Life-Cycle and Sustainability of Civil Infrastructure Systems – Strauss, Frangopol & Bergmeister (Eds)

Wooden products – positive material in life-cycle analysis

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ABSTRACT: The construction industry accounts for a large part of material and energy consumption. Many studies show that, up to now, the operating of buildings has the maximum impact on environmental pollution. When energy efficiency for the operation is increased, the impact and effect of the construction process on the environment will come into the foreground. Because of the capacity of storing carbon and being a renewable material wood is examined in detail. Data for wooden products in life cycle analysis and calculations of timber buildings in life cycle analysis are discussed. Discussion in various research and standardisation projects in the past showed that simplification and transparency in LCA data for wood products are necessary. The issues of bound solar energy, imbedded carbon and renewable energy consumption have to be addressed. Further research needs to be conducted in end of life scenarios for wood and possibilities of a "regrowing potential" for wooden products.

1 INTRODUCTION

The construction industry is responsible for a high proportion of material and energy consumption. This necessitates action in the building sector, that can be documented with the following figures. According to Hegger:

– „The building sector uses approximately 50% of all raw material processed in the world.

– the building and construction industry produces more than 60% of the arising waste in Germany.

– The operation of buildings accounts for around 50% the energy input in Germany." (Hegger 2008)

In the building sector the classification of different materials is roughly divided up into mineral and organic materials according to divisions in chemistry. The classification of the origin of carbon in the material in renewable or non-renewable resources is not considered in that separation. (König 2011)

This paper focuses on the organic materials and their influence on life cycle analysis in buildings. Examples for organic materials are on the one hand plastics and on the other hand materials made from plants. The ecological difference in both material groups is that the carbon is from nonrenewable (plastic) or from renewable (plant) sources.

Plastic in its various forms can have many different attributes and qualities. It can be very light or heavy, flexible, hard or soft. It might also not decompose. It is produced from oil and releases carbon into the atmosphere in the production process, which is partly responsible for the greenhouse gases. (König 2011)

Plants on the other hand (this paper especially refers to wood) transform carbon dioxide of the atmosphere into carbon. This happens with the use of the sun´s energy trough photosynthesis.

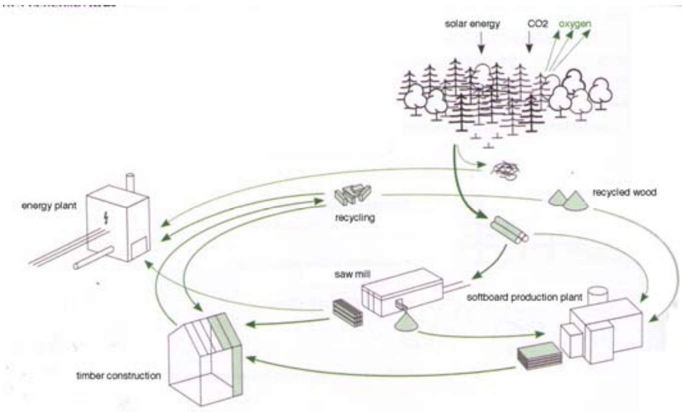


Figure 1. Life cycle from trees to wood (Wegener 2011).

Oxygen as a by-product, which is important for mankind, is released. A full life cycle from tree to end product is shown in figure 1.

In that context the term renewable material implies that all organic material has the capacity to store carbon during growth and can be used as a carbon sink until the material is burned at the end of life releasing the CO_2 again. This is the characteristic of renewable materials. Their influence on life cycle analysis shall be looked at closer.

2 WOOD IN LIFE CYCLE ANALYSIS

This paper focuses on renewable materials, specifically on the material wood / timber. It is important to note, that all positive attributes wood is associated with are only valid, if the wood comes from sustainable forestry.

2.1 *Wooden products*

In life cycle analysis the main characteristics of wooden products can be outlined as follows:
Wood stores carbon. This means the reported global warming potential in the construction is negative (more carbon stored than emissions of carbon dioxide during processing and production) or very small.
The weight of the material is lower than in massive structures like concrete or brick. The content of 'primary energy renewable' in the material is much higher than in many other materials.

Recycling of wooden materials can be carried out by down-cycling, reusing the wooden material or burning it. The bound solar energy is released when burning the wood. This is described as the heating value. Some sources presume and count in addition, that this heating value substitutes other non-renewable fuel sources by allocating additional 'negative' CO_2 release to the products when burning their residues, e.g. sawdust from sawn-timber production. This issue is discussed later.

Through life cycle analysis the ecological impact of different wooden materials is shown. It is dependent on the length and intensity of the production process from the raw material to the final product (cradle to gate).

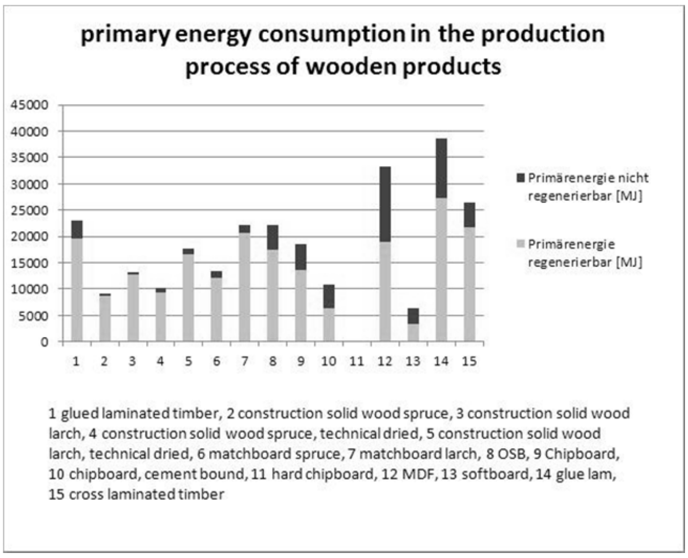


Figure 2. Primary energy in wooden products.

In figures 2 and 3 the different wooden materials are compared in the categories of primary energy and global warming potential. The basic data for these figures was taken from the public available database of wecobis (Greitemann 2010). Wecobis is a german information system which includes neutral data of products with environmental and hygienic aspects in all phases of life cycle.

Figures show that a large part of the primary energy in the wooden products can be allocated to 'primary energy renewable'. Even the global warming potential rises with a longer production process and more components involved.

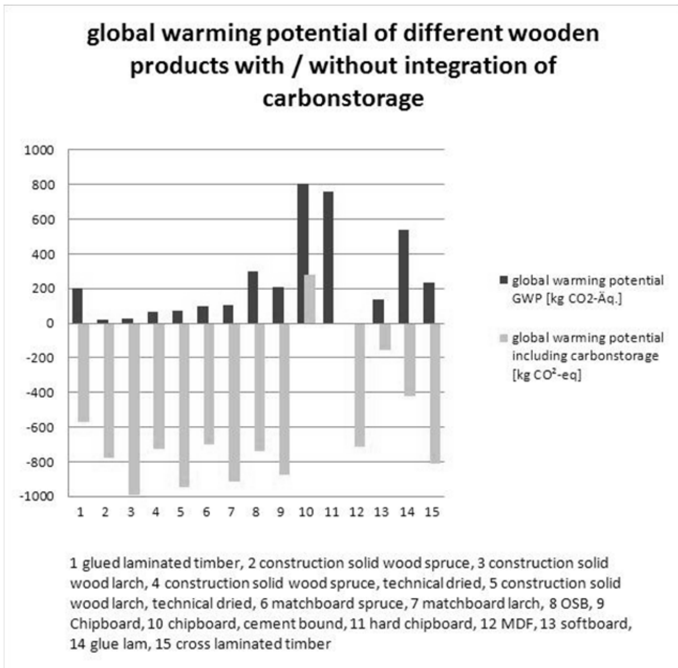


Figure 3. Global warming potential in wooden products.

2.2 *Timber buildings in life cycle analysis*

When wooden buildings are examined in life cycle calculations, it is generally assumed, that they have positive results in the different categories.

As shown in the paper (Hafner 2012) the differences within the various materials are not very high.

Including the operational period, comparisons between different construction methods only show minor differences in global warming potential and also in the primary energy (renewable and non renewable). It can be observed that there are minor reductions of global warming potential in massive timber constructions and element constructions compared to construction with external thermal insulation composite systems (ETICS) or masonry construction. The overall primary energy consumption is slightly lower in wooden constructions than with the other construction methods. This is caused by the lower rate of 'primary energy non-renewable'. The percentage of 'primary energy renewable' is higher in wooden constructions (for details see (Hafner 2012)). The results are astonishing, as a bigger difference was expected.

2.3 *How to count imbedded solar energy in LCA?*

Looking at the complete chain of wooden products from the forest to gate it may be stated: “Wood material generally has a very low carbon footprint. One cubic meter of wood captures roughly one ton of CO_2 from the atmosphere. Therefore, many wood products can become carbon sinks.

Qualifying the potential of wood construction in combating the climate change requires additional scientific research. Although sophisticated tools for the analysis of life cycle environmental impacts of many goods and services have been developed over the last several decades, the typical life cycle assessment methods are not fully adequate for analysing the primary energy and greenhouse gas balances of wood products and buildings. (ECO2 2012) There is still a discrepancy in the perception of the wooden products and calculations of life cycle analysis when looking at the evaluation of life cycle carbon dioxid emissions including the carbon storage capacity of the buildings. Relevant evaluation methods for the full value chain of wood construction have to be defined. These methods must then be taken into practice by specifying solutions that enable producing components and building carbon efficient wood houses.

In (ECO2 2012) different European datasets were compared. As a main target, the differences of databases for the categories primary energy consumption and global warming potential were evaluated. The comparison of the different databases (ökobau.dat, IBO, Econinvent, KBOB, Synergy) showed, that they vary a lot. The existing data in that field is greatly differing in detail, very old or not available. The comparison of these databases is not helpful in all matters, because of different country specific data (energy mix), allocation method and accuracy. One important issue however, realized through these comparisons, is that wood based materials have some specific attributes that effect life cycle assessment. (Linkosalmi 2011a)

“Bound solar energy and carbon storage of wood materials are included in database datasets. But these storage-values should be separated to enable effective comparability with different materials. Trees grow in a biological system (mainly forests) based on photosynthesis, water and soil-nutrients. Consequence of this biological production is:

- 1 kg of wood “store” 1,851 kg carbon dioxide in form of carbon (app. 50 % of wood density)
- 1 kg of wood “store” 19,271 MJ (Softwood) or 18,112 MJ (Hardwood) solar energy” (Linkosalmi 2011a)

This means, that the category of ‘primary energy renewable’ includes for life cycle analysis the solar energy incorporated for the growth of trees. The bound solar energy hereby appears as primary energy consumption of wooden products. This results in high values for ‘primary energy renewable’ and also in higher values in primary energy in total. ‘Primary energy renewable’ consumption and bound solar energy therefore is accumulated in life cycle analysis calculations for buildings. But this mixes up the energy consumption and the potential of naturally imbedded solar energy. To show the influence of this bound solar energy on the results the value of bound solar energy was subtracted from the original value of renewable primary energy consumption. The changes are described in Figures 4. As an example calculations were carried out on small box buildings with three different constructions (light weight timber, massive timber, concrete with external thermal insulation composite system). (Linkosalmi 2011a)

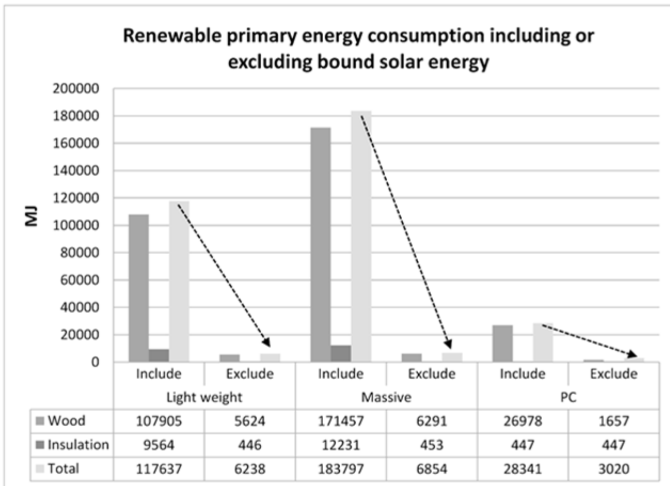


Figure 4a. Change of renewable primary energy consumption when the bound solar energy of wooden product is excluded, in the three box buildings (Linkosalmi 2011a).

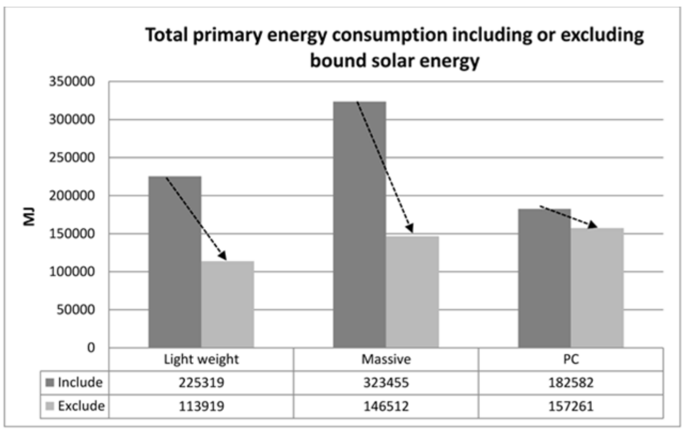


Figure 4b. Comparison of the three box buildings excluding bound solar energy in total primary energy consumption (Linkosalmi 2011a).

The figures show that the ‘primary energy renewable’ and also primary energy total is much lower, when only the real consumption of primary energy during the production process is allocated. Bound solar energy in that context is a potential included in renewable materials. Only if the bound solar energy is used as heating value through burning at the end of life primary energy is consumed. An agreement needs to be realized how to calculate the imbedded solar energy.

In a next step the calculation data for primary energy and global warming potential values for the whole life cycle chain were questioned. For that the different life cycle phases of wooden products, steel and concrete have been described with their energy and carbon balances. The input and output flows of the various materials are shown in figure 5. In all processes energy is used as an input and greenhouse gases are created as an output. In the process of wooden products there are two additional characteristics:

- greenhouse gases get bound through growing of the trees and during that process primary energy (renewable) gets stored in the material. As shown before, this is integrated in the 'primary energy renewable' - values at the moment.

- at the end of life the material can be burned and the enclosed primary energy can be consumed (heating value). Other materials like plastic also have the heating value at the end of life, which is included in calculations. Of course at this point the CO_2 release has to be counted in addition.

In some life cycle analysis for wooden products there is also the argument of avoided greenhouse gas emissions by replacing fossil fuels with recovered biofuels and reduced greenhouse gas emissions by replacing cement products through wooden products (product substitution effect). This approach has a big influence on the environmental assessment calculations.

To demonstrate the differences of such virtual "biomass benefits", two different life cycle systems for the amount of spruce sawn timber in a multi-storey dwelling in Sweden were calculated based on data from (Gustavsson 2009). Both the primary energy balance and carbon balance of the case study are based on two different scenarios. In system 1 only the actual inputs and outputs related to the life cycle activities are taken into account. In system 2 the energy and carbon balance includes a 'virtual' substitution effect of fossil fuel by biomass (residues of production process).

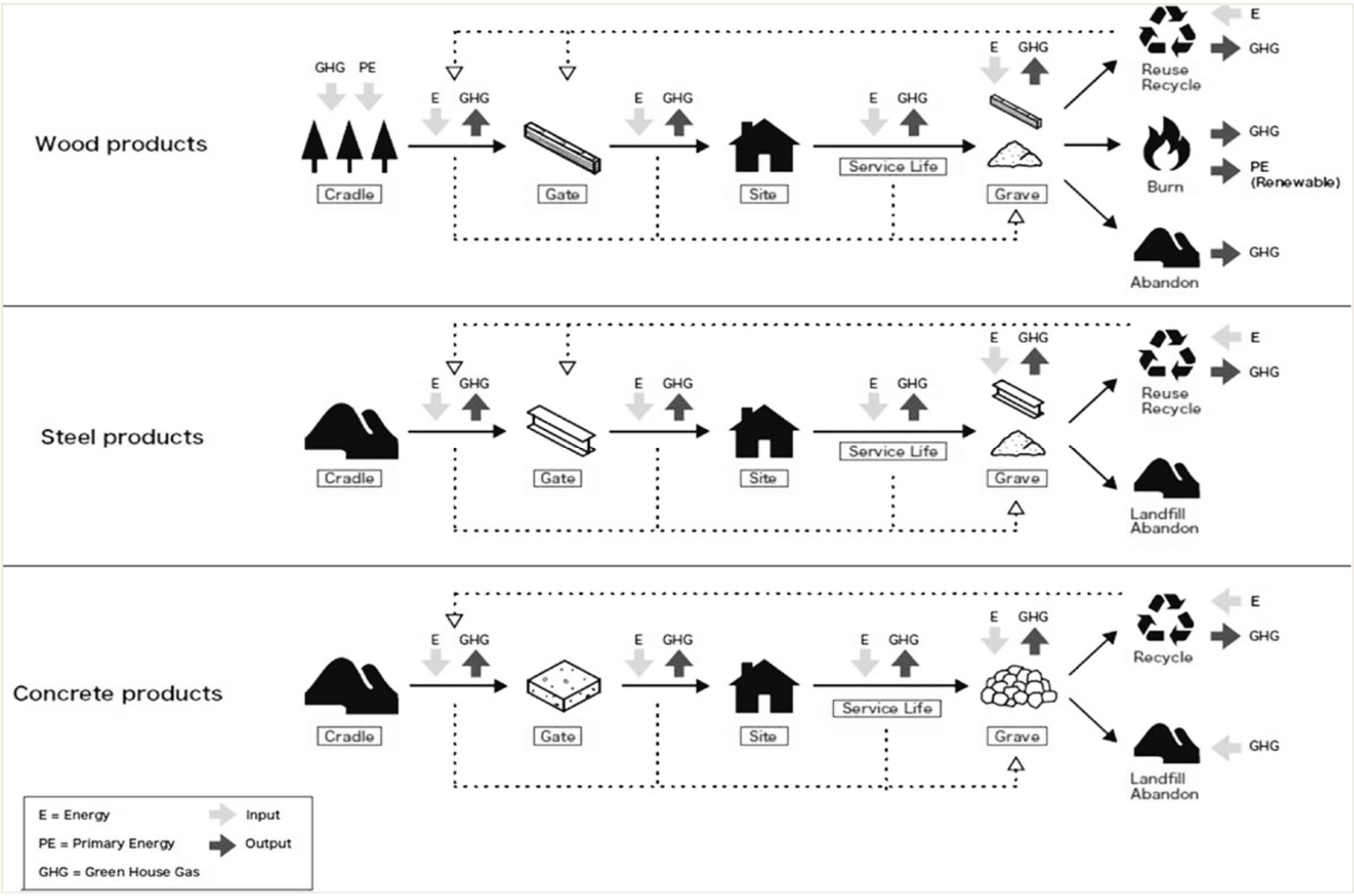


Figure 5. Life cycle of construction materials (Linkosalmi 2011a).

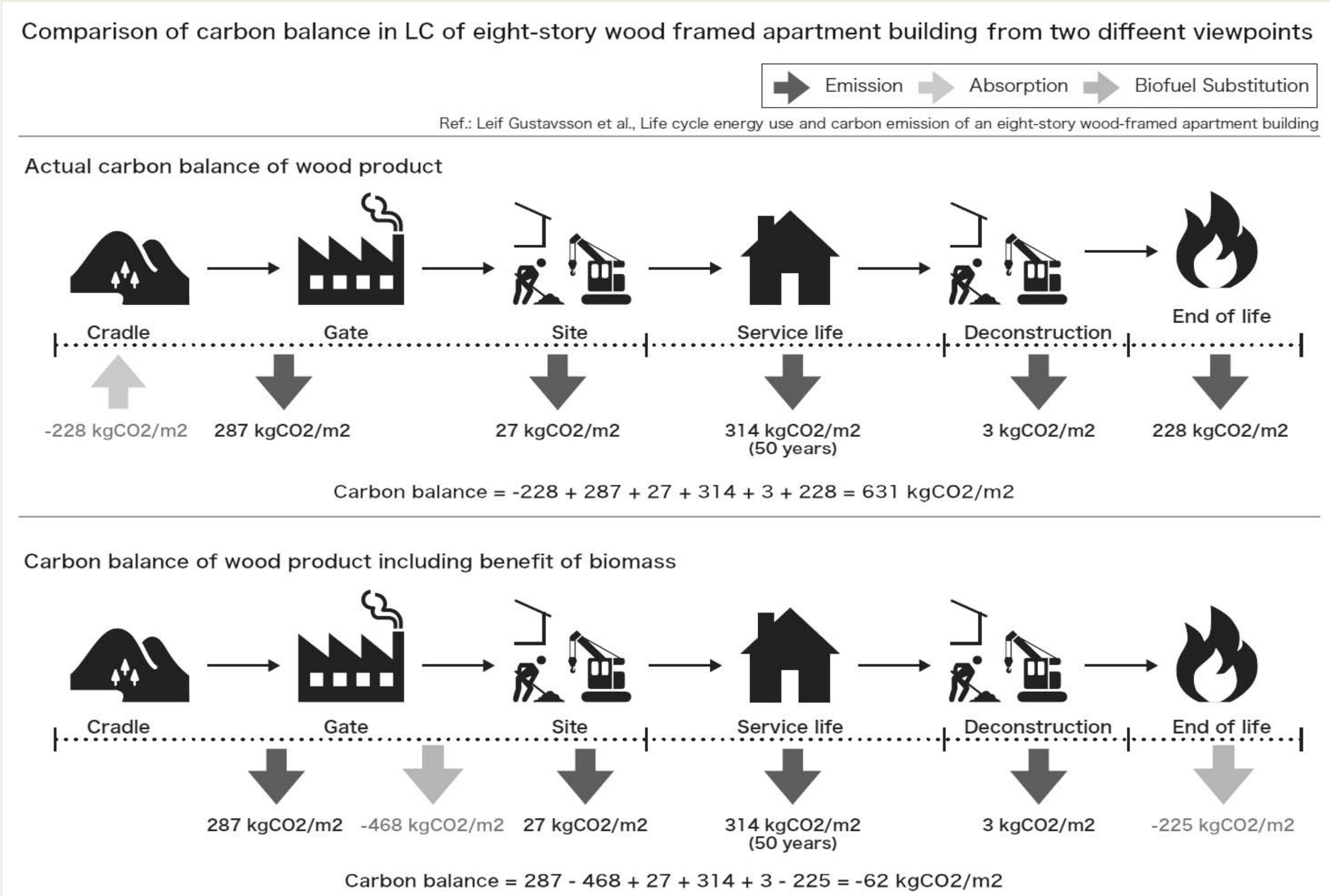
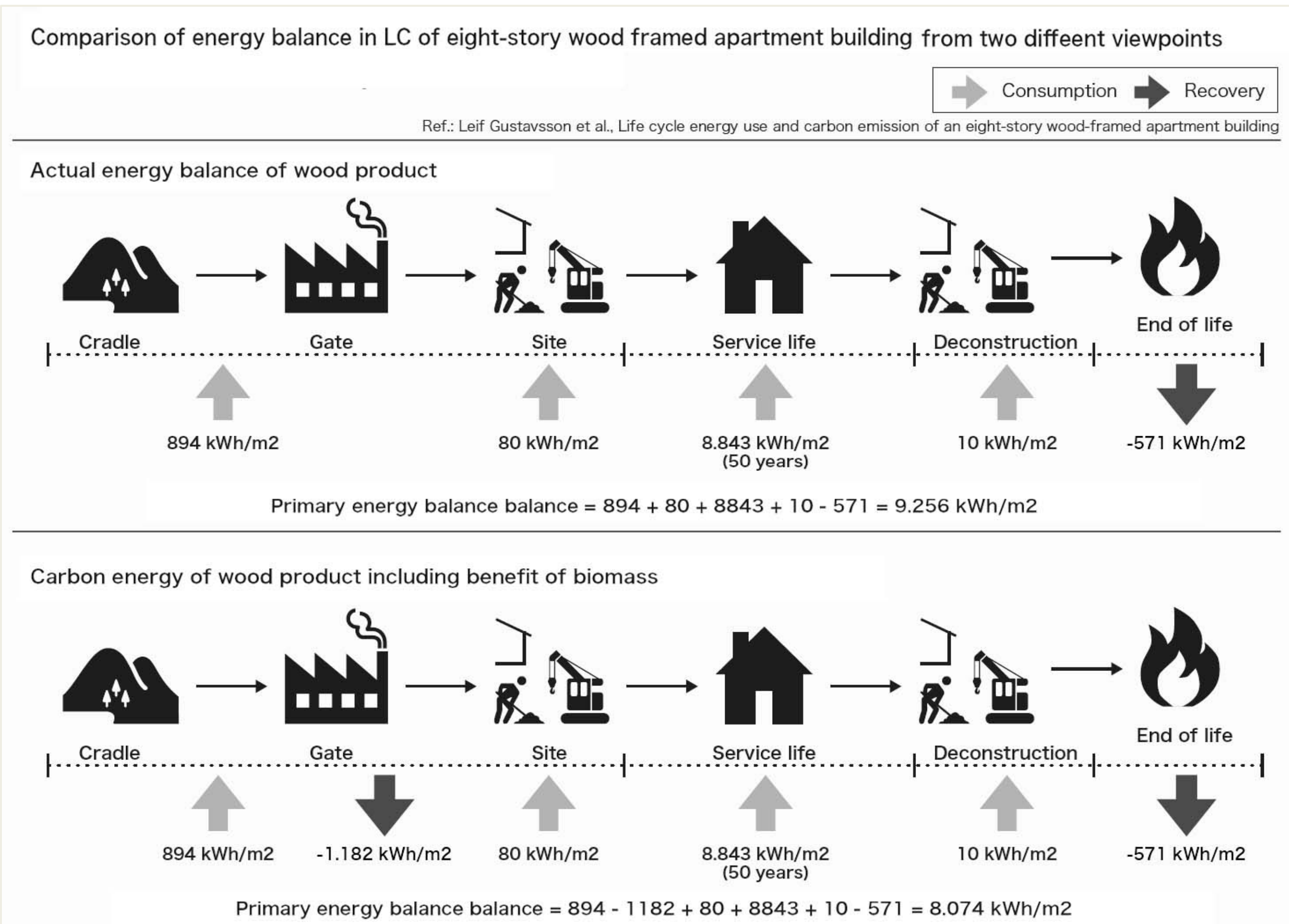


Figure 7. Energy balance (Linkosalmi 2011b).

Figure 6. Carbon balance (Linkosalmi 2011b).



There is a big difference between energy balance and greenhouse gas balance in the various systems. The energy is quite similar in system 1 and 2. But the greenhouse gas balance shows different results in system 1 and 2. The big negative value in greenhouse gas balance results, in this case, from the nearly carbon neutral energy-mix of Sweden in combination with the 'virtual' restitution of fossil fuel by the residues of the process and counting this value as 'avoided CO_2-release from fossil fuel'. In our opinion this allocation is incorrect, because it doesn't reflect the real emission of CO_2. It is very easily understandable, that after a use-time of 50 years of a wooden structure the CO_2 content of the atmosphere is not reduced – this is an incorrect balance. In addition, it is even not prooven, that the residues are in fact used as a restitution of fossil fuel. However, it is possible that they are transferred to another production process, used e.g. as a particle board and counted in this new process as a renewable material.

These results show that the data for wooden products varies greatly, depending on the handling of input and output related to wood. Transparent methods for calculation are needed.

3 FUTURE DEVELOPMENT

The calculation of 'primary energy renewable' as well as the global warming potential will be a vital aspect of future planning processes. As life cycle analysis is part of sustainability certification the results can also influence the evaluation of life cycle analysis and environmental impacts in the building. At the moment the impacts on the building are mostly affected by the energetic standard of the building. In future development the influence will shift to the material side. Then the choice of the material and its influence on life cycle analysis becomes important.

3.1 *Energetic standard*

Until now, the mayor proportion of environmental pollution is generated in the operational period of the buildings. Various calculations on life cycle analysis show, that the operational phase accounts for around 65 % in buildings, considering the energetic standard used today. If, however, buildings are constructed with a higher energetic standard or even with a passive houses standard, the matter of the building material becomes vital. In figure 8 different energetic standards and their influence on the proportion of construction and operation in a life cycle analysis are shown. For that graphic the comparison in the life cycle analysis is made for residential buildings containing around sixty to eighty flats. The calculations are conducted according to the German sustainability certification system with a life cycle of 50 years and the database ökobau.dat. Comparison shows that the more energy efficient the building in the operational phase is, the bigger the influence of the construction gets. The influence of the construction phase can rise up to more than 50% of the whole impacts and outputs of a building. This primarily depends on the material used in construction.

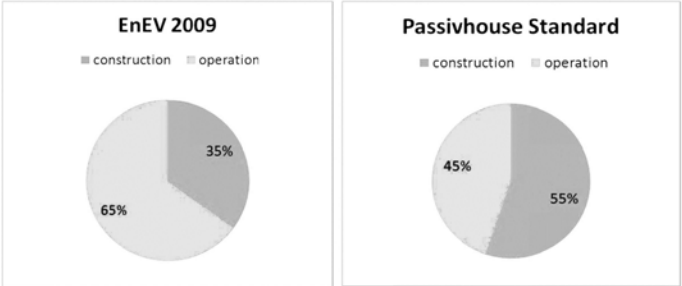


Figure 8. Proportion of erection and operation of different energetic standards in a life cycle analysis.

When energy efficiency for the operational period is increased, the impact and effect of the construction side on the environment will emerge (according to European regulations the energy consumption should reach nearly zero for new buildings by 2020). As zero energy buildings do not require external energy during their operational phase, the environmental impacts of their construction material becomes important. The choice of material used for building and its impact on the environment during the whole production process becomes the most important factor.

3.2 *Influence on choice of material*

The environmental footprints of different materials vary, and each material shows its own advantages and disadvantages. The influence in wood on construction generally has an impact in life cycle analysis when wood is used as the primary construction material. The effect of wooden products solely used for interior purposes are almost neglectable in life cycle analysis today as especially usage periods are very uncertain.

As different calculations of buildings constructed from timber show (König 2011), wood in these types of buildings can account for a weight of 126 to 199 kg/m² per gross floor area. In comparison, building in massive mineral construction only has a wood content weighting approximately 14 kg /m². (Hafner 2011). But to be able to calculate and compare the different materials in a fair and transparent way, common standards have to be established, avoiding 'tricks' in calculation. The imbedded energy of timber should, for example, not be counted in the same row with 'primary energy renewable' used for production and erection of the building. Also, the timber society should not count virtual restitution of fossil fuel by residues as advantages for the main products, e.g. sawn timber.

4 CONCLUSION

Common European solutions need to be arranged for calculation. They need to be transparent and the same for all material industries. Calculation in LCA databases has to undergo a rethinking. As shown in this paper there is a need to distinguish between used renewable energy in material process and bound solar energy. This will have a significant influence on environmental analysis of buildings.

A possible energetic use of combustible materials at end of life is a benefit, which has to be allocated to the life cycle in a similar way for all materials, but any prolonged material use is even better:

For wooden products the extension of the carbon storage cycles for reuse and recycling of wood and timber structures need to be considered and researched further. The longer the cycle of wood is, the more carbon can be stored on a global level. Important for that is, that the timber is processed without any wood preservative and pesticides.

In (König 2011) it is stated that there might be the possibility to build up a new category in life cycle analysis. As the recycling potential accounts for the ability to reuse the material, for example steel, aluminium, there could also be a “regrowing potential” for wooden products. In (König 2011) this potential is described as following: in life cycle analysis the carbon storage is not accounted for and not shown. The “regrowing potential” enables to show that the usage of wooden products stores a certain amount of carbon. In addition it clarifies that cutting the trees for timber production makes room for the growing of new young trees and, thus, is storing carbon again. Precondition to that is that the forest is harvested under the principal of sustainable forestry. Monocultures and the usage of pesticides are not acceptable with this modell. Until this description can be allocated to the wooden materials more research needs to be done. It should also be taken into account that even in the case of energetic use at the end of life cycle this energy is, in the case of wood, a ‘renewable ressource’ which can be included in the “regrowing potential” proposed by König.

Even a CO2-labelling system which illustrates the stored carbon in the material – as an appendix of an environmental declaration is possible (Rueter 2009).

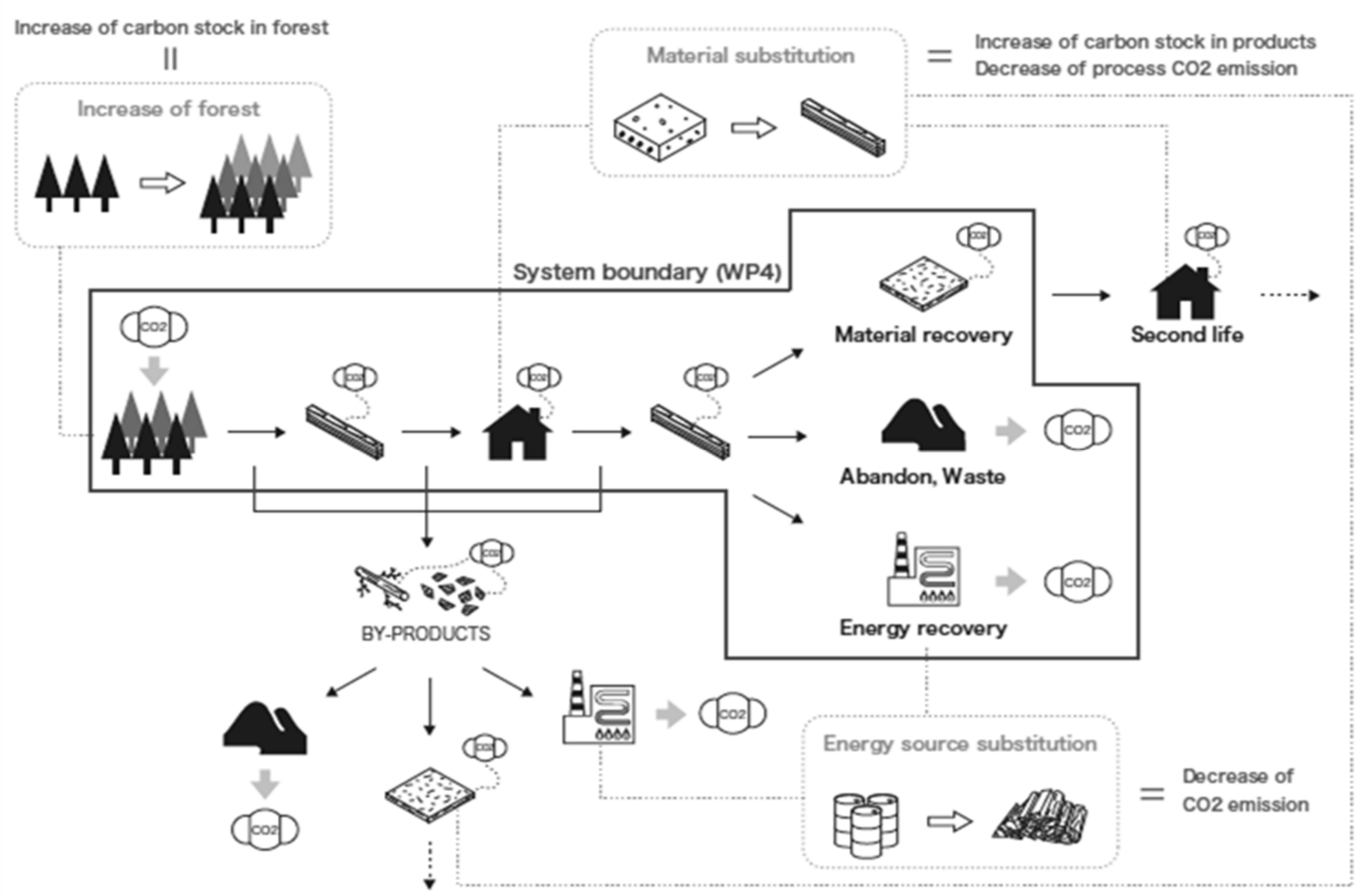


Figure 9. Proposed system boundaries for LCA of building materials.

Understanding the characteristic of wooden products and their uncertainties in environmental assessment, the minor differences between materials in life cycle analysis of whole buildings can be explained. By reorganizing the calculation data in the wood sector, the usage of wooden products as environmental friendly material can be verified.

Finally figure 9 shows the proposed system boundaries to count the contributions and consumptions of (wooden-) building materials. Overall, common and fair regulations and standards are necessary.

REFERENCES

ECO2. 2012. *Objectives of the €CO2 project*. http://www.eco2wood.com/4; 23.01.2012

Greitemann, P. 2010. *Datengrundlagen für die Ökobilanzierung von Holzprodukten, Studienarbeit*. München: Technische Universität München.

Gustavsson L .& Joelsson A. & Sathre R. 2009. Life cycle primary energy use and carbon emission of an eight-storey wood-framed apartment building. *Energy and Buildings, 42 (2010)*, 230-242. Elsevier B.V.

Hafner, A. 2011. *Comparison of renewable materials in LCA*. Data used from König, H. Chair of Timber Structures and Building Construction. München: Technische Universität München.

Hafner, A. Winter, S. 2012. *Ecological and economic impact of various materials and constructions for buildings over the whole life cycle*. Rotterdam: Balkema.

Hegger, M. & Fuchs, M. & Stark, T. & Zeumer, M. 2008. *Energie Atlas. Nachhaltige Architektur*. Page 26. München: Institut für internationale Architektur-Dokumentation.

König, H. 2011. Bauen mit Holz als aktiver Klimaschutz. In: *Bauen mit Holz.* München, London, New York: Prestel.

Linkosalmi, L. & Kairi, M. & Takano, A. & Kuittinen, M. & Winter, S. 2011a. *Summary of database studies - Background material for €CO2 project*. Helsinki: Aalto University.

Linkosalmi, L. & Kairi, M. & Takano, A. & Kuittinen, M. & Winter, S. 2011b. *Comparable LCA scenarios of wood building and wood product.* Mid-term report for €CO2 project. Helsinki: Aalto University.

Rueter, S. 2009: *Chancen einer Anrechnung der stofflichen Nutzung von Holz in einem zukünftigen Klimaschutzabkommen*. 15. Internationales Holzbau-Forum. Garmisch.

Wegener, G. 2011. Der Wald und seine Bedeutung. In: *Bauen mit Holz*. München, London, New York: Prestel.