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INFLUENCE OF CARBON ACCOUNTING ON ASSESSMENT OF WOOD-BASED PRODUCTS

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ABSTRACT

As the population grows, the number of products and services increases escalating the burden on the environment. Carbon dioxide is the largest contributor to global warming among all greenhouse gases. Life Cycle Assessment defines specific impacts of anthropogenic activities through multiple calculation methods, the majority of which are not identical. Carbon uptake accounting can substantially affect the perception of wood products in the overall assessment. Different approaches to the inclusion of greenhouse gases to global warming and their impact on the production of selected wood-based products – glued laminated timber, dimensional timber, solid structural timber, oriented strand board, particleboard, and light, medium and high-density fibreboard are shown in the paper. Dimensional timber achieved the lowest emissions proving the easier the manufacture the least the product burdens the environment. However, glulam seems to be the best carbon sink when carbon uptake is taken into account. Fibreboards were ranked the worst by the majority of methods.

Key words: carbon balance, structural timber, life cycle assessment.

INTRODUCION

In order to reduce negative impacts of human activities on the Earth ecosystems, sustainability becames one of the most important pillars of the global building agenda enhanced by the intense worldwide interest in carbon dioxide (CO_2) emission reduction (WOODARD and MILNER 2016). In 2019, building construction and operations accounted for the largest share of global total final energy consumption (35%) and energy-related CO_2 emissions (38%) (UNEP 2020). Therefore, attention was drawn on manufacturing and usage of sustainable construction materials and buildings (RÉH *et al.* 2021, VANOVA *et al.* 2021).

Life Cycle Assessment (LCA) method is an analytic tool evaluating the impact of human activities on the environment using various impact categories based on material and energy balances of input and output flows of the system under study (ISO 14040). One of the most common categories used in the evaluation is global warming or climate change, driven by large amount of greenhouse gases (GHG) emissions; particularly CO_2, methane (CH_4) and nitrous oxide (N_2O); in the atmosphere (MONTZKA *et al*. 2011).

Wood-based products are one of the key aspects of climate change impact mitigation (SKULLESTAD *et al*. 2016). Wood represents one of the earliest construction material (RYBNÍČEK *et al.* 2020). As it grows, wood sequesters CO_2 from the air and stores it until the combustion or decomposition. Therefore, wood biomass can be considered carbon neutral over time (COWIE *et al*. 2019, PAROBEK *et al*. 2019). However, the perception of wood from the environmental point of view remains inconsistent.

Two types of carbon sources exist – fossil and biogenic. Fossil carbon emissions comprise vast amount of substances of which CO_2 is the most represented. Transport and fossil-based electricity and heat production contribute to majority of global CO_2 emissions. Efforts are currently being made to reduce fossil fuels and increase the share of renewable energy sources (PARASCHIV and PARASCHIV 2020).

The treatment of biogenic carbon emissions and removals is a challenging issue in environmental assessment (BRANDÃO *et al*. 2013, LEVASSEUR *et al*. 2012). Biogenic carbon can be stocked in biological matter and soil. Wood represents a natural source of CO_2. Thanks to photosynthesis, it is possible to remove carbon in the air by its incorporating into the organic matter. However, combustion of biomass forms the main source of biogenic CO_2 (RODIN *et al*. 2020). Therefore, extending the service life of wood-based products is one of strategies to improve resource efficiency (CARUS and DAMMER 2018). This can be done through incorporating circular economy practises, e.g. recycling of waste wood. Though, allocation of burdens and benefits of recycling materials throughout their sequence of applications is rather unclear as a consequence of shifting from one life cycle stage to another (DJURIC ILIC *et al*. 2018).

In most LCA studies the related climate change effect is not taken into account: biogenic CO_2 is either not considered or biogenic CO_2 emissions are assumed to balance out carbon uptake during biomass growth. Emission and removal of biogenic CO_2 in wood biomass usually occur at different points in time. Uneven approaches to carbon life cycle assessment complicate the expression of related global warming and climate change (GARCIA *et al.* 2020). As a consequence, wood-based products or even whole buildings are considered more or less environmentally beneficial (HOSSAIN and POON 2018, HÄFLIGER *et al*. 2017, PIEROBON *et al*. 2019, SAADE *et al*. 2020, ZIEGER *et al*. 2020).

The choice of calculation method can affect the overall assessment due to different scores of substances (SAFARI and AZARIJAFARI 2021, SARTORI *et al*. 2021). This study compares production burdens of selected wood products by different GHG emissions calculation methods in order to distinguish between carbon captures and emissions that consequently affect overall environmental impact of these products.

MATERIALS AND METHOD

For the assessment purposes, 8 wood-based products were chosen (Table 1). LCA methodology was applied considering the cradle-to-gate assessment (ISO 14044). Hence, all operations from resource extraction to the factory gate were accounted. Data were taken from an international Life Cycle Inventory (LCI) database (WERNET *et al*. 2016) covering average global production activities extrapolated from existing regional datasets. Global datasets reflect the global average based on international data. The composition and share of specific datasets on the overall product database as well as other specific information is described in Table 1.

Functional unit was set to 1 m^3 of a particular product. Analysis was carried out by SimaPro software, version 9.1.1.1 (PRÉ CONSULTANTS 2016). Products were assessed due to global warming potential (GWP) by several calculation methods – CML-IA (GUINÉE 2002), EDIP (HAUSCHILD and POTTING 2003), Environmental Footprint (EF) (FAZIO *et al*. 2018), EPD (EPD INTERNATIONAL AB 2019), ILCD (JOINT RESEARCH CENTRE 2010), IMPACT 2002+ (JOLLIET *et al*. 2003), ReCiPe (HUIJBREGTS *et al*. 2017), BEES (LIPPIATT 2007), TRACI (BARE 2011) and IPCC (INTERNATIONAL PANEL ON CLIMATE CHANGE 2014).

All these methods are part of the SimaPro software and serve to identify specific environmental impacts. Each calculation method transforms input and output material and energy flows within the system under study into the GWP impact of GHG emissions expressed as carbon dioxide equivalent (CO_2 eq). The calculation methods use different characterization factors for GHG emissions to compute the GWP impact of a product.

Tab. 1 Selected wood-based products specification. RoW – rest of the world, GB – Great Britain, EwS – Europe without Switzerland, PF – phenolic resin, UF – urea formaldehyde resin, PMDI – polymeric methylene diphenyl diisocyanate, VWE – virgin wood (eucalyptus species), WP – wet process, WDP – wet and dry processes.

Product	Density	Geographic area of a dataset	Share of a dataset on the overall database	Used resin	Other specific data
Glued Laminated Timber for indoor use (Glulam)	625 kg/m^3	Canada	0.003	PF	Kiln dried
		Europe	0.671	UF	Air dried
		RoW	0.326		
Solid Structural Timber (SST)	625 kg/m^3	Europe	1	UF	Air dried
Dimensional Timber (DT)	475 kg/m^3	Canada	0.036	none	Air dried
			0.001		Kiln dried
		Switzerland	0.004		Air dried
		RoW	0.923		Air dried
			0.035		Kiln dried
Oriented Strand Board (OSB)	640 kg/m^3	Canada	0.001	PF	-
		Europe	0.382	PMDI	
		RoW	0.617		
Particle Board (PB)	650 kg/m^3	GB	0.035	UF	VWE
		Europe	0.298		-
		RoW	0.352		
			0.316		VWE
High Density Fibreboard (HDF)	920 kg/m^3	Europe	0.295	PF	WP
		RoW	0.705		
Medium Density Fibreboard (MDF)	750 kg/m^3	Europe	0.135	MEF	-
		RoW	0.865		
Light Density Fibreboard (LDF)	200 kg/m^3	Canada	0.004	PUR	WDP
		EwS	0.280		
		RoW	0.682		
		Switzerland	0.034	-	WP

RESULTS

The amount of GHG emissions produced in the manufacturing stage of selected products were compared by 12 calculation methods (Table 2). CML-IA and EPD methods had the same basis resulting in equal GHG amounts; as well as EDIP and TRACI calculation methods. ILCD and IPCC including CO_2 uptake were the only methods concerning CO_2 in the air as a raw material stored in biological matter, thus CO_2 values were negative indicating carbon removal. Slight discrepancies in the results between selected methods were caused by different inclusion of some emissions into the air, especially fossil ones.

Tab. 2 LCI results of selected wood-based products (kg CO_2 eq; a - years); functional unit – 1 m^3.

Method	Glulam	SST	DT	OSB	PB	HDF	MDF	LDF
CML-IA	235.78	180.76	67.87	376.00	365.09	1163.15	761.90	87.80
EDIP	234.93	180.37	67.66	376.69	361.42	1152.98	757.06	87.42
EF	241.40	184.75	69.36	389.83	375.75	1198.10	781.96	89.69
EPD	235.78	180.76	67.87	376.00	365.09	1163.15	761.90	87.80
ILCD	–1341.70	–1199.10	–1186.27	–837.24	–642.98	–249.60	340.51	0.96
IMPACT 2002+	227.36	175.32	66.44	351.39	343.74	1100.59	727.72	84.72
ReCiPe	239.85	183.44	68.74	386.66	373.87	1190.92	778.06	89.23
BEES	233.43	179.28	67.35	373.96	358.54	1143.93	751.90	86.87
TRACI	234.93	180.37	67.66	376.69	361.42	1152.98	757.06	87.42
IPCC 100a	236.76	181.34	68.10	378.16	366.98	1170.04	766.41	88.14
IPCC 20a	260.65	196.08	73.37	427.02	427.32	1355.77	869.66	96.90
IPCC uptake	–1339.89	–1198.15	–1185.83	–835.82	–637.55	–232.62	349.73	1.66

To clarify the different approach of carbon accounting specific carbon emissions and captures were listed (Table 3). Almost all methods used similar pattern in carbon accounting each based on fossil carbon emissions and emissions from land transformation. Carbon storage in soil was also present except for ILCD method where it was replaced by CO_2 uptake from the air and supplemented by biogenic carbon emissions and emissions from peat oxidation. IPCC uptake method contained all carbon emissions and removals mentioned except for the last one.

Tab. 3 Carbon accounting in particular calculation methods (the value represents the contribution to climate change; negative sign refers to removal); LT – Land Transformation, PO – Peat Oxidation.

Method	Carbon emissions and removals					
	Fossil	**LT**	**Soil**	**Biogenic**	**Uptake**	**PO**
CML-IA	1	1	-1	0	0	0
EDIP	1	1	-1	0	0	0
EF	1	1	-1	0	0	0
EPD	1	1	-1	0	0	0
ILCD	1	1	0	1	-1	1
IMPACT 2002+	1	1	-1	0	0	0
ReCiPe	1	1	-1	0	0	0
BEES	1	1	-1	0	0	0
TRACI	1	1	-1	0	0	0
IPCC 100a	1	1	-1	0	0	0
IPCC 20a	1	1	-1	0	0	0
IPCC uptake	1	1	-1	1	-1	0

Table 4 shows the distribution of CO_2 emissions and removals according to IPCC uptake method. Obviously, sequestrated carbon played a substantial role in the overall assessment. Emissions from land transformation were negligible. Fossil carbon emissions replicate CO_2 emissions in methods non-considering carbon uptake reflecting mainly emissions associated with transport and fossil-based heat and electricity. Biogenic carbon emissions came from wood incineration within the particular life cycle. Fossil and biogenic carbon emissions were similar in most cases.

Tab. 4 Assessment of selected wood-based products using IPCC including CO_2 uptake method (emissions to soil were assigned to fossil carbon); functional unit – 1 m^3.

Impact category	Carbon emissions and removals				
	Fossil	Biogenic	Uptake	LT	Total
Glulam	234.62	330.97	–1906.50	1.02	–1339.89
SST	179.33	335.14	–1713.57	0.95	–1198.15
DT	67.51	4.53	–1258.36	0.48	–1185.83
OSB	376.35	374.75	–1587.96	1.04	–835.82
PB	357.22	394.01	–1389.83	1.06	–637.55
HDF	1137.78	553.40	–1940.37	16.57	–232.62
MDF	762.89	544.11	–958.69	1.43	349.73
LDF	86.94	152.09	–237.94	0.57	1.66

In order to determine the magnitude of the products impact two methods were selected – IPCC uptake and CML-IA – representing the inclusion and non-inclusion of carbon uptake (Table 5). In the first case, glulam was found the most beneficial product followed by SST and simple dimensional timber. During production of LDF and MDF fossil carbon prevailed which led to positive signs indicating environmental burden. The second approach rejecting carbon uptake considered DT as a product with the lowest impact on climate change. As the worst wood-based alternative HDF was shown. The sequence has changed for almost all products except PB that stayed at the 5th rank in both cases.

Tab. 5 Ranking of selected wood-based products according to different carbon accounting (products were sorted from the most beneficial to the most burdensome); functional unit – 1 m^3.

Rank	IPCC uptake		CML-IA	
1	Glulam	-1339.89	DT	67.87
2	SST	-1198.15	LDF	87.80
3	DT	-1185.83	SST	180.76
4	OSB	-835.82	Glulam	235.78
5	PB	-637.55	PB	365.09
6	HDF	-232.62	OSB	376.00
7	LDF	1.66	MDF	761.90
8	MDF	349.73	HDF	1163.15

So far, the calculations have considered the environmental load of 1 m^3 of the product. As the density of the selected products varied mass allocation was performed (Fig. 1). With decreasing amounts of wood per unit weight, the content of sequestrated carbon declined leading to dominance of CO_2 emissions into the air. According to the IPCC uptake method DT was the most environmentally beneficial product. On the other hand, MDF was found the worst.

Pursuant to the CML-IA results highest emissions reported HDF followed by MDF. These products had the highest densities; thus they should act environmentally beneficial in terms of carbon uptake. As this is not the case, they will be considered below.

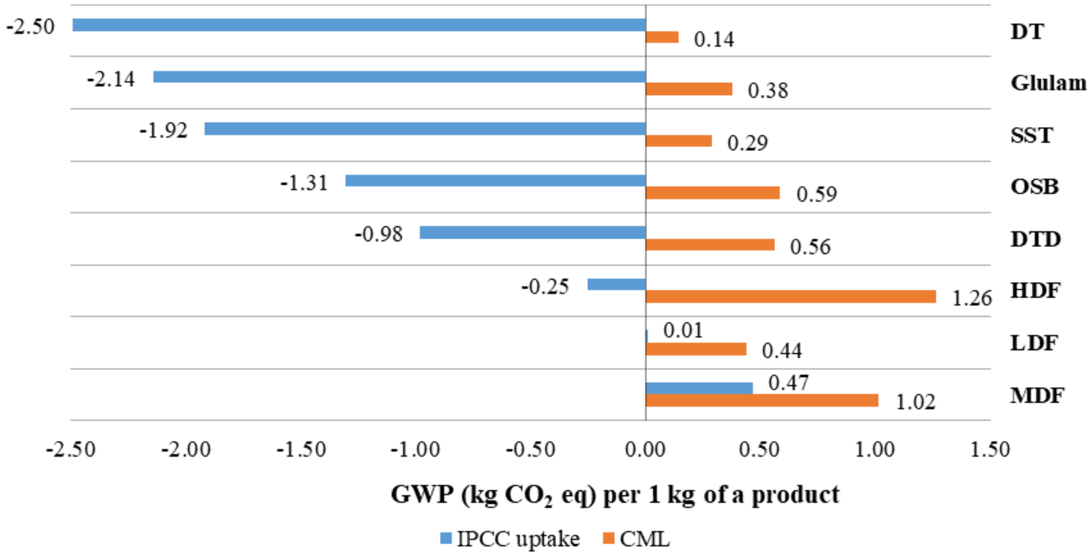

Fig. 1 GWP per 1 kg of a particular wood-based product (total weight of CO_2 eq).

Comparison of IPCC uptake and CML-IA methods recorded the highest difference in CO_2 emissions by dimensional timber reaching 2.64 kg CO_2 eq/kg of product. Therefore, DT remained considered the most unstable product in terms of GWP due to different carbon accounting. However, DT was ranked the best according to both methods.

In order to justify diverse amounts CO_2 emissions from production, glulam, DT, HDF and MDF were chosen for a deeper evaluation of fossil emissions according to the IPCC uptake method (Fig. 2).

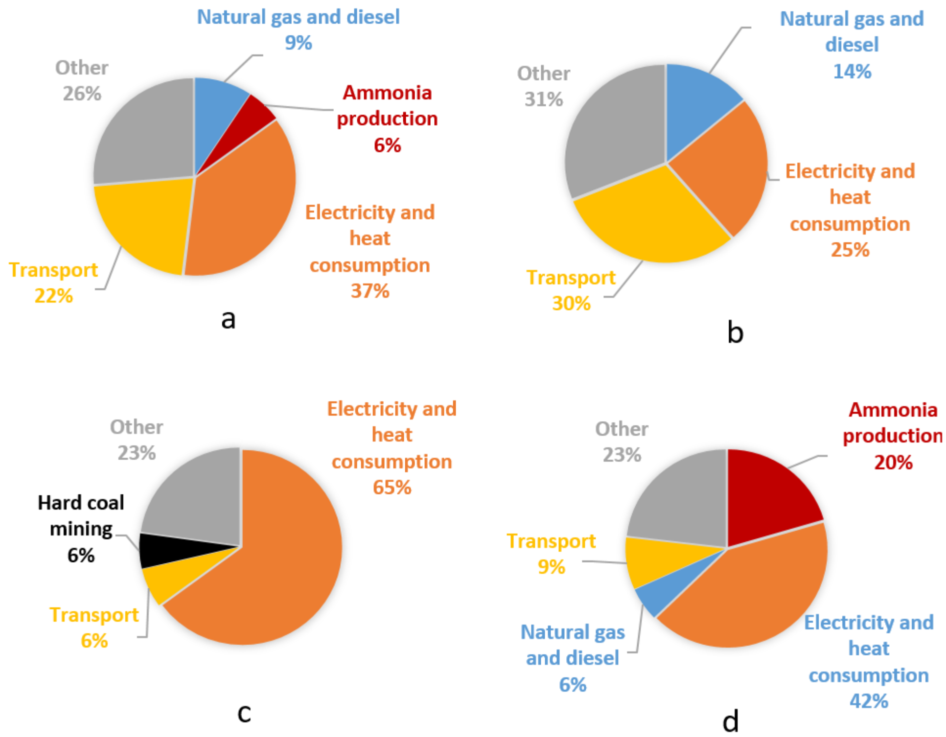

Fig. 2 Fossil carbon emission contribution per 1 m³; a – Glulam, b – DT, c – HDF, d – MDF; IPCC uptake method.

Dimensional timber production was technologically undemanding, corresponding to proportional distribution of fossil carbon emissions. Electricity and heat consumption took one fourth of overall emissions. Natural gas and diesel were bound to internal transport and associated processes. Transport referred to distances necessary for materials import. High share of other fossil-based emissions suggested numerous minor processes incorporated.

MDF was ranked the worst by IPCC uptake method and the second worst by CML-IA method. Notably, 42% of the fossil carbon emissions were bound to energy consumption. Moreover, one fifth of the emissions created within the MDF production was directly linked to ammonia manufacture as an essential element of urea-formaldehyde adhesives. Only 6% and 9% were connected with natural gas and diesel; and transport, respectively.

Most of the glulam production emissions (37%) were related to energy consumption, 22% were due to transport and about a quarter were associated to other minor processes. Ammonia production accounted for 6% of total fossil emissions.

Fossil emissions from HDF production were the highest within all products, reaching 1137.78 kg CO_2 eq/m^3 HDF and 1.26 kg CO_2 eq/kg HDF. Up to 65% of these emissions accounted for energy consumption. Notably, 6% was caused by hard coal mining operations.

DISCUSSION

Product databases used for the analysis contained average data from all over the world, designed according to average production technologies and transport distances. So, they could be used for any geographical region. Specific production in specific areas might, therefore, report different values more or less burdensome than the stated GWP.

CO_2 uptake included all inputs within the scope of product manufacturing. Higher amounts of carbon also indicated wood losses during processing. Moreover, the choice of a calculation method affected dimensional timber as the simplest material the most. The higher the difference was, the higher the inaccuracies could have risen if the product was subsequently evaluated as a part of another system, for example wood-based building. This is the reason why negative emission results could occur according to (MONOKOVA and VILCEKOVA 2019). At the same time, this points out that simple production technology is less harmful to the environment than the production of complicated products containing several raw materials.

Fossil emissions were largely influenced by the energy mix used (PARASCHIV and PARASCHIV 2020). That was evident predominantly in HDF production. Also, adhesives created a significant burden on the environment, particularly in the case of MDF manufacture, due to ammonia production by steam reforming.

For both, bulk and mass allocation, results indicated the production of HDF to cause the greatest burden in terms of the highest fossil carbon emissions, in general. Carbon uptake caused negative carbon emissions and placed HDF two rank higher, leaving LDF and MDF behind.

According to the IPCC uptake method, dimensional timber was the most environmentally beneficial product when mass allocation was applied. Bulk allocation reported glulam the best option.

With decreasing amounts of wood per unit weight, the content of sequestrated carbon declined leading to dominance of CO_2 emissions into the air. Insufficient identification of carbon emissions and removals treating during calculation could lead to discrepancies. A comparison of the individual studies should be therefore avoided.

CONCLUSION

Sustainable, renewable and natural characteristics make wood a required construction material. However, its environmental impact is not uniform and depends on a calculation method in terms of life cycle approach.

Carbon accounting in LCA is a controversial topic. Diverse calculation methods a create vast space for LCA practitioners to express the environmental impact of wood products. Neglecting of carbon uptake can omit significant positive impacts of wood-based products. It may happen that some studies show wood products as environmentally beneficial in the stage of their production. However, the decomposition of wood returns sequestrated carbon emissions back into the atmosphere, creating a virtual circle. To avoid inconsistencies, carbon emission and capture data should be mentioned for each LCA study. Therefore, the selection of a particular calculation method is an important step in assessment of the whole system.

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