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How Transport Modelling affects the building Life Cycle Assessment (LCA) results: A Case Study Analysis

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Abstract. The Life Cycle Assessment (LCA) of a building involves the use of various types of information about the building, including the products, processes, and services related to the building throughout its life cycle. The modelling of the transport process can be complex and may be performed based on a variety of approaches and assumptions. With existing approaches, the most accurate results those closest to the real scenario, are calculated once the building has already been built. Other approaches are based on estimations at the design stage using generic scenarios and data sources. The variation of the LCA results when employing different modelling options for transport modules is studied herein. To this end, and to identify the possible errors or dispersion of the LCA results related to the various transport modelling options, transport impacts are calculated using a case study, whereby five different modelling options are compared. The results show that the transport impact difference between the lowest values (the real scenario) and the highest values (normalised detailed scenario) is approximately 30%. To conclude, efforts should be made to better define the default scenarios, especially regarding transport distances and the correction for volumetric capacity of the transport vessels, adapted to the real scenario.

1. Introduction

The application of building LCA includes the integration of different types of information about the building, including all products, processes and services related to the building throughout its life cycle [1]. Although certain information regarding the LCA modules can be directly extracted from predefined and normalised data sources (such as product stage information A1-3, included in the specific products of Environmental Product Declarations (EPD)), accounting of inputs and outputs for the transport process (Modules A4 and C2) remain complex and demand specific modelling strategies.

In recent decades, the consideration of the environmental impact from transport has received increased attention in several national LCA methods for buildings [2]. The current efforts put into reducing the environmental embodied impacts are largely focused on transforming the energy mix for manufacturing into renewable resources. Thus, if these impacts are reduced to a minimum, then other potential impacts derived from transport and fuel consumption (currently the main source of energy for transportation [3]) should also be measured and reduced.

The EN 15978 [1] standard establishes the framework for the LCA application to buildings and the description of the modularity principle (see Figure 1) and defines the system boundaries and the activities and processes that should be included in each module. Related to the modelling of the transport process (see Figure 1), Module 4 involves not only the transport of materials and products from the manufacturer (gate) to the construction site, including intermediate transport and distribution, but also the transport of the construction machinery from and to the construction site, and all impacts and aspects related to transport losses (i.e., production, transport, and waste management of products and materials that have been damaged or lost in transport). The transport of the construction workers should not be considered in this module. Module C2 contains the impacts due to transport to landfill and/or until end-of-life status is reached. This includes transport to and from possible intermediate storage or treatment sites.

Nevertheless, the specific methods for the modelling of the transport modules are not described in the EN 15978 [1] standard. The impact derived from transport can easily be calculated and involves the fuel consumption of transport activities once the building is constructed, but this information may be largely unavailable or even inexistent during the design stages. This lack of information provides evidence of the relevance of using specific methods to supply this information to the LCA. The modelling of transport should involve the number and type of activities, processes, and services, such as the consideration of transport distances, means of transport, and product logistic chain, which are considered in various ways in the literature. For example, the consideration of the transport distances can be addressed using average distances depending on the type of material, such as in Soust-Verdaguer et al. [4] and in Lavagna et al. [5]. Other studies, such as Shirazi & Ashuri [6] and Pacheco-Torres et al. [7], extract the transport distances from the EPD specific products, or employ GIS-based methods, such as in Göswein et al. [8].
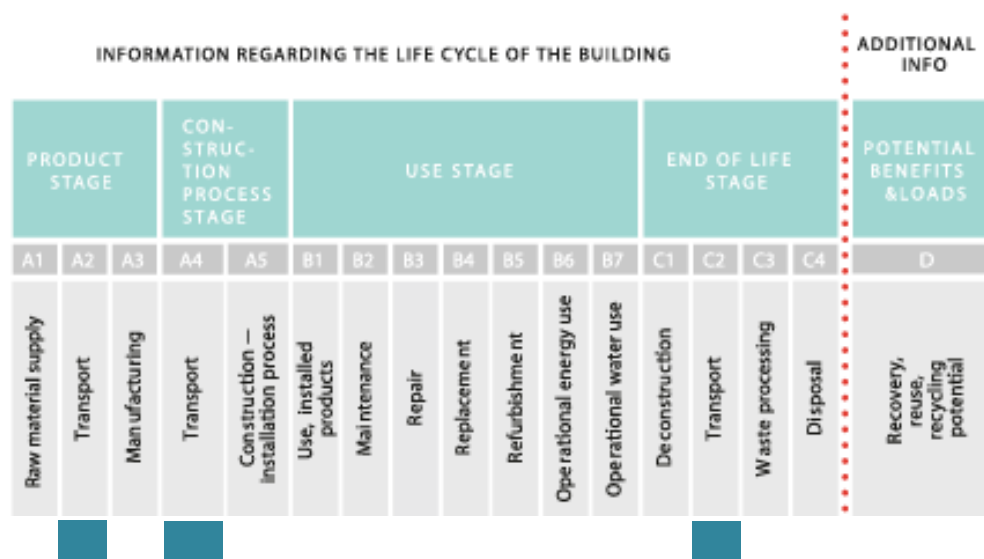
Figure 1. Transport modules in building LCA

Transport modelling is generally performed considering the quantities of the building materials that are transported and the estimated impact that the means of transport produces per km and ton of material transported [9]. It is calculated by multiplying the values for material quantities, the impact factors for the truck transportation (tons per km) (extracted from an environmental database, such as ecoinvent [10]), the estimated distance from the manufacturing point to the construction site, and the return (empty) trip and the means of transport.

A detected limitation of this approach involves the definition of the building material quantities. Hence, for the LCA implementation at the early design stages, the uncertainty and variability in the LCA

can be high [11], because certain materials are yet to be defined. However, the utility of the LCA results in improving the building design is the highest [12]. Thus, in order to integrate the LCA into the design stages, the certification from the German Sustainable Building Council (DGNB) [13] proposes an LCA method to consider the level of detail of the building information throughout the design process. This defines the boundaries of the simplified and detailed Life Cycle Inventory (LCI). On the other hand, the utility of using a simplified LCI instead of a detailed one is also related to the availability of information and to the level of completeness of the information regarding the building [14]. However, one limitation of this simplified approach is the influence of the LCI. Simplified inventories can lead to different results compared to those of detailed inventories [15]. Questions therefore arise as to the size of this difference related to the transport modelling, and how this difference can be reduced.

Another limitation involves the distances and how their consideration influences the impact calculation. This means that the representativeness of the assumptions regarding the distance values can be significant. How can the consideration of default values or normalised values for all the materials influence the resulting impacts? In order to overcome the aforementioned limitations, the present study aims to contribute towards the understanding of how the use of different transport modelling methods can affect the LCA results. To this end, five modelling options are compared: i) the real scenario (based on fuel consumption); ii) detailed inventory with estimated distances, type of transport and fuel consumption; iii) simplified inventory with estimated distances, type of transport and fuel consumption; iv) normalised values for transport and type of transport for detailed inventory; and v) normalised values for transport and type of transport for simplified inventory.

2.   Methods
The present study conducted the LCA calculation of the transport (Module A4) in compliance with the EN 15978 [1] standard. As a case study, the Electronics Based Systems Building (EBS), located in Graz, Austria, was chosen for the assessment of the environmental impacts related to transport to the site (Module 4). This building was constructed in 2019 and has also been used in a reference study [11]. The study compared five transport scenarios for Module A4 (see Figure 1):

Table 1. Scenario definition and assumptions

Transport modelling scenario	Type of Inventory	Transport impact calculation assumptions
1	-	Real fuel consumption of transport
2	Simplified	Product-by-product transport distances
3	Detailed	Product-by-product transport distances
4	Simplified	Normalised distance (30 km)
5	Detailed	Normalised distance (30 km)

For Scenario 1, real fuel consumption, the method to calculate the impacts derived from transport (A4) was based on the multiplication of the fuel consumption (diesel) provided by the constructor with the impact factors. Scenarios 2 and 3 were calculated based on the (product-by-product) multiplication of the material quantities with the transport distance assumptions (extracted from [11]), the impact factors (depending on the type of truck or means of transport), and the empty return factor (2). The transport distances were assumed based on [11], which were provided by the foreperson of the construction site.

Scenarios 4 and 5 were calculated based on the inventories of Scenarios 2 and 3 (simplified and detailed) but included normalised distances from manufacturer to site. The normalised distances were calculated based on the quantity of building components:

$$T_m = \frac{\sum_{i0=1}^{n} q_i \cdot T_i}{\sum_{i0=1}^{n} q_i}$$

where T_m presents the normalised average transport distance; q_i presents the quantity of material i employed in the building; T_i present the transport distance of material i.

The simplified inventory included 93.22% of the total material quantities of the detailed inventory and integrated a selection of the most significant materials (30 from a list of 89 in total). The approach followed the LCA method guidelines for DGNB certification [12] and only 6 were included: (i) external walls (including doors and windows); (ii) roofs; (iii) internal floors and ceilings; (iv) foundations; (v) internal walls; and, finally, (vi) heating, cooling, and ventilation systems [11]. A detailed description of the materials and the transport distance assumptions is included in the Supplementary data section.

The inventory was based on background data from the ecoinvent database v.3.5 [10] and on European average data adapted whenever possible to fit Austrian specificities. The calculation was called a 'cut-off approach' and was performed in the LCA software SimaPro v.8. [13]. The impact categories assessed were defined in accordance with the compulsory EN 15804 [14] standards: the Global Warming Potential (GWP) including total, fossil, biogenic, and land use and transformation; Ozone Depletion Potential (ODP); Acidification terrestrial and freshwater Potential (AP); Eutrophication Potential (EP) including freshwater, marine and terrestrial; Water depletion (WD); Photochemical Ozone Formation (POFP); Abiotic depletion (ADP-e); and Abiotic depletion (ADP-f).

3. Results and Discussion

Figure 2 presents the results of Scenarios 1, 2, 3, 4, and 5 for global warming potential (GWP, including total, fossil, biogenic, and land use and transformation) indicators. The values of Scenarios 1 and 3 present similar values. Figures 2 and 3 show that the variation of the impact categories is proportional in the five scenarios assessed, which means that a reduction in transport can be beneficial for all impact categories.

Figure 2 shows that the results derived from the modelling of transport (Scenarios 2 to 5) for all the impact categories can be from 10 to 25% higher than the real impacts calculated based on fuel consumption of transport. In the detailed inventory (Scenario 3), the results for impacts were approximately 20% higher than the real impacts (Scenario 1). One interesting aspect that emerged from the analysis involves the influence of the truck capacity, the material density, and the logistic chain organisation, which are probably the reason why differences in the results can be observed. In a real scenario, the transport of different products can be combined and the truck charge capacity optimised, while the modelling of transport using a product-by-product strategy (detailed inventory) simplifies this consideration. However, when a simplified inventory (Scenario 3) was employed (approximately 90% of the material quantities (MQ)), the transport impacts were closer to the real scenario (Scenario 1). This means that the possible errors or adjustment in the modelling of transport of the detailed scenario can be corrected by modelling the transport impact of the most representative materials.
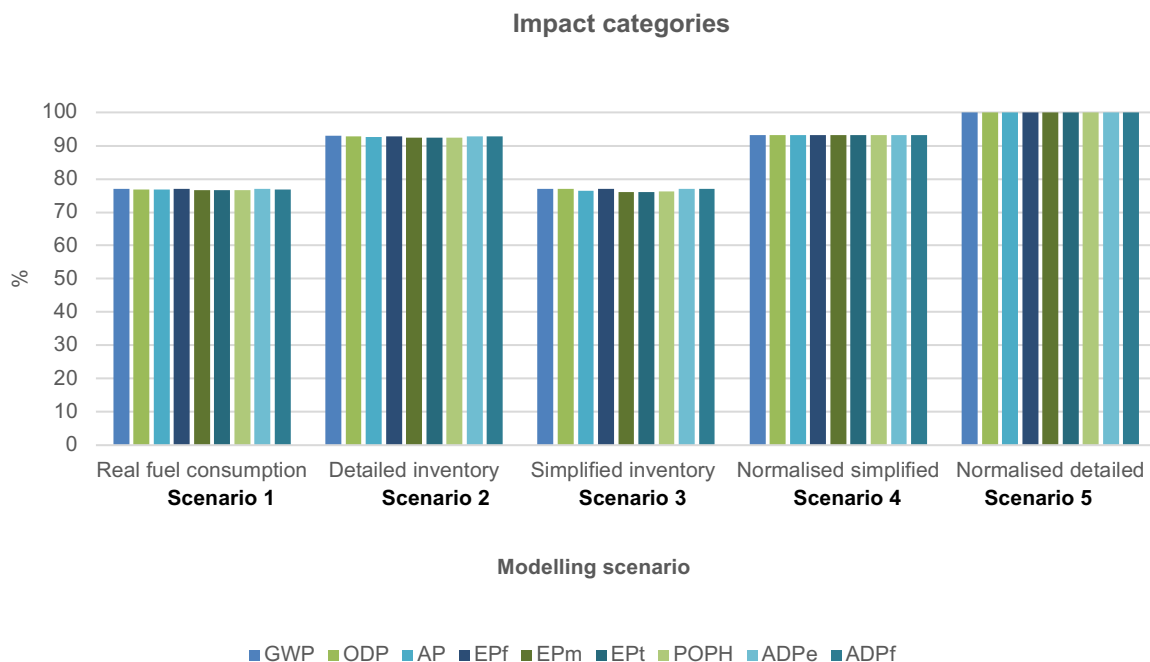
Impact categories

Figure 2. Percentage of the resulting values of the impact categories and scenarios assessed.
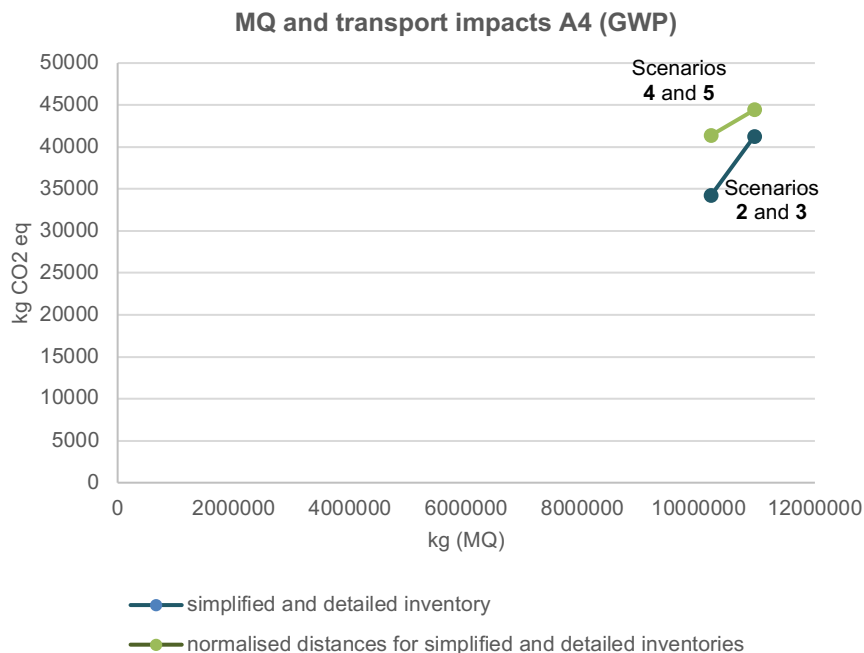

Figure 3. Correlation between the material quantities (MQ) included in the LCI, the equivalent kg of CO_2 (GWP) and the consideration of the distances.

In order to better understand the results obtained and to identify how the two main variables (material quantities (density and weight) and transport distances) can influence the LCA results, we analysed these

two possible variables. Figure 3 shows that the impacts (GWP, for example) derived from the transport module (A4) and the quantity of materials can exponentially increase when those distances are modelled by considering a product-by-product strategy (different distance per product). Nevertheless, it is observed that the impact calculated using the normalised scenario for distances proportionally increases with the increase in MQ. This means that a normalised strategy for the modelling of transport could be useful for the reduction of effort and could have predictable behaviour, but it may lead to an overestimation of the resulting impacts (Figure 2).
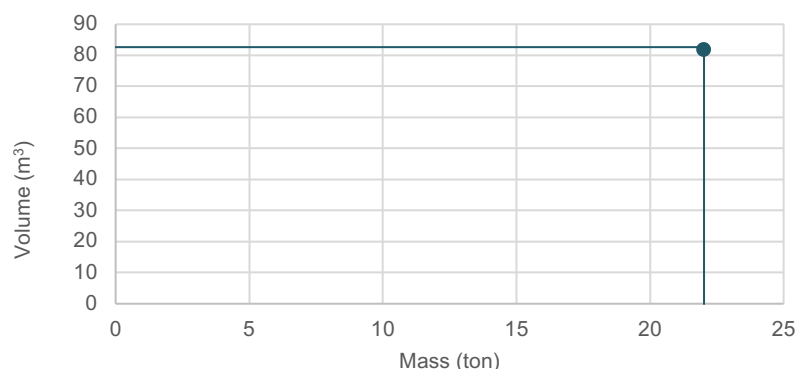

Figure 4. Volume and Mass capacity of a 22-ton truck.

Figure 4 shows the optimal relation between the volume and the weight of the transported materials of a 22-ton truck. It reveals that the truck capacity is optimal if the material density is $268.29 kg/m^3$. Thus, for those materials whose density is lower than the optimal (e.g., Rockwool), the resulting transport impact per ton of transported material can be higher. For example, if a 22-ton truck transports material with the optimal mass/volume relation for a distance of 100 km, then the resulting GWP value derived from the fuel consumption of the truck is 0.140483217 kg CO_2 eq. per km and ton of transported material. However, for a truck that transports a low-density material (e.g., Rockwool $175 kg/m^3$), the resulting transported mass will be 14.350 tons. In this case, the truck capacity is at 65.22%, and therefore, for an equal weight load transported, two half-loaded trucks are needed. The resulting GWP value derived from the fuel consumption of the truck can be 0.241631121 kg CO_2 eq. per km and ton of transported material, which includes a half-load reduction factor of 86%, as given in [15]. The correlation between the mass and volume of the transported materials and the resulting truck capacity constitute key aspects in the consideration of the number of trips, its load characteristics (full, half-load, and empty) and the derived fuel consumption. This provides evidence of the relevance of the material density, the volumetric capacity of the transport vessels and the fuel consumption derived from the load capacity in the transport impact calculations.

4.   Conclusions

When conducting LCA, the modelling of transport is considered a complex and data-intensive process due to the difficulties and uncertainties in the product logistic chains in terms of the means of transport and distances. Based on these crucial aspects and by employing a case study located in Austria, the present study compares five different scenarios: one considering real fuel used for transport from manufacturer to site; two scenarios varying the amount of material included in the life cycle inventory (simplified and detailed); and two scenarios varying the consideration of the distances. This demonstrates the influence of the Life Cycle Inventory (approximately 20%) and of the consideration of the transport distances in the modelling of transport (Module A4) in the LCA results (approximately 25%), and shows that, given uncertainties in the modelling of transport, the contribution of the most representative material (in terms of material quantities) can be substantial in the resulting environmental impact. Therefore, derived from these results, it is recommended when using the product-by-product strategy to model the transport impacts (Module A4) considering approximately 90% of the material

quantities included in the assessment, which can be closer to the real scenario than a detailed inventory (product-by-product). One limitation of the current study involves the reduced number of case studies, and it is therefore necessary to confirm the present observation with a wide variety of case studies. Furthermore, future research should explore the correction factors for impacts derived from the transport of different material densities and product logistic chains, in order to better adjust the modelling of the transport of detailed inventories (product-by-product) to the real scenario (fuel consumption).

This study also demonstrates the relevance of the consideration of the transport distances and how it can influence the environmental impact, when the transport distances can increase proportionally with the MQ (Scenarios 4 and 5) and when this increase is exponential (Scenarios 2 and 3). This emphasises the importance of defining representative distances for the materials included in the LCA.

Supplementary data

A detailed description of the materials and transport distances for LCA calculation is included in the following folder: Supplementary data.xlsm.

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