance of the emissions from the production of the building materials increases [35]-[41]. Hubermann and Pearlmutter [41] give an example where upstream energy use is responsible for 60 percent of the total energy use. Dependent on type of building, location and type of model applied for the calculations of CO2 factor for electricity, the balance between the impacts from each life cycle phase may shift even more. Simultaneously, awareness should be raised with regard to interaction between the life cycle phases. A narrow focus on the importance of each individual life cycle stage must not lead to ignorance of the significance of choices done when designing the building, such as choice of building materials, as these choices has large impact life cycle of a building [17].

Sartori and Hestnes has performed a literature review where the objective was to clarify the relative importance of energy use during operation opposed to energy use in upstream processes, including energy use to extraction of raw materials, production of building materials and on site construction and transport to site - especially related to low energy buildings [39]. Most of the 60 cases studied concluded that energy use during operation represent the largest contribution, and that low energy buildings are more energy efficient than conventional buildings although energy use for production of (upstream) materials increases.

4 Discussion

To ensure greater use of life cycle considerations, focus should be on the challenges along two axes: on the one hand, to strengthen the credibility of the underlying data and calculation methods of LCAs and on the other hand facilitate the use of results in actual construction processes, companies' product development and overall priorities at the state and municipal levels. There are a number of measures that could increase the use of lifetime considerations along the two axes. Examples of such measures could be:

Methodology – strengthen the credibility of calculations:

- Ensure equal calculation methodologies for LCAs of building materials, though the development of product category rules (PCR) for building materials and composite building elements such as external wall solutions, roof structures and floors.
- Develop and make data available; eestablish key values or databases with realistic lifetimes for maintenance and development phases and investigate the relationship between user patterns and energy consumption.
- Clarify the relationship between the building's adaptability and consequences on maintenance and replacements.
- Establish consensus on how the environmental data for different building materials can be calculated on the entire building's lifecycle; i.e. how to connect the material properties and technical properties different materials have, singularly or in combination with other materials.

Encourage increased use of LCA in decision making processes and policy formulation:

- Clarify what environmental information decision-makers need in the various phases of the construction process.
- Increase knowledge in the industry about the relationship between choices in the construction process and environmental performance through, for example, training courses, education and other outreach.
- Integrate LCA results in existing tools that are traditionally used in the construction process (e.g. BIM).

- Encourage the private sector to increase their focus and knowledge of their own products by requiring the use of LCAs in the tender processes, in relation to new construction processes, rehabilitation and maintenance.
- Encourage increased use of interaction processes in public development projects, where LCA can be used as a communication forum though simulation of the environmental consequences of choice.
- Require LCA documentation with future scenarios for buildings of a given size in building permit procedures.

5 Conclusion

Based on the reviewed LCA literature, we highlight the following main findings;

- The environmental impacts and energy consumption associated with the operation, maintenance and development phases (OMD) are of great and greater importance than the production of various materials.
- For low energy buildings, the relative importance of the production of building materials will increase.
- There is no basis to claim that one kind of building material should be prioritized over another with regard to environmental impacts.
- Through the inclusion of the overarching choices of solutions, which means that more phases and activities will be incorporated in the LCA, the total environmental loads through the building's life span will increase. The importance and scope of the various phases will depend on the purpose of the analysis, the type of construction, user patterns and more.
- LCA as a method makes it possible to assess the environmental consequences of different choices during the early planning stages, the design phase and the MOMD stage.
- Because it within the LCA modelling is given opportunities to make large variations in terms of calculation methods, it will be possible to get different results with regard to environmental impacts. The variations are explained in relation to the purpose of the study, the available data used and the quality of the data used as well as how the system boundaries are determined (which phases to include / exclude).
- Excising models and methods for calculating the LCA presents results in a form that is not necessarily adapted to the specific actors in the construction industry's need for environmental information. Neither are

they adapted to existing tools which traditionally are used in the building process.

- LCAs are mostly used for documenting the consequences of already established choices and decisions or completed construction projects, and are to a lesser extent used as a planning tool for simulation of consequences of different choices in various phases of the construction process or though the lifetime of a building.

6 References

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