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Life Cycle Assessment of Building Materials for a Single-family House in Sweden

Bojana Petrovic[ab]*, Jonn Are Myhren[a], Xingxing Zhang[a], Marita Wallhagen[b], Ola Eriksson[b]

[a]*Department of Energy, Forest and Construction Technology, Dalarna University, Falun, SE-791 88, Sweden*
[b]*Department of Building, Energy and Environmental Engineering, Gävle University, Gävle, SE-801 76, Sweden*

Abstract

The Nordic countries have shown great interest in using Life Cycle Assessment (LCA) in the building sector compared to the past years. Sweden has set up an objective to be carbon neutral (no greenhouse gas emissions to the atmosphere) by 2045. This paper presents a case study of a single-family house "Dalarnas Villa" in the region Dalarna, Sweden within a 100-year perspective. The assessment is implemented using a new software based on hard data agreed by Environmental Product Declarations (EPDs). It focuses on building materials, transport distances of the materials, and replacement of essential construction materials. The LCA in this study demonstrates the environmental impact related to building materials from production and construction phase including transport, replacement and deconstruction phase. The study does not cover energy use and water consumption. The results show that the building slab made by concrete is the part of the construction most contributing to CO_2e, while the wood frame and cellulose insulation have low environmental impact. Replacement of materials takes nearly half of total environmental impact over 100 years. Having a large share of wood-based products, make greenhouse gas emissions remains low.

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Keywords: carbon dioxide equivalent (CO_2e); global warming potential (GWP); life cycle assessment (LCA); One Click LCA;

* Corresponding author. Tel.:+46739272972.
E-mail address: bpv@du.se

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1. Introduction

The building sector is responsible for about 40% of environmental overload mainly produced by developed countries in European Union (EU) [1]. Substantial savings can be achieved by more efficient construction and usage of buildings. These savings could be made by the influence of 42% total energy consumption, 35% of Greenhouse Gas Emissions (GHG), 50% of the extracted raw materials and, in some areas, 30% of water could be saved according to the Roadmap to Resource Efficient Europe [2]. The building sector can become more resource efficient through incorporating Life Cycle Assessments (LCAs) to decrease the environmental impacts from the buildings whole life cycle [3]. By using LCA sub-optimization can be avoided and it may have impact on design and choice of construction materials. LCA is a tool to assess potential environmental impact from material extraction and production, through construction, user phase to the waste treatment and end-of-life of the product [4]. In the context of sustainable buildings, energy efficiency and renewable energy are covered by EU policy as the main keys in promoting resource efficiency in the building sector by making full LCA [2]. The European Commission has established an objective to decrease CO_2 for the building sector by 90% until 2050 [5, 6]. To achieve the goal of reducing CO_2 emissions, a life cycle approach is required to detail the carbon footprint in buildings for feasible carbon reduction strategy, according to Vilches et al [6]. The European Commission came to the conclusion that LCA is one of the best tools for evaluating environmental impacts through all phases of the building [7]. LCA in building sector is characterized by: (1) long lifespan of the buildings (usually more than 50 years) and its difficulty to predict the whole life cycle; (2) significant changes with many stakeholders involved during the buildings life span. Hence, there is a need to perform full LCA and estimate relationship between alternative materials and energy performance of the buildings [8]. The benefits of using LCA that assist in term of sustainability in the building sector are: environmental, social and economic. Environmental benefits are followed by comparison of alternative products and providing information about environmental impact helping stakeholders to make informed decisions. Social benefits could drive government regulations and includes decision making. Economic benefits are based on promotion of products for the green market, lower cost for constructions [9] and decreased costs because of reduced negative environmental impacts. Furthermore, LCA methodology is followed by ISO standard and uses a long term perspective [10].

In recent years, Nordic countries have shown increased interests in uses of LCA for analysis of environmental performance in the building sector [7]. The Nordic countries are strong actors in providing deep collaboration and common network for the innovative use of LCA in sustainable building and construction [7]. Boverket (The Swedish National Board of Housing, Building and Planning) has been commissioned by the Swedish government to propose methods for reporting climate impacts, taking into account a life cycle perspective. The national target of Sweden is to become carbon neutral by the year 2045. The climate declaration is proposed by following LCA according to the European Standard EN 15987. The standard proposes that LCA in buildings have to be implemented [11].

A number of existing studies using LCA in Scandinavia have been found for single-family houses and multi-family residence buildings. A full LCA was performed for eight design alternatives based on four-storey building in Växjö in Sweden [12]. Their study used data from Environmental Product Declarations (EPDs) of products. In their research, global warming potential and primary energy demand were analyzed as environmental impacts categories. Similarly, LCA of a single-family residence built to conventional or passive house standard due to [13] and multi-family residence by [14]. Furthermore, there is a research about Danish single-family house by [15]. In this case, three buildings were evaluated in the sense of life cycle embodied and operational energy for a period of 100 years. Taking into account the whole life of the building, Danish single-family house recognized the importance of embodied primary energy in relation to operational energy caused by more insulation and technical systems needed for buildings. Bribián et al has shown results of an LCA using three different environmental impact categories with some eco based materials. The study shows the importance of using more eco-efficient products in the production phase with encouragement to use EPDs to significantly reduce impacts [16]. Single-family houses often have different construction components compared to multi-family buildings. A large share of wood as construction material has an importance for eco based single-family house in comparison with conventional house based on concrete as the main construction material. As observed from these previous studies, none of them have addressed the LCA challenge in a single-family house in a Nordic climate scenario. Furthermore, there has been no standardized tool for buildings LCAs, which enables the difficulty in comparison of results in various scenarios.

This paper aims to fill in such two research gaps by focusing on green building materials applied in a Swedish single-family house - the case of Dalarnas Villa in the region Dalarna in Sweden, based on the One Click LCA software [17]. The main objectives in this research are as follows: (1) evaluate environmental impact of building materials using One Click LCA software; (2) demonstrate preliminary results of most contributing materials in different environmental impact categories from production stage, over the building life cycle including replacements and maintenance, as shown in Figure 1. This paper estimated the production stage that includes (A1-A3 modules), the construction process (A4 module), the maintenance and replacement (B1-B5 modules) in the use phase and end-of life stage (C1-C4 modules).

Product Stage			**Construction Process Stage**		**Use Stage**							**End-of-Life Stage**				**Benefits and loads beyond the system boundary**		
Raw material supply	Transport	Manufacturing	Transport to building site	Installation into building	Use/application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D
*marked modules are included in the paper																		

Figure 1. Life cycle stages according to EN 15804:2012 [17].

The preliminary research results are expected to present environmental impacts of building materials and transport distance of materials, without including energy use and water consumption. However, the latter part will be fulfilled in next step with continued research based on experiments and measurements on the single-family demonstration house "Dalarnas Villa" to achieve a full LCA.

2. Methodology

The One Click LCA software is developed by Bionova Ltd. The software is compliant with EN 15978 standard [17]. It is a standardized platform to perform Life Cycle Costing alongside Life Cycle Assessment with great opportunity to reduce costs including environmental impacts. The software One Click LCA consists of using different factors from production and construction phase through the use-phase until end-of life, namely the "grave" phase. One Click LCA is followed by Environmental Product Declarations (EPDs) based on the ISO 14044 and EN 15804 standards. EPD is a verified description of the environmental profile of any product, based on Life-cycle assessment calculations according to ISO 14040, ISO 14044 and EN 15804 standard for EU countries. An EPD is connected with environmental performance of the product or building materials over its lifespan. The strength of using this software is time efficiency in calculation of a whole LCA. Furthermore, within One Click LCA it is possible to change and choose building materials and simulate how to reduce carbon emissions [17].

2.1. Case study

"Dalarnas Villa" is a single-family demonstration house in the region Dalarna, Sweden. The project is a collaboration between a research team at Dalarna University and Dalarnas Försäkringsbolag Company. The functional equivalent is a single-family house with an expected lifetime of 100 years and a total gross floor area of 180 m^2 (main building 150 m^2 and garage 30 m^2), which comply with the functional requirements of Swedish building regulations. In order to show the quantities of environmental impacts through all phases of single-family house, an inventory was made of building materials with suggested replacement and estimation of transport distance. Figure 2 presents the technical drawings and facade for Dalarnas Villa in Sweden made by the company Fiskarhedenvillan AB, Sweden.

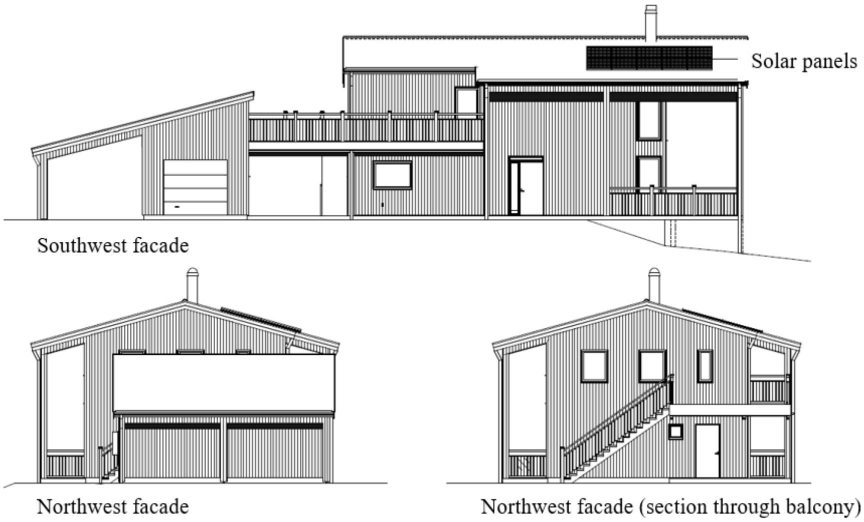

Figure 2. Technical drawings of ground and upper level and facade for Dalarnas Villa.

Material documentation for "Dalarnas Villa" has been provided from the supplier company Fiskarhedenvillan AB. In comparison with data for building products in the report: "Carbon footprint for building products" by [18], some predictions of CO_2 emissions included in building materials are in relations with data available in One Click LCA. The main contributing building materials with recommended replacement periods and transport distances of materials are presented in Table 1. It can be seen that concrete and thermo wood has the highest CO_2e (the amount of CO_2, which has the equivalent Global Warming Impact (GWP)). The other more contributed materials are: steel, gypsum, gypsum, doors and windows. All materials have transport distances already included in the software One Click LCA in the production stage, therefore only the transport distance from material manufacturer to the building site is entered. It is suggested that wood panel, roof and windows could be changed once per life time of the building. Due to "current practice", doors could be changed two times, while thermo-treated wood for external use and parquet for the floor inside the house could be changed three times during the life span.

Table 1. Main groups of construction materials with transport distance and replacement.

Material	**Quantity/Unit**	**GWP: kg CO_2e/unit**	**Tons CO_2e**	**Replacement**	**Transport distance [km]**
Concrete	21.8 m^3	268.68/m^3	6.10	0	19
Wood framework (internal + external)	23.4 m^3	25/m^3	0.50	0	264
Wood panel facade	15.6 m^3	25/m^3	0.40	1	264
CLT (cross-laminated timber)	5.4 m^3	140/m^3	0.70	0	264
Thermo wood external (heat treated wood)	4.4 m^3	514.03/m^3	9.10	3	264
Cellulose insulation	114.2 m^3	3.6/m^3	0.41	0	212
Wood fiber insulation	5.7 m^3	79.63/m^3	0.45	0	212
Expanded Polystyrene (EPS) insulation for foundation	21.8 m^3	50/m^3	1.13	0	380
Gypsum	1306.2 m^2	2.1/m^2	2.70	0	220
Floor internal	132 m^2	4.5/m^2	2.40	3	215
Plastic details	1521.8 m^2	0.35/m^2	0.53	0	200
Windows-triple glazed	25 pieces	115/piece	5.90	1	400
Doors	15 pieces	93/piece	5.50	2	470
Roof-galvanized steel	155 m^2	11.5/m^2	3.60	1	410
Total			39,4		

3. Results and Discussion

Figure 3 illustrates the most contributing building elements, building types and material subtypes presented in Global Warming Potential as an indicator for carbon footprint, which refers to amount of carbon dioxide released to the atmosphere as a mixture of greenhouse gases. Within the software One Click LCA, building elements includes foundations and substructure; vertical structures and facade; horizontal structures; other structures and materials. The buildings total impact of all life-cycle stages discharges about 39 tons CO_2e for study period of 100 years, which is equal 2 kg CO_2e per m^2/year. Concrete, thermo-treated wood, gypsum, roof, doors and windows have the highest rates of CO_2e per m^2.

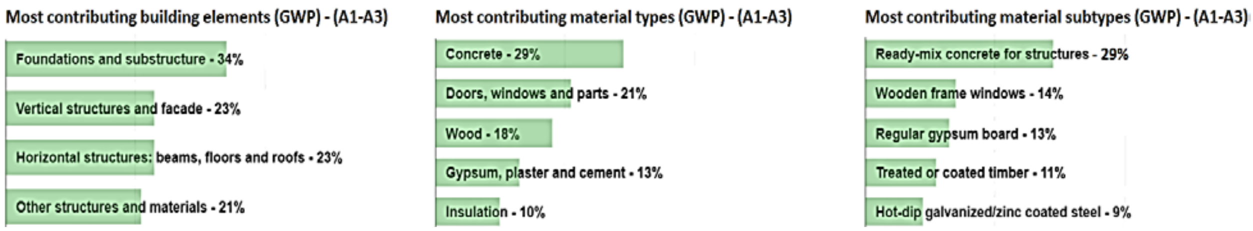

Figure 3. Most contributing building elements and material types for global warming potential (GWP) by One Click LCA.

Figure 4 presents the results at building life-cycle stages. Global Warming Potential describes changes in temperatures caused by increased GHG in the atmosphere. Acidification Potential shows the effects of some acid substances (SO_2e) in the environment. Eutrophication Potential describes effects of added nutrients (phosphorus and nitrogen) to soil or water. Ozone Depletion Potential describes influence of some substances, which affect the ozone layer. Formation of ozone of lower atmosphere presents photochemical smog existing in the atmosphere [17]. We can state that all indicators have shown high environmental impacts in the production stage and replacement part. The transportation stage (A4) and Deconstruction stage (C1-C4) has shown the lowest contribution.

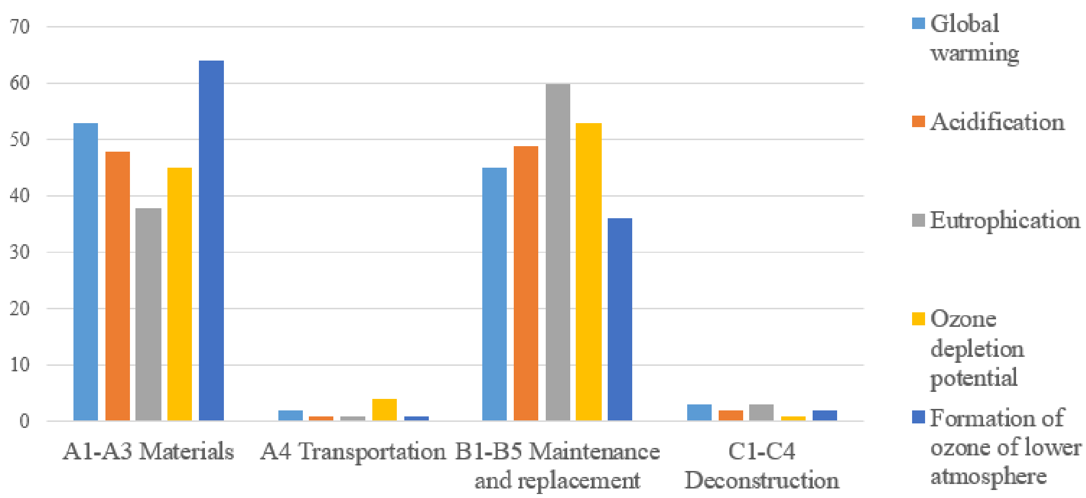

Figure 4. Analyzed different impact categories in life cycle stages by One Click LCA.

4. Conclusions

This paper presents evaluation of environmental impacts for building materials for single-family house in Sweden mostly built by eco materials. It shows that concrete slab and thermo-treated wood has the highest environmental impact while untreated wood-based materials, such as wood frame and cellulose insulation, has the lowest. In this study case, the importance of using green building materials, such as untreated wood, and cellulose insulation is presented. Furthermore, except for GWP, construction materials cause other environmental impacts. Therefore other environmental impact indicators are also crucial for evaluation through LCA stages. These assessed impact indicators are: acidification potential, eutrophication potential, ozone depletion potential and formation of ozone of lower atmosphere. The major contributors of GWP are located in the foundation. Replacement parts takes nearly half of total environmental impact over 100 years. The LCA methodology is based on hard data and is fully standardized, which gives the user confidence to implement it in future studies.

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