Method and assessment decisions in the evaluation of the LCA-results of timber construction components

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ABSTRACT: The increase of the application and interest in life cycle assessment (LCA) studies in the construction sector implies a parallel increase of responsibility. With LCA-results as an important additional decision criteria for planers, the significance of the individual results shown gain more and more center stage. This paper discusses different aspects for LCA-planers regarding method and assessment decisions. This contribution constitutes the relevant aspects regarding environmental impact, carbon storage and use of resources, especially with the use of renewable resource based construction components. The LCA-results of the "dataholz.eu"-project provide the background data and argument stated in this paper.

1 INTRODUCTION

1.1 *Background*

Due to the increasing pressure and importance of an ecological assessment and evaluation of decisions within the construction process, clear and helpful conclusions are essential for proper responses and action steps. The life cycle assessment technique is one option developed to identify opportunities for environmental improvement and to inform decision makers (ISO 14040). LCA standards already define and provide elements for effective communications.

However, various personal discussions with planers and professionals who do not have an explicit knowledge in life cycle assessment, have shown, that the capability to interpret LCA-results and to act or react accordingly rarely exists. This is primarily not their fault, but a deficit of the studies and the given communication of content and results.

1.2 *Methodical Basics*

Ecological studies and assessments can vary in many different assumptions, indicators and methods according to the intended goal and scope. Therefore, the result of a study can consider and present different indicators, as well as present different results for identical indicators (Albrecht et al., 2008; Kuittinen, Ludwig & Weiss, 2013; Sölkner et al., 2014).

ISO 14040:2009 and ISO 14044:2006 standards define the structure to perform a life cycle assessment and divide the process in the following framework:

1. Goal and Scope Definition
2. Life Cycle Inventory Analysis
3. Life Cycle Impact Assessment
4. Interpretation

The goal and scope phase of a LCA-calculation defines important decisions on how to proceed with the functional unit, impact categories, dataset quality and system borders (CEN, 2006). The optimization of the goal and scope definition in consideration of the interpretation can only be met with various iteration processes, which reveal the interdependencies and relations (ILCD, 2010).

In a regular LCA calculation for buildings and building components, based on EN 15978:2012 and EN 15804:2014, the life cycle of a building is divided in three modules A, B and C:

- A Product and Construction stage
- B Use stage
- C End of Life stage

In addition, all potential benefits and burdens can be accumulated in the Module D. The standards subdivide impact categories and category indicators deliberately in different categories:

- Use of Resources
- Environmental Impacts

Within the last development, indicators were distinguished especially for primary energy in addition to renewable/non-renewable, between energy use and material use of primary energy. This is why an integral approach, transparency and iteration are part of the main principles of life cycle assessment (CEN, 2009). This paper will outline proposals for the communication and presentation of the results of these indicators for better decision and optimization processes.

2 BACKGROUND, CONTENT AND CALCULATION METHOD

2.1 *Background – 'dataholz.eu' project*

The development of appropriate decisions regarding the method and assessment of timber construction components is based on a LCA study in the context of an online database for timber structure. The following sections gives all relevant details regarding background, goal, scope, impact categories and results of the study.

The 'dataholz.eu' database is an online-catalogue for building materials, components and details especially for timber structures. The platform already existed for 14 years and was renewed in December 2017 (HFA Austria, 2018) with additional timber construction components for the German market as part of a cooperative project between the Technical University of Munich and 'Holzforschung' Austria funded by the 'Deutsche Bundesumweltstiftung' (DBU).

2.2 *Timber construction components*

One exemplary construction component is shown in Figure 1 with the following construction layers:

A – 24.0 mm timber façade
B – 30.0 mm timber battens
C – 15.0 mm medium-density fiberboard (MDF)
D – 160.0 mm solid wood
E – 160.0 mm mineral wool
F – 22.0 mm oriented strand board (OSB)
G – 12.5 mm gypsum fiberboard

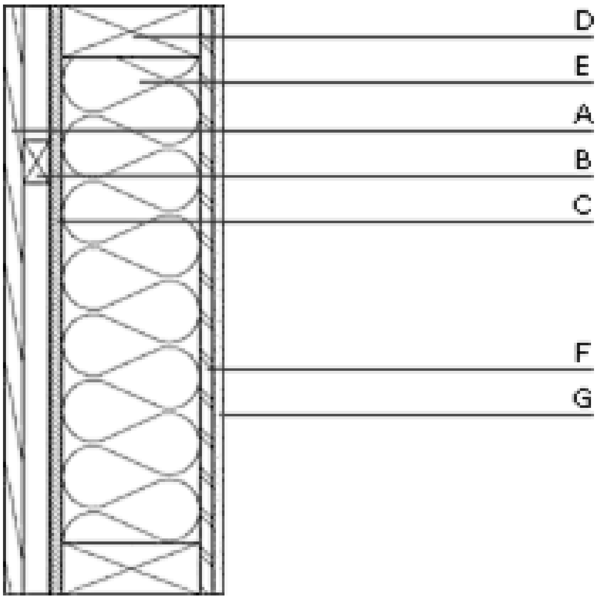

Figure 1. Exemplary timber construction component of the 'dataholz.eu' catalogue – component alternative outer wall awrhho01a-09 (HFA Austria, 2018)

Within in the scope of the 'dataholz.eu'-platform's renewal over 350 new and additional timber construction components especially for an application in the German market were added. The implementation included a life cycle assessment for all these components as well as an ideal solution for a clear and helpful presentation of the results for all users of this catalogue.

The calculated components include 116 outer wall components consisting of 35 massive timber constructions and 81 timber frame components. The insulation material varies between mineral wool (43 components), wood fiber (41 components) and cellulose (32 components). The thickness of the insulation also varies from a minimum of 120 mm to 300 mm maximum. Due to fire safety reasons, the covering consists of either OSB (oriental strand board) or gypsum boards, or a combination of both. The outer façade consists of either wooden panels or plaster systems.

2.3 *Goal and Scope definition*

The calculation method is based on the ISO standards 14040 and 14044 (see chapter 1.2) and performed according to EN ISO 15084. The goal in the project is a purely accounting LCA, describing and documenting the ecological indicators for a variety of timber construction components without unification of different functions. On the contrary, the difference of fire safety, thermal comfort and mass or acoustic qualities is an essential part of the database's content. Therefore, the functional unit is per definition as one square meter [m²] of construction area of the component. The goal of the comparison shown is not to compare functional identical components, but to deduce basic principles between different parameters of these components. The presented impact categories are conform to EN ISO 15084 standards:

Environmental Impacts:

- GWP [kg CO2e] – global warming potential
- AP [kg SO2e] – acidification potential
- EP [kg PO4e] – eutrophication potential
- ODP [kg R11e] – ozone depletion potential
- POCP [kg Ethen-e] – photochemical ozone creation potential

Use of Resources:

- PERE [MJ] – renewable primary energy for energy use
- PERM [MJ] – renewable primary energy for material use
- PERT [MJ] – total renewable primary energy
- PENRE [MJ] – non-renewable primary energy for energy use
- PENRM [MJ] – non-renewable primary energy for material use
- PENRT [MJ] – total non-renewable primary energy

The database used is the ÖKOBAUDAT version 2017-I from 27.11.2017, based on the background data of the GaBi database and others. All data on the ÖKOBAUDAT database are conform with the EN ISO standard 15804 (BMUB, 2017). For calculation purposes, no material flows of fasteners, joints, connections and tapes with less than one percent of the total material flow of the wall structure were considered. The calculated results cover the life cycle according to a cradle-to-gate (with options) approach (CEN, 2013). The Use Phase with replacement (B3/B4) of different elements is not part of the calculation, because the context of the building and its use is not defined in the focus on mere construction components. Furthermore, the module D was calculated but not shown in the results, because recycling scenarios and different substitution approaches could not be consistently defined and transparently presented. Due to the calculation of renewable materials (compare to 2.4), the results consider the End-of-life-phase (EoL – C) explicitly. If the available datasets did not consider the EoL-phase, additional datasets for construction waste were used, if the contribution of this aspect was more than one percent.

2.4 *Renewable resources, biogenic carbon and carbon storage*

The ‘dataholz.eu’ database covers many construction components, which are primarily based on renewable materials. Due to the capacity of timber and other renewable materials to embed carbon during its growth, this aspect has to be considered in particular. The European standard EN 16485 outlines the method to be used to consider embedded biogenic carbon in the biomass of construction products. Biogenic carbon enters the studied system only with a credit note, if carbon neutrality exists. If no carbon neutrality exists, there is no contribution of the embedded biogenic carbon to the global warming potential (GWP) of the product system. Carbon neutrality is defined as the equilibrium between biogenic carbon absorption during the growth and the release during the decay or incineration of biomass, e.g. in the forests of origin (CEN, 2014b). See Figure 2 with the following key:

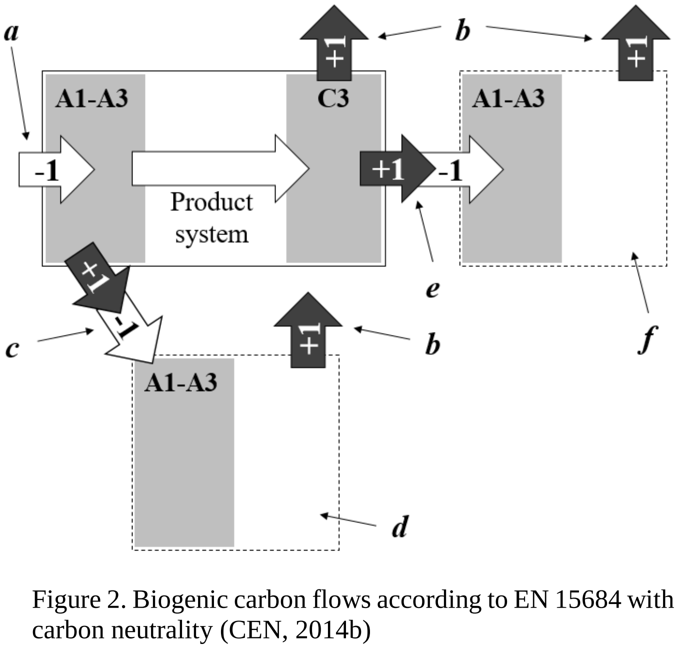

Figure 2. Biogenic carbon flows according to EN 15684 with carbon neutrality (CEN, 2014b)

a. Biogenic carbon flow from the forest into the product system
b. Emissions into the atmosphere
c. Co-product
d. Parallel co-product system
e. Recycling product
f. Following recycling product system

This methodical background is the explanation for the explicit consideration of the EoL-phase (C) within all calculations for the German components of the ‘dataholz.eu’ project. This approach gives two possibility to show the difference in the GWP between biogenic carbon embedded in the construction component itself and GWP emissions of the processes during the production and end of life stage. The cumulative result of the GWP shows solemnly the emissions of the different processes during the life cycle (see chapter 3)

In order to show also the embedded carbon within the construction, which contributes to a carbon storage over the use time, an additional calculation and parameter was added. The amount of regrowing resources (in German “nachwachsende Rohstoffe” – nawaro) is the basis for the calculation of the embedded carbon. The proportion of the wooden content and therefore the carbon content of these materials was taken from the background data of the used datasets (Rüter & Diederichs, 2012) and environmental product declarations (EPDs) as part of the database ÖKOBAUDAT. The biogenic carbon was calculated according to EN 16449 (CEN, 2014a):

$$P_{CO_2} = \frac{44}{12} \times 0{,}5 \times \frac{\rho_\omega \times V_\omega}{1+{}^{\omega}/_{100}}\,, \qquad (1)$$

where P_{CO2} = the biogenic carbon dioxide content; ω = the moisture content; ρ_ω = the bulk density for this moisture content; V_ω = the volume for this moisture content.

Similar to the embedded biogenic carbon, the embedded primary energy can be outlined accordingly. The distinction of primary energy between the material use (M) and energy use (E) in addition to the distinction between renewable (R) and non-renewable (NR), separates the different aspects clearly for interpretation (compare also chapter 2.3 and chapter 3). Therefore, the total use as energy use (PERE + PENRE) is calculated as well as the percentage of renewable primary energy ($P_{\text{ren.}}$) of the total primary energy use as energy use during all processes:

$$P_{\text{ren.}} = PERE/(PERE + PENRE) \qquad (2)$$

3 EXAMPLARY RESULTS FOR SINGLE COMPONENTS AND THE CATALOGUE

3.1 *Single component results (e.g. awrhho01a-09)*

According to the Goal and scope definition and the selected impact categories the results for one single timber construction component ‘awrhho01a-09’ (compare Figure 1) are shown below:

Table 1. Results for the timber construction component ‘awrhho01a-09’ over the whole life cycle.

	A1-3	C	A-C
GWP [kg CO2e]	-46.99	72.52	27.49
AP [kg SO2e]	0.108	0.002	0.112
EP [kg PO4e]	0.019	0.002	0.021
ODP [kg R11e]	1.6 x10-6	9.0 x10-8	1.7 x10-6
POCP [kg Eth.e]	0.028	0.000	0.028
PERE [MJ]	186.13	0.92	187.44
PERM [MJ]	756.88	-751.75	5.40
PERT [MJ]	943.14	-750.82	192.96
PENRE [MJ]	435.88	10.80	452.75
PENRM [MJ]	32.39	-24.35	8.09
PENRT [MJ]	468.35	-13.55	460.91
Embedded biogenic carbon [kgCO2e]			65.17
Regrowing resources “nawaro” [kg]			44.62
Primary energy – energy use [MJ]			640.19
Percentage of renewable PE – energy use [%]			29.28

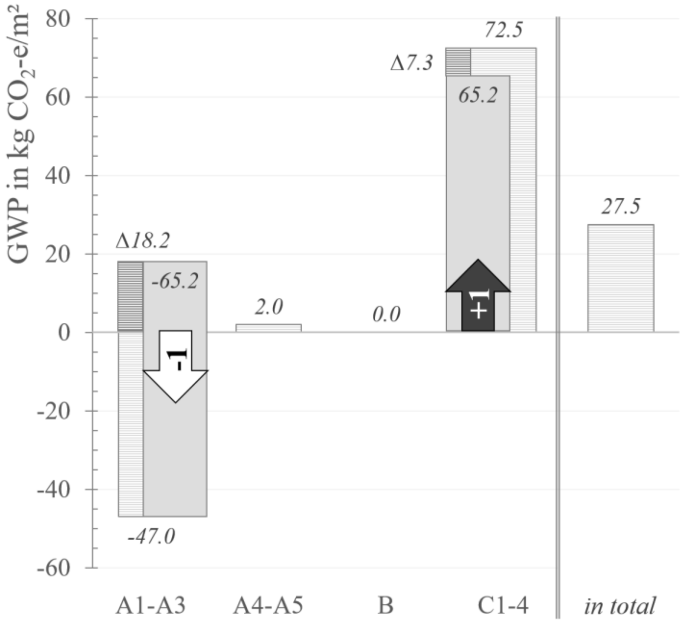

Figure 3. GWP results for ‘awrhho01a-09’ over the whole LC with the illustration of the embedded carbon flow.

The illustration of the results for the GWP (see Figure 3) demonstrates the importance of the consideration of the End of Life stage for a holistic interpretation of the results. A solemnly consideration of the construction phase only shows a negative impact of the GWP (see first column). Only with the implication of the end of life (EoL) phase C (see fourth column) the embedded biogenic carbon is balanced. The results ‘in total’ show all GWP emissions over the whole life cycle, e.g. 27.5 kg CO2e.

Figure 3 illustrates the flow of biogenic embedded carbon with the benefit (negative accounting) in stage A1 and the load (positive accounting) in stage C3 (see also chapter 2.4). Similar to the results for the GWP the illustration of the results for the renewable primary energy considering both the material and the energy use (PERM and PERE) show the flow of the embedded primary energy.

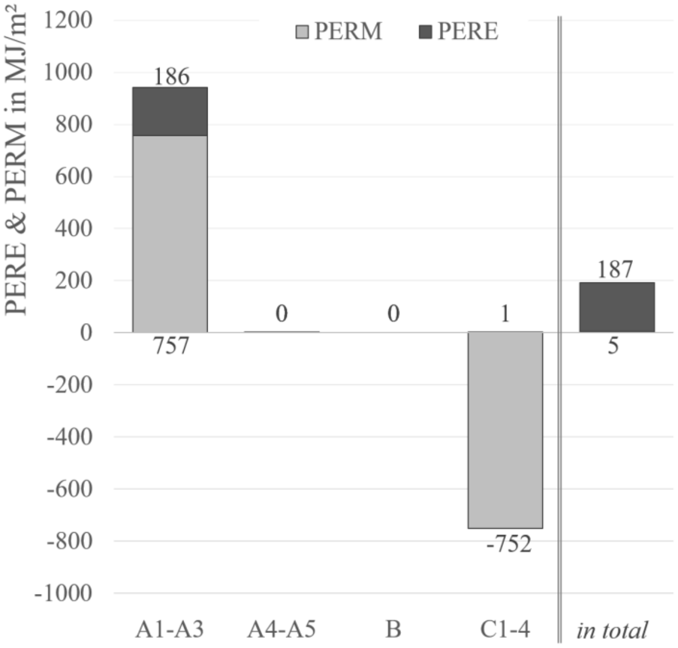

Figure 4. Renewable Primary Energy results for ‘awrhho01a-09’ over the whole LC clustered in energy and material use.

The primary energy embedded in the timber components enters the system as a load (PERM first column), because it is bound to the system and not ‘available’ anymore outside of the system. The amount of timber components exiting the system in the end of life stage C contributes to the benefit of primary energy provided by the system still embedded in the components itself (PERM in fourth column). A mere focus on the construction phase (A1-A3) may lead to a misleading conclusion of a high use of primary energy, if the difference between primary energy for material and energy use is not considered. One possibility to avoid this risk is the presentation of the results of the whole life cycle. As an alternative, the results can be presented accumulated not only as renewable and non-renewable but also as primary energy for material use and for energy use. This distinction offers the possibility for relevant conclusions and recommendations for action and optimization.

3.2 *Overall results – environmental impact*

The environmental impact is represented by various impact categories with its category indicators as shown in the section above. The results for all different wall types are shown in Table 2:

Table 2. Results for all 116 different timber construction components over the whole life cycle.

	Mean Average	*Standard Deviation*
GWP [kg CO2e]	30.1	*8.4*
AP [kg SO2e]	0.126	*0.040*
EP [kg PO4e]	0.027	*0.007*
ODP [kg R11e]	1.9 x10-6	*1.0 x10-6*
POCP [kg Eth.e]	0.025	*0.008*
Embedded biogenic carbon [kgCO2e]	78.8	*25.1*
Regrowing resources “nawaro” [kg]	54.9	*17.6*

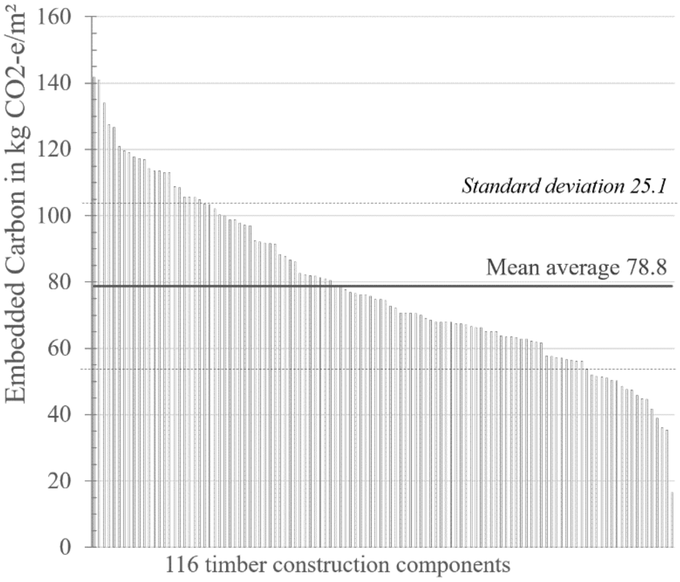

Figure 5. Results for the embedded biogenic carbon in the components over the whole LC - sorted in descending order.

For further interpretation the overall GWP results for all 116 different timber construction components shows a mean average of 30.1 and a standard deviation of 8.4 kg CO2e/m² over the whole life cycle. Figure 5 shows the results for the embedded biogenic carbon for all the different construction components from timber frame to massive timber constructions with a mean average of 78.8 and a standard deviation of 25.1 kg CO2e/m².

The illustration in addition with the relatively high standard deviations for the indicators show the variation in the results. Therefore, different parameters of the construction components (e.g. construction type or insulation) are analyzed separately for a better interpretation of the results (see chapter 4).

3.3 *Overall results – use of resources*

The results for all different types of primary energy representing the use of resources is listed in Table 3, calculated for all timber construction components.

Figure 6 illustrates the results and the distribution of the total sum of primary energy used in all processes (PERE + PENRE) over the whole life cycle with a mean average of 827 and a standard deviation of 288 MJ/m². In addition, the percentage of the renewable share (see formula 2) is illustrated as well with 35 percent as a mean percentage.

Table 3. Results for all 116 different timber construction components over the whole life cycle.

	Mean Average	*Standard Deviation*
PERE [MJ]	297	*133*
PERM [MJ]	53	*78*
PERT [MJ]	350	*132*
PENRE [MJ]	530	*162*
PENRM [MJ]	17	*15*
PENRT [MJ]	550	*160*
Primary energy – energy use [MJ]	827	*288*
Percentage of renewable PE – energy use [%]	35.0	*4.7*

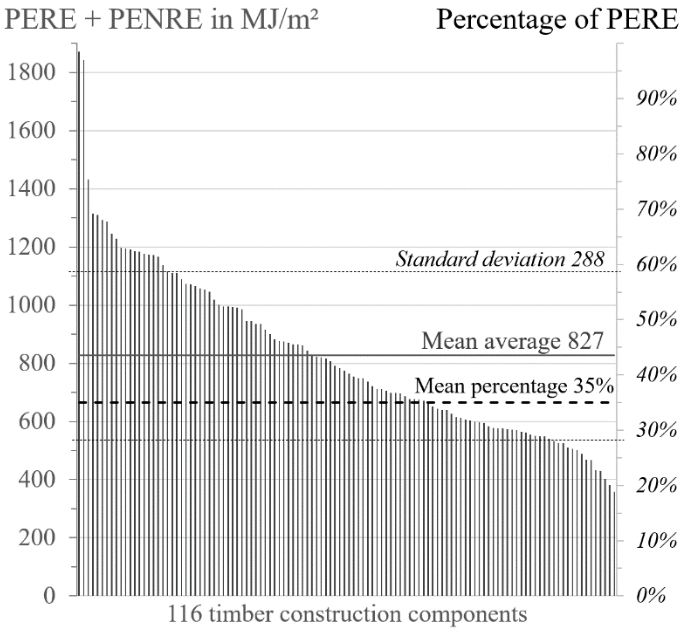

Figure 6. Primary Energy results regarding the energy use for all timber construction components over the whole life cycle (A-C) – sorted in descending order.

4 INTERPRETATION AND INTERDEPENDENCIES

4.1 *Distinction according to construction method*

For better analysis and interpretation, all results were clustered between timber frame components and massive timber components. The results also reflect the improvement regarding the standard deviation of all cumulated results (compare chapter 3).

The results show a reduction of the standard deviation for almost all indicators. Furthermore, the distinction between timber frame and massive timber components is more effective considering the change (18 to 34%) in the standard deviation for regrowing resources and therefore the embedded biogenic carbon, then the change in the standard deviation for primary energy and its renewable share.

Table 4. Results for all timber frame and massive timber construction components over the whole life cycle.

	Mean Average	*Standard Deviation*	*Change in s. d.*
Timber Frame Components			
Embedded b. carbon [kgCO2e]	67.2	*16.6*	*-34%*
Regrowing resources [kg]	46.7	*11.7*	*-34%*
PE – energy use [MJ]	756	*263*	*-9%*
Percentage of renewable PE – energy use [%]	33.9	*4.1*	*-13%*
Massive Timber Components			
Embedded b. carbon [kgCO2e]	105.7	*20.2*	*-20%*
Regrowing resources [kg]	73.7	*14.4*	*-18%*
PE – energy use [MJ]	992	*277*	*-4%*
Percentage of renewable PE – energy use [%]	37.5	*5.0*	*+4%*

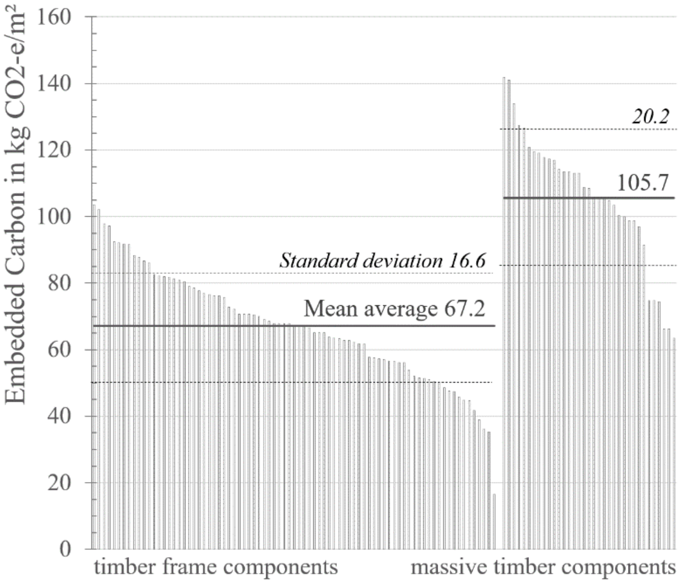

Figure 7. Results for the embedded biogenic carbon for timber frame and massive timber components - sorted in descending order.

Figure 7 and Figure 8 show that the interdependencies between timber frame and massive timber construction. With the benefit of approx. +57 % more embedded carbon regarding the mean averages for the results, the increase of primary energy use of approx. +31% regarding the mean averages is connected. Despite single deviations, the results demonstrate clearly the interconnection between embedded biogenic carbon and the primary energy for the energy use over the whole life cycle in general. Massive timber construction bear the benefit of a higher amount of embedded biogenic carbon, but with the costs of a higher need for primary energy as energy use.

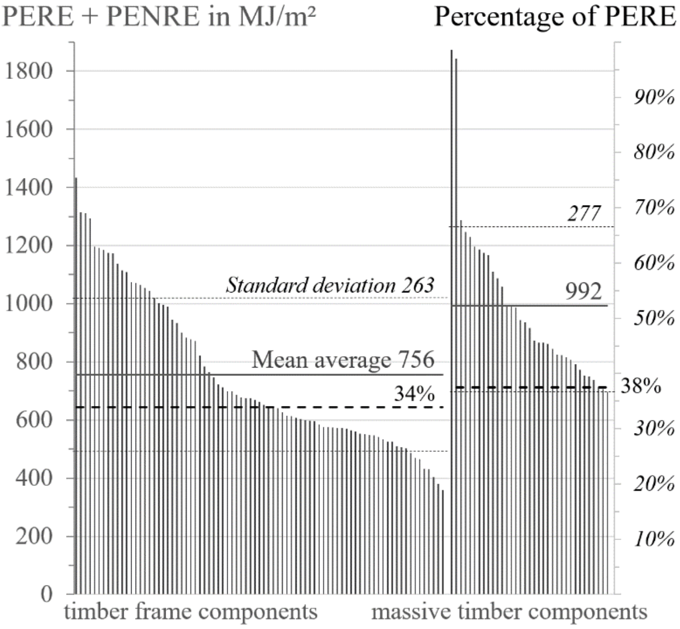

Figure 8. Primary Energy results regarding the energy use for timber frame and massive timber components - sorted in descending order.

4.2 *Distinction between insulation material*

The distinction between timber frame and massive timber construction lead to a more nuanced presentation of the results, especially to a decreased standard deviation for regrowing resources and therefore the embedded biogenic carbon. In addition to this distinction, the results can be clustered according to the main insulation material for more nuanced results regarding the deviation of for primary energy use and its renewable share.

Table 5. Results for all different insulation materials used in the timber construction components.

	Mean Average	*Standard Deviation*	*Change in s. d.*
Wood fiber			
Embedded b. carbon [kgCO2e]	86.6	*24.5*	*-2%*
Regrowing resources [kg]	60.0	*17.1*	*-3%*
PE – energy use [MJ]	1114	*228*	*-21%*
Percentage of PERE [%]	38.5	*1.7*	*-64%*
Mineral wool			
Embedded b. carbon [kgCO2e]	66.2	*22.3*	*-11%*
Regrowing resources [kg]	45.7	*15.5*	*-12%*
PE – energy use [MJ]	703	*173*	*-40%*
Percentage of PERE [%]	30.8	*4.2*	*-11%*
Cellulose			
Embedded b. carbon [kgCO2e]	85.6	*23.1*	*-8%*
Regrowing resources [kg]	60.8	*16.2*	*-8%*
PE – energy use [MJ]	626	*165*	*-43%*
Percentage of PERE [%]	36.1	*3.3*	*-30%*

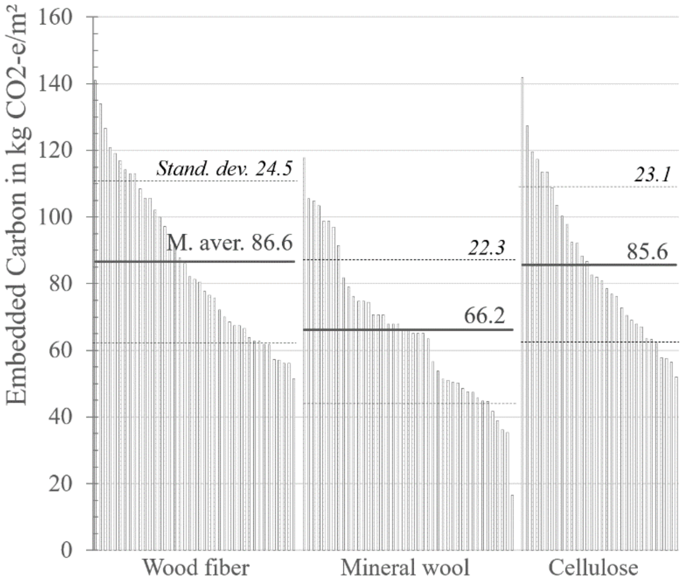

Figure 9. Results for the embedded biogenic carbon for wood fiber, mineral wool and cellulose components - sorted in descending order.

The distinction shows an improvement for the standard deviation regarding the primary energy use for up to 43% and regarding the renewable share for up to 64%. The results of the direct comparison of the construction components with different insulation materials show the increase of 30% more embedded biogenic carbon for wood fiber and cellulose components compared to mineral wool components (see Figure 9). This difference is obvious based on the mineral-based substance of mineral wool compared to the wood-based substance of wood fiber and cellulose. On the other side the amount of primary energy as energy use is divided differently.

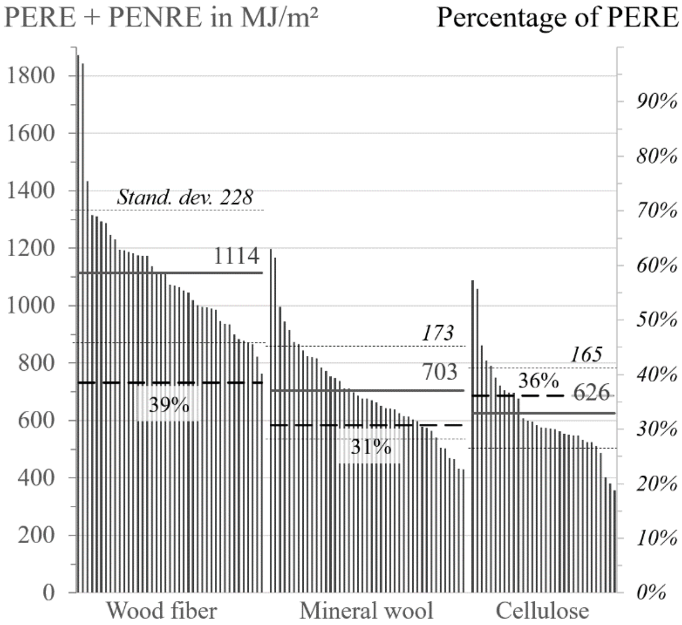

Figure 10. Primary Energy results regarding the energy use for wood fiber, mineral wool and cellulose components - sorted in descending order.

Whereas cellulose sets the minimum standard of 626 MJ/m² the mean average for mineral wool increases +12% and for wood fiber +78%. Nevertheless wood fiber holds the maximum mean percentage of renewable primary energy (39 %), +21% more compared to the mean percentage of renewable energy use for mineral wool components.

5 CONCLUSION

5.1 *Methodical conclusions*

On the one hand, the results show the importance of a transparent calculation und presentation of the results for an easy and clear communication to outsiders as well as LCA-experts. On the other hand, basic trends and recommendations for action regarding different construction methods and insulation materials can be outlined.

With the normative background (chapter 2.4), the necessity of a calculation of components containing renewable resources especially over the product and construction stage to the end of life stage becomes very clear. The illustration in Figure 3 demonstrates that a focus on single life stages may lead to incomplete and confusing conclusions. A separation between the GWP from different processes and regarding the embedded biogenic carbon as currently discussed would also assist in a more comprehensible communication. Concisely, two conclusions can be stated:

1. The embedded biogenic carbon has to be considered specifically in LCAs with regrowing components, i.e. through consideration of the life stages A and C (see Figure 3).
2. To achieve transparency and comprehension the results should be presented according to clear recommendations (see 5.2).

5.2 *Conclusion of the results with recommendations*

Though the study does not compare functional equivalents of the different timber components, principal trends and characteristics can be derived.

The comparison between different insulation materials show the effect of insulation based on regrowing material with 30% more embedded biogenic carbon. An increase of primary energy as energy use is not consequently related. With cellulose showing the lowest mean average, wood fiber insulation shows 78% higher results. This shows the higher effort in production on the one side, but also arise from the specific datasets used, which contain a mix of different wood fiber insulation products (BMUB, 2017). As a result, cellulose insulation can be recommended from an ecological standpoint regarding the ratio between embedded carbon and primary energy use. Wood fiber insulation products still have a high potential for energy efficiency measures, though the percentage of renewable energy use is already quite high. Mineral wool lacks the advantage of additional embedded carbon but shows good results in the low use of primary energy as energy use.

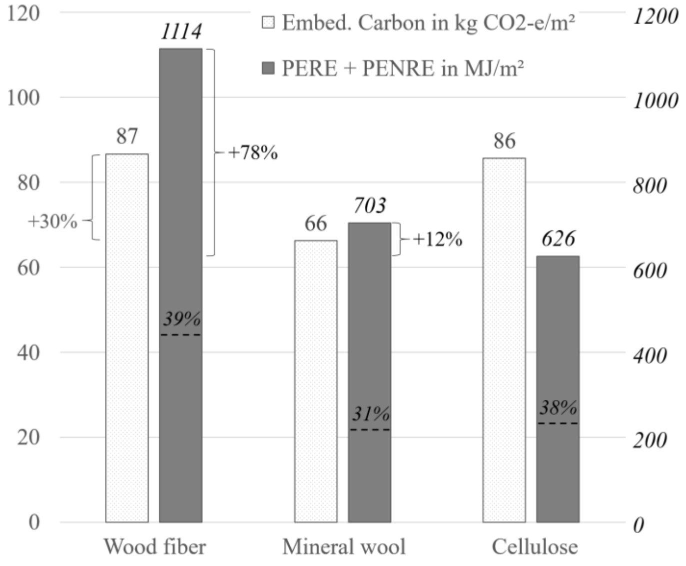

Figure 11. Comparison of the mean average between timber components with wood fiber, mineral wool and cellulose insulation.

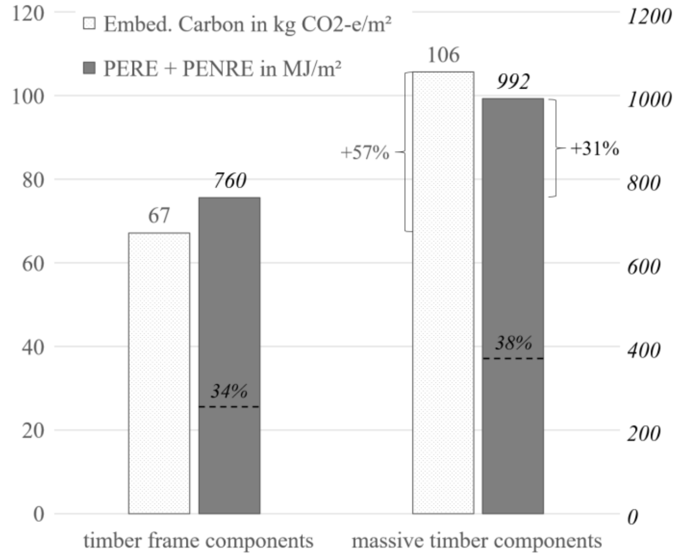

Figure 12. Comparison of the mean average between timber frame and massive timber components.

The comparison between timber frame and massive timber components show an increase of the embedded carbon with a simultaneously increase in primary energy as energy use for the outer wall components in this study.

This trend is in line with similar studies comparing whole buildings in timber frame and massive timber construction. The results for the single-family house (Building 1.2) show an increase of primary energy as energy use of approx. +36% (Hafner, Rüter, & Ebert, 2017, annex 8.3). In addition the comparison of the embedded carbon in different timber construction types show an increase from timber frame to massive timber construction of approx. +65% (Hafner et al, 2017, p. 31). These results underline the trends of this study. However, the comparison is drawn between results on a building level and results on a construction component level. Therefore, this only affirms a certain trend, which has to be manifested and differentiated regarding additional aspects and calculations. As a result, the ambivalence of the two aspects (a) the-positive effects due to the use of wood products and the embedded carbon (Rüter et al., 2016) and (b) the reduction of primary energy use are most important and cannot be played off against each other.

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