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Mountain Wood vs. Lowland Wood Harvesting Methods: An Ecological Case Study

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Abstract: Are Austrian mountain wood harvesting techniques more ecological than techniques applied in the lowlands of southern Germany? For this comparative study, the authors selected the area of Lower Bavaria for lowland wood, as a great deal of wood is imported from this region to western Austria. At first, the felling area is described for both regions, from forest site to sawmill. Thereby, the authors create mean values related to timber harvesting and transportation, which are applicable to the whole of western Austria and Lower Bavaria, southern Germany. Secondly, the eco-balance of mountain and lowland wood is established. It is based on the following impact categories: global warming potential, acidification potential, eutrophication potential, ozone depletion potential and non-renewable primary energy. The environmental impact is more expressive if the results are applied to a specific construction part (i.e., glued laminated timber-ceiling). Our research study showed the eco-balance of western Austrian mountain wood is more favourable than the environmental impact of harvesting lowland wood in southern Germany.

Key words: Mountain wood, lowland wood, harvesting techniques, eco-balance, global warming potential.

1. Introduction

This paper investigates how useful ecological database values are for generating tree harvesting eco-balances. The main objective is to establish whether harvesting mountain wood has a lower environmental impact than wood harvested in the lowlands.

In the research project "Mountain Wood—Forests without Limits" samples of mountain wood (spruce) at various altitudes (810-2,060 m above sea level) were investigated in the mountain regions of western Austria. The samples were taken from slopes exposed to the north and south, as well as from locations north and south of the main ridge of the Alps.

One part of the project explored the question: Are differences in the strength of the wood dependent on elevation and slope exposure? If so—what are the reasons? Is it the altitude, the slope exposure, the supply of nutrients and water in the soil, or other factors?

In a further stage of this research project, the question was pursued: How ecologically sound is the harvesting process of mountain wood, which is mainly carried out manually by means of chainsaw and cable crane, as compared to machine harvesting in gentle and flat terrain.

In cooperation with the Austrian forestry sector a location in southern Germany was selected for the lowland wood, given that a lot of timber is imported from this region to the western Austria.

Despite the fact that increasingly eco-balances for various products and processes are created, there are still deficiencies in relation to overall and comprehensive ecological assessments, in particular concerning mountain wood life cycle assessments. A comprehensive assessment of native mountain woods, ranging from forest management to the final product, which includes a systematic analysis of all environmental impacts during the entire LCA (life cycle assessment) [1-4] is not available as yet. One of the main elements is, on the one hand, the different harvesting methods (manual, e.g., chainsaw versus

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mechanical, e.g., harvester), and on the other hand, the description of the felling area and the harvesting procedures as expressed in mean values, so that they reflect the conditions of both regions.

A special feature of this research study is that it does not only rely on the values that are available in the database ecoinvent (commercial database program), but determines the actual environmental impacts specific to each region for this case study. The question is explored whether the environmental impact values in the database concerning the electricity mix match the actual ones that are relevant for wood harvesting in western Austria.

Life cycle assessments for mountain and lowland wood are created for the most common impact categories, such as global warming potential, acidification and eutrophication potential, ozone depletion potential, as well as renewable and non-renewable primary energy.

For better illustration of the resulting values the environmental impacts of a raw product (glued laminated timber-ceiling) are investigated. The fact that the use of local materials also improves the social cohesion in the region concerned is not taken into consideration. Indeed, it is hardly possible to determine the exact values and it would exceed the limitations of this project.

The objective of this research study is to establish to which extent different harvesting methods and transport routes impact the environment in a positive or negative way. In addition, the comparative approach is to show the difficulty of applying life cycle assessments to similar products and processes (database values vs. specific local values). If the life cycle assessment is created for a specific process or product, then it is true for this particular process or product. If more general data are used, the life cycle assessments can be compared better, but as this case study shows, the results may deviate more extensively from the actual local environmental impacts.

2. Method

Two case studies were elaborated in cooperation with the Austrian forest sector. Typical timber harvesting methods [5] and transport distances between logging sites and sawmills in the regions of Austria and Germany were established. The specified parameters for the eco-balancing process are listed in Tables 1-3.

3. Eco-balancing

The functional unit/m^3 wood is specified based on a mass allocation distinguishing between timber and fuel wood. The data are based on the present-day timber industry figures. Growth periods vary in wood production and therefore cannot be clearly defined. The data collection goes back to the year 1995 [6].

Table 1 Comparison of case studies.

Specified parameters	Lowland wood	Mountain wood
Available timber amount	550 m^3/ha	400 m^3/ha
Logging amount	550 m^3/ha	180 m^3/ha
Ratio: structural timber/fuel wood	80/20	80/20
Stocking level	0.9	0.9
Felling area	1 ha	0.4 ha
Harvesting time	Winter	Winter
Development density	40 running m/ha	21 running m/ha
Distance to main road		
Gravel road	1 km	10 km
Sea level of the valley floor	n.a.	600 m
Gradient conditions	0-30%	50-100%
Morphology of the terrain	Homogeneous	Homogeneous/concave
Harvesting losses	10%	11.5% loss on bark 13% felling residue

Table 2 Harvesting machinery use.

	Lowland wood	Mountain wood
Haulage	Forwarder/harvester Log trails: 10 Distance between the logging trails: 20 m Length of the log trails: 50 m	Chainsaw/mobile cable crane Ropelines: 1 Length of the rope trail: 200 running m Lateral access15 m
Harvesting losses	10%	0%

Table 3 Harvesting transportation routes.

	Lowland wood	Mountain wood
Transport-distance for round wood to sawmill (gravel road)	1 km	3 km (pre-carriage)
Transport-distance for round wood to sawmill (gravel road)	n.a.	7 km
Transport-distance for round wood to sawmill (paved road)	100 km	30 km
Transport-distance for fuel-wood (gravel road)	1 km	3 km (pre-carriage)
Transport-distance for fuel-wood (gravel road)	n.a.	7 km
Transport-distance for fuel-wood (paved road)	50 km	30 km

The following upstream chains are not taken into account for all modules in this eco-balance: exceptional occurrences (accidents), transportation of workforce to place of work, administrative costs, the protective function of the forest, upstream chains for tree nurseries, upstream chains and depositing of auxiliary materials.

The used datasets are based on generalised data (harvesters, chainsaws).

3.1 Life Cycle Inventory

3.1.1 Mountain Wood Timber Harvest

The following management practices are carried out with mountain wood [7]:

- Tree planting: Completed manually and therefore no environmental footprint;
- Forest cultivation: The forest shrubs are cut once during an average tree-age of about 40 years;
- Preliminary thinning: The initial planting density is reduced down to 40% within 40 years;
- Thinning: After the first half of the average rotation period, the forest is thinned by about 100 vfm/ha (volume m^3/hectare). The same machines and harvesting methods are applied for this process as for the final harvesting. The wood harvested in the thinning process is economically used and therefore also included the eco-balancing;
- Liming: In the framework of this research program liming is not taken into consideration. Therefore, it accounts for no additional environmental impact;
- Pesticides: The use of pesticides is not considered. Therefore, there is no additional environmental impact;
- Maintenance of forest dirt roads: For the on-going maintenance of forest dirt roads it is assumed that gravel cover is renewed every 5 to 10 years, using locally available gravel;
- Debarking: The debarking of logs is carried out in sawmills, therefore, there is no additional environmental impact;
- Wet storage: Logs are transported to the sawmills right after harvesting, therefore, there is no additional environmental impact;
- Harvesting losses: 11.5% loss of bark and 13.5% on felling residue.

3.1.2 Quantitative Description of Transportation of Mountain Wood

The work processes from the harvesting of the mountain wood through arrival at the sawmill are divided into separate steps and recorded in detail. It is assumed that harvesting is carried out with a chain saw. The felled tree is transported to the loading site by a mobile cable crane, loaded onto a truck and transported to the sawmill. The harvesting losses in this process are taken into consideration, as well as the expenditure and consumption of the machines and means of transport involved.

3.1.3 Lowland Wood Timber Harvest

The following management practices are carried out with lowland wood:

- Tree planting: The rejuvenation of the free forest area is accomplished with the help of a forestry tractor with a mountable planter machine;
- Forest cultivation: The forest shrubs are cut once during an average tree-age of about 40 years;
- Maintenance of saplings: Improved quality of the forest stand and composition of tree species is the goal. The forest shrubs are cut once during an average tree-age of about 40 years;
- Preliminary thinning: The planting density is reduced, surplus plants are removed and the quality of the remaining trees is enhanced. Depending on the kind of thinning, either a tractor or brush cutter may be used;
- Thinning: After the first half of the average rotation period, the forest is thinned by about 100 vfm/ha (volume m3/hectare). The same machines and harvesting methods are applied for this process as for the final harvesting. The wood harvested in the thinning process is economically used and therefore also included in the eco-balancing;
- Liming: In the framework of this research program liming is not taken into consideration. Therefore, it accounts for no additional environmental impact;
- Pesticides: The use of pesticides is not considered. Therefore, there is no additional environmental impact;
- Maintenance of forest dirt roads: For the on-going maintenance of forest dirt roads, it is assumed that gravel cover is renewed every 5 to 10 years. The gravel, which is locally available, is applied with a road paver and subsequently compressed with road roller with no further surface processing. Excavators and lorries are required for the loading and transportation of the gravel along the road;
- Debarking: The debarking of the logs is carried out in sawmills, therefore, there is no additional environmental impact;
- Wet storage: Logs are transported right after harvesting to the sawmills, therefore, there is no additional environmental impact;
- Harvesting losses: 10 % loss of bark and 13.5% on felling residue.

3.1.4 Quantitative Description of Transportation of Lowland Wood

The work processes from the harvesting of the lowland wood through arrival at the sawmill are divided into separate steps and recorded in detail. It is assumed that the harvesting is carried out with a harvester. A forwarder takes the felled trees to the loading site, where they are loaded onto a truck and transported to sawmill. The harvesting losses in this harvesting process are taken into consideration as well as the expenditure and consumption of the machines and means of transport involved.

3.2 Impact Assessment

In this study, the most common effects categories, such as global warming potential, acidification potential, eutrophication potential, ozone depletion potential and the non-renewable and renewable primary energy, are investigated. Effects on the eco-toxicity of water, oceans, the earth, etc. are small [8].

The management of both fuel wood and timber in mountainous regions has the same ecological impacts. The results of the impact assessment differ with lowland wood, because the transportation part for fuel wood is smaller. In the following, only the results of the impact assessments for fuel wood will be dealt with in greater detail.

Figs. 1 and 2 show the impact assessments for timber from mountain and lowland wood. The transportation part plays a prominent role among the impact categories. The 30 km and 100 km transport on paved roads causes an overall environmental impact of 20% to 25% (mountain wood) and 35% to nearly 50% (lowland wood) within the impact categories of acidification, eutrophication and ozone depletion potential.

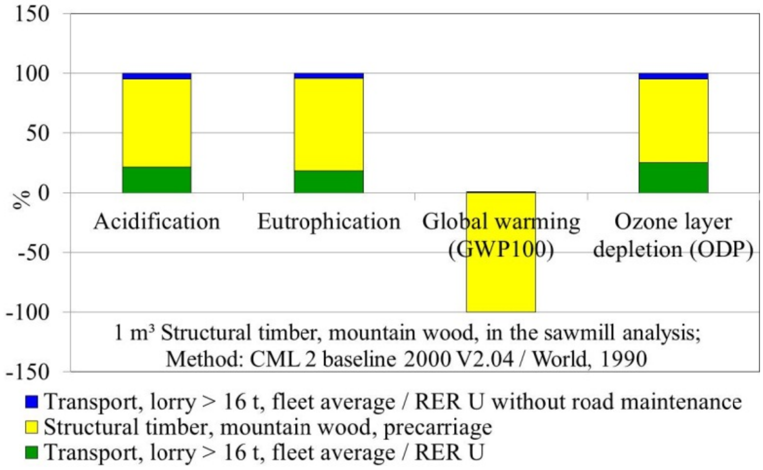

Fig. 1 Impact assessment—mountain wood.

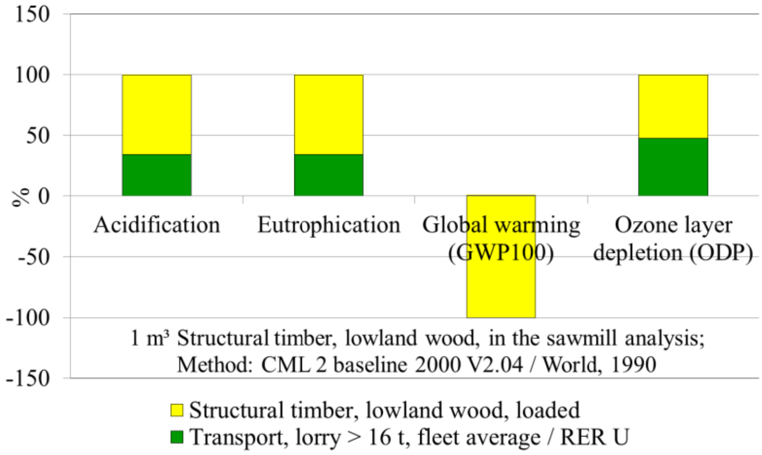

Fig. 2 Impact assessment—lowland wood.

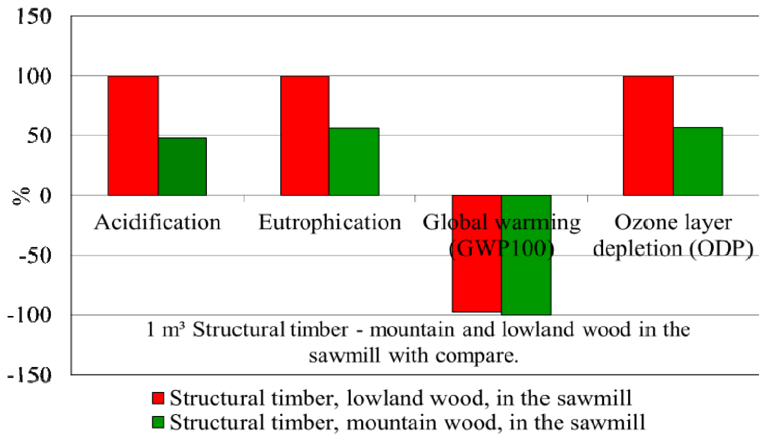

Fig. 3 Comparison of mountain wood—lowland wood.

Fig. 3 compares the impact assessments of mountain wood and lowland wood. It becomes clear that mountain wood shows, on the whole, a 50% lower impact than lowland wood in the impact categories of acidification, eutrophication and ozone layer depletion.

4. Evaluation of Mountain Wood—Lowland Wood

Table 4 lists the results of the impact assessments for timber and fuel wood for both mountain and lowland wood. The negative global warming potential value indicates that in the process from felling area to sawmill more CO_2 is bound than is used up by machines and transport.

The evaluation of the process chains of the individual impact categories for lowland and mountain wood suggests that the decisive factors for the global warming potential—acidification and eutrophication—are in the areas of transport and fuel gas (diesel for engines). On the other hand, mineral oil production processes are mainly responsible for the ozone depletion potential (Tables 5 and 6).

Fig. 4 shows the process impact of mountain structural timber on the global warming potential.

Fig. 5 shows the process impact of lowland structural timber on the global warming potential.

5. Comparison with Ecoinvent Wood Database

The comparison with the wood database, ecoinvent, which offers impact values for completed process data, reveals big differences. The deviations relate to procedures starting at the forest road. The following procedures are compared with (Table 7):

- timber, lowland wood at forest road;
- timber, mountain wood at forest road;
- ecoinvent: round wood, softwood under bark at forest road.

The ecoinvent process shows impact numbers that are about twice as high. This is mainly due to higher diesel consumption and power sawing input.

Reason: Since all further inputs until end-use (technical production) have only little impact on the final values of mountain wood at sawmill, the harvester and forwarder which are used in this study must be very efficient. The thinning in the ecoinvent data is carried out with chainsaws. Mountain wood requires a

Table 4 Results of impact assessment.

GWPkg CO_2-eq	AP kg SO_2-eq	EP kg PO_4^{3}-eq	ODP kg CFC-11-eq	PEI_{ne}kg MJ-eq
Mountain wood—fuel wood				
-996	0.0515	0.0129	1.3 E-6	147
Mountain wood—structural timber				
-996	0.0515	0.0129	1.3 E-6	147
Lowland wood—fuel wood				
-974	0.0889	0.0191	1.75E-6	19
Lowland wood—structural timber				
-970	0.107	0.0231	2.30E-6	252

Table 5 Impact factors (mountain wood).

	Diesel burned in building machines	Mineral oilproduction
Acidification (AP)	38%	-
Eutrophication (EP)	38%	-
Ozone layer depletion (ODP)	-	96%

Table 6 Impact factors (lowland wood).

	Diesel burned in building machines	Mineral oil production
Acidification (AP)	49%	-
Eutrophication (EP)	56%	-
Ozone layer depletion (ODP)	-	95%

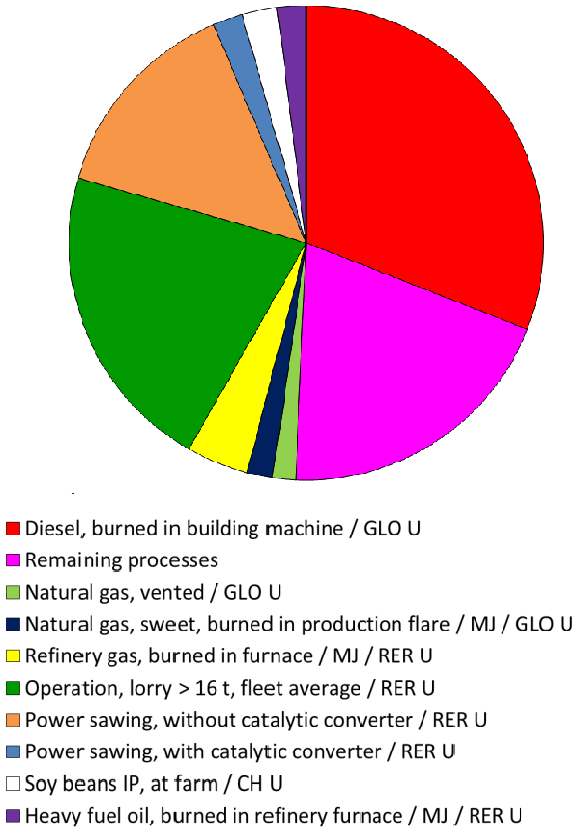

Fig. 4 GLW process impact—mountain wood.

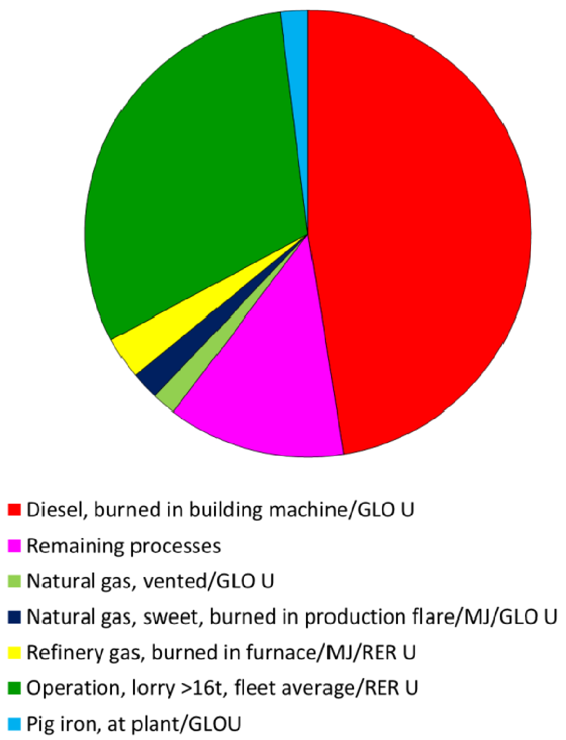

Fig. 5 GLW process impact—lowland wood.

Table 7 Comparison with the ecoinvent wood database.

Process	Diesel, burned in building machine (MJ/m^3)	Power sawing (s/m^3)
Structural timber, lowland wood, from the forest road	78	235
Structural timber, mountain wood, from the forest road	22	1,440
Ecoinvent: round wood	107	1,290

Table 8 Input energy expenditure THEURL HOLZ (Timber company).

Power consumption	58 kWh	
Energy for drying	295.2 kWh	1,062.72 MJ
Transport	100 km	41 tkm

Table 9 Transport chemicals.

	Weight	Distance	Tons/km
Train	12 kg	600 km	7.2 tkm
Lorry	12 kg	100 km	1.2 tkm

Table 10 Ecoinvent: Input data glued laminated timber.

Input data glued laminated timber per m^3	Values
Diesel consumption of the machines	33.6 MJ
European power mix for the production	129 kWh
Oil-firing, light oil	23 MJ
Sawn timber 20%	1 m^3
Transport by train	81.2 tkm
Transport by lorry	38.2 tkm
Urea-formal dehyde	12 kg
Wood chip furnaces	2,660 MJ
Wood chip from sawmill	-0.84751 m^3
Wood panel factory	3.33E-08 p

Table 11 For Tyrol: Input data glued laminated timber.

Input data glued laminated timber per m^3	Values
Diesel consumption of the machines	33.6 MJ
Power for the production (Fa. Theurl)	58 (208.8) kWh (MJ)
Mountain wood:sawnwood 70%	1 m^3
Transport by lorry-wood	41 tkm
Transport by lorry-chemicals	1.2 tkm
Transport bytrain	7.2 tkm
Urea-formal dehyde	12 kg
Wood chip furnaces	1,062.72 MJ
Wood chip from sawmill	-0.336 m^3
Wood panel factory	3.33E-08 p

less complex technical production process. Harvesting is carried out with a chainsaw. The share of forwarding machinery to forest road is comparatively small.

6. Comparison for Wood Products—Example: Glued Laminated Timber Ceiling

The non-predried mountain wood (spruce) taken for the study is cut in the sawmill. In the next stage, the sawn timber is transported to the glued laminated timber plant, where the product is manufactured. For 1 m^3 glued laminated timber 2.2 m^3 round wood including 11.5% bark loss is required, which amounts in total to 2.453 m^3.

The manufacturing process leads to by-products which can be economically utilised, such as wood chippings, bark and sawdust. Through eco-balancing allocation (emission and energy impact allocated to actual source) these by-products are taken into account.

The following is assumed: Glued laminated timber costs 460.00 €/m^3 and the average price of the by-products is 20.05 €/m^3.

Two big Austrian companies were requested to provide their values: TheurlHolz and Binderholz. The values were the same and therefore the values of TheurlHolz are used (Table 8).

A heat and power plant provides electricity. The energy for the drying process is generated by the burning of residual timber materials.

The transport of chemicals involves a 600 km train and 100 km lorry journey (Table 9).

Tables 10 and 11 show the values of glued laminated timber ceiling produced in Tyrol with specific data, as well as the values of the sigma pro program of ecoinvent database in which the implemented glued laminated timber ceiling is included.

Fig. 6 shows the following results. It is clearly noticeable that there is a remarkable positive effect on the global warming potential impact category due to the storage of CO_2 (100%) in wood. In comparison, the

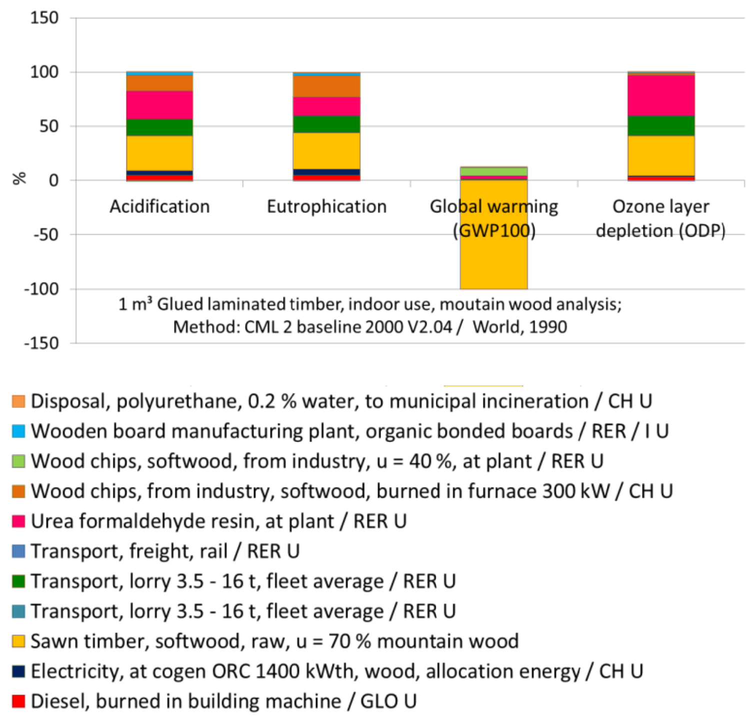

Fig. 6 Process impacts—glued laminated timber, mountain wood.

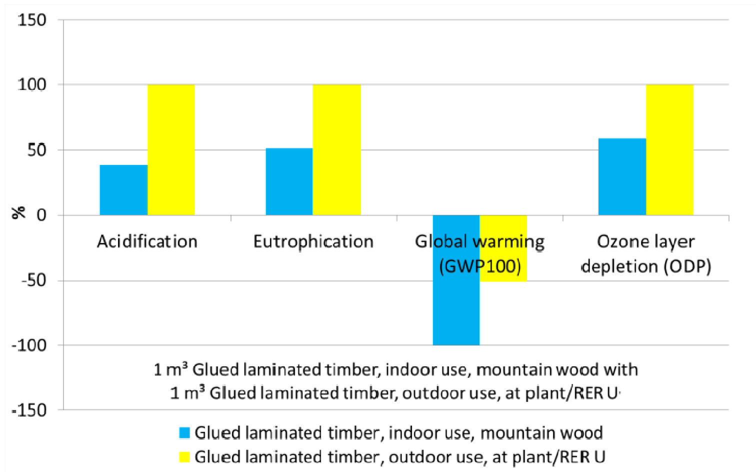

Fig. 7 Impact assessment glued laminated timber, mountain wood (Tyrol)—glued laminated timber, ecoinvent database.

CO_2 emission, due to formaldehyde and transport (10%) is low. This means that CO_2 storage is always higher than CO_2 emission. The use of formaldehyde shows negative results in all impact categories. Moreover, the transport of sawn timber (mountain wood) also exerts negative consequences on all impact categories. The transport of sawn timber from the sawmill to the glued laminated timber plant amounts to about 10% of the overall environmental impact of the impact category in question (acidification, eutrophication, global warming potential and ozone depletion potential). The figure also shows that the burning of wood chips for drying wood has a negative effect on the impact categories of acidification and eutrophication.

As can be seen in Fig. 7, mountain wood shows significantly better results in all impact categories when compared to ecoinvent database values (100%).

7. Comparison with the OI3-Indicator of the Austrian Institute for Healthy and Ecological Building

The Austrian Institute for Healthy and Ecological Building (IBO) issued guidelines for the computation of eco-indicators for buildings. In particular, the computation of OI3-Indicators is harmonised. The computation of the OI3-Indicator is designed for residential buildings [9]. In some Austrian provinces, it is used as an additional criterion for the granting of public subsidies for residential buildings. From a wide range of environmental indicators IBO currently uses the following:

- GWP (global warming potential);
- AP (acidification potential);
- PEI_{ne} (non-renewable primary energy input).

The composition of the individual OI3-Indicators is presented in this paper in brief.

7.1 The OI3 Factor of a Construction Unit

The *OI3* factor of a construction unit $OI3_{KON}$ consists of the following Eq. (1):

$$OI3_{KON} = 1/3\ OI_{PEIne} + 1/3\ OI_{GWP} + 1/3\ OI_{AP} \quad (1)$$

The primary energy of MJ/m² construction area is converted into points with the linear function Eq. (2):

$$OI_{PEIne} = 1/10 \times (x - 500) \quad (2)$$

The conversion of kg CO_2-eq/m² construction area into OI_{GWP} points is carried out respectively with the linear function Eq. (3):

$$OI_{GWP} = 1/2 \times (x + 50) \quad (3)$$

The conversion of kg SO_2-eq/m² construction area into OI_{AP} points is carried out respectively with linear function Eq. (4):

$$OI_{AP} = 100/(0.25) \times (x - 0.21) \quad (4)$$

7.2 The Value Range of $OI3_{KON}$-Indicators

The ecological quality of common constructions is presented in the eco-indicator $OI3_{KON}$ in a range between 0 and 100 points. An exterior wall $OI3_{KON}$ of 70 points constitutes standard construction without ecological optimizing measures. 15 points or less can only be achieved through ecological optimization or through a very light construction design.

7.3 OI3 Factor of a Glue Laminated Timber Ceiling

The ecologically assessed glue laminated timber ceiling made of mountain wood described in chapter 6 is used for the calculation of an OI3 factor. The values for acidification, global warming potential and non-renewable primary energy input listed in Table 12 are converted into points. Each part subsequently constitutes a third of the overall figure (compare formula in 7.1).

This results in the following value:

$OI3_{KON}$ glued laminated timber ceiling = -48.8.

To put the value of the glue laminated timber ceiling OI3 factor into perspective, it is compared to the OI3 factor of a steel concrete slap produced in western Austria. For that purpose specific data for the life cycle inventory of a steel concrete ceiling manufactured in western Austria are collected and calculated with the sigma pro and ecoinvent database. The results are shown in Table 13.

This results in the following value:

$OI3_{KON}$ steel concrete ceiling = 25.7.

Table 12 Impact assessment-glued laminated timber (Austria).

Impact assessment	Unit	Total/m^2 (d = 18 cm)
AP	kg SO_2-eq	0.087
EP	kg PO_4^3-eq	0.019
ODP	kg CO_2-eq	-208.800
Ozon	kg CFC-11-eq	2.16E-06
PEI_{ne}	MJ-eq	319.500
PEI_e	MJ-eq	2844.547

Table 13 Impact assessment- steel concrete slap (Austria).

Impact assessment	Unit	Total/m^2 (d = 16 cm)
AP	kg SO_2-eq	0.197
EP	kg PO_4^3-eq	0.036
ODP	kg CO_2-eq	74.880
Ozon	kg CFC-11-eq	0.000
PEI_{ne}	MJ-eq	698.720
PEI_e	MJ-eq	35.477

The reason why the values of the construction unit are relatively low is that only one construction layer was taken into account. The inclusion of additional floor layers would increase the values and the entire construction would fall into the usual value range between 0 and 100 points.

In comparison to both raw ceilings, it is apparent that the glue laminated timber ceiling constitutes a much lower value and is therefore more ecological.

8. Conclusions and Prospects

From the eco-balance of the defined case studies (wood harvesting, manufacturing of glued laminated timber ceiling), it can be concluded that mountain wood at sawmill has a lower environmental impact than lowland wood. Moreover, a glued laminated timber ceiling made of mountain or lowland wood in western Austria, based on the local specified values, shows a lower value than for a glued laminated timber ceiling calculated with sigma pro of ecoinvent. In the production of a glued laminated timber ceiling, transportation and the use of formaldehyde make up the major overall negative factor on the individual impact categories.

When compared to the OI3 indicator for a generalized glued laminated timber ceiling, which can be used in every region, the value of the established OI3 Indicator in point 7 for a glued laminated timber ceiling made of mountain wood seems too low. The reason is that sawn timber from Europe has much longer transport routes. Moreover, part of the energy used for drying of wood is not renewable and more power of a less ecological electricity mix is used. Therefore, to receive validated data for sawn timber or a manufactured glued laminated timber ceiling from western Austria, further studies are necessary.

In order to carry out a statistical evaluation, more data need to be collected in various regions of western Austria concerning types of forwarding, transportation routes and further processing in sawmills and glued laminated timber manufacturing plants. Subsequently, data valid for the whole of western Austria can be fed into a database.

Further profound research in the use of formaldehyde in the production of glued laminated timber ceiling could provide ways to optimize the use of wood. A study of various construction units in their entire life cycle might underpin the positive properties of wood as a re-useable building material.

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