Life cycle assessment of Austrian and Slovenian raw wood production

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Abstract. Forestry will play an increasingly important role as a raw material contributor since climate change mitigation requires a shift from fossil-based materials to renewable, bio-based materials. Consequently, an increase in wood demand is expected. Slovenia has a forest coverage of 59 % while almost half of Austria is covered by forest (43 %). In these countries, the forest-based sector has an important role. We look at the environmental impact of forestry in Slovenia and Austria under an increase in wood demand. This contribution has a twofold purpose: 1) to describe the environmental impact of Slovenian and Austrian forestry and forest products with a focus on sawlogs, and 2) to provide life cycle inventory data for Slovenian and Austrian forestry and importing countries for other LCA needs, for example, LCAs in the construction or biorefinery sectors and for benchmarking purposes. This contribution explores the use of the European Life Cycle Inventory of Forestry Operations (EFO-LCI) database [1]. The life cycle impact assessment applies the 16 impact categories as recommended by the European Commissions for LCA/Environmental Footprint in Europe [2] and provides additional indicators important for bio-based materials.

1 Introduction

More than one-hundred-ninety nations, including the European Union, have signed the Paris Agreement to strengthen the global response to the threat of climate change by "Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C …" (Art. 2 a) [3]. To meet these conditions requires a steep decline in greenhouse gas (GHG) emissions by the year 2030 and zero emissions by 2050 [4].

With the bioeconomic transition, Europe wants to speed up the progress on a low-carbon and circular economy. This transition is expected to increase the efficiency of resource use, create new business opportunities and create an array of positive side effects. For example, the material intensity of the construction sector makes it responsible for 12 % of the total

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GHG emissions of the EU28 [5]. Due to their typically lower carbon footprint [6], wood-based products represent an alternative to GHG-intensive construction materials such as steel and concrete.

Forests and the forest-based sector provide wood, one of the most abundant and important bio-based feedstocks, sequester carbon and deliver a wealth of other services. The transition from a fossil-based to bio-based economy poses the issue of how to sustainably produce and increase biomass supply while sustaining forest carbon sinks. Securing a sustainable biomass supply is one of the key issues for deploying a sustainable bioeconomy [7].

As can be seen from Figure 1, Austria (north) and Slovenia (south) have a high forest coverage (dark green colour) [8].

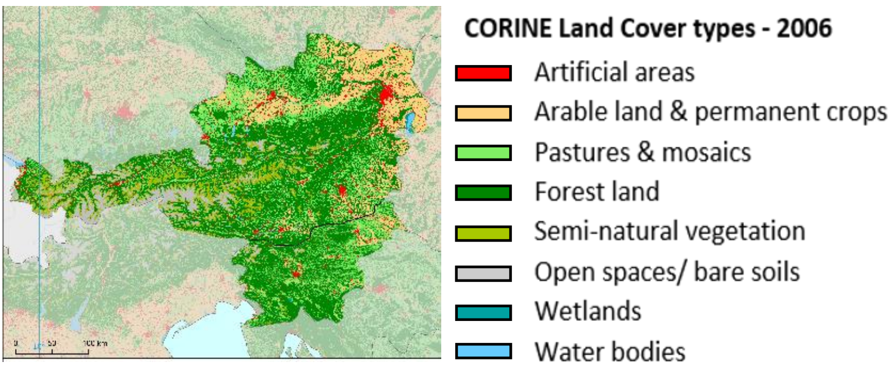

Fig. 1. Austria and Slovenia and CORINE Land Cover types (based on EEA [8]).

Almost half of Austria is covered by forest (43.3 %) and Slovenia has a forest coverage of 59.8 %, which makes it one of the most forested countries in Europe [9]. The Austrian forest covers an area of 4.0 million ha, while the Slovenian forest covers an area of 1.2 million ha. The growing stock, increment, and harvest in Austria are 337 m^3/ha, 9.0 m^3/ha, and 7.7 m^3/ha, respectively [10], and in Slovenia, 303 m^3/ha, 7.5 m^3/ha, and 4.5 m^3/ha, respectively [11]. In Austria, wood use is largely driven by the sawmill industry (53 %), the pulp and paper industry (14 %), and direct energy recovery (33 %) [12]. Similarly in Slovenia, sawlogs and veneer logs represent the highest share of purchased roundwood (72 %), followed by pulpwood (18 %) and wood fuel (8 %) [11].

The purpose of this contribution is twofold: 1) to describe the environmental impact of Slovenian and Austrian forestry and forest products with a focus on sawlogs, and 2) to provide life cycle inventory data for Slovenian and Austrian forestry and importing countries for other LCA needs, for example, LCAs in the construction or biorefinery sectors and for benchmarking purposes.

2 Data and method

LCA is a standardised method to evaluate the environmental impacts of products and services with a life cycle perspective. A cradle-to-gate LCA starts with the raw material extraction and ends when the product is finished at the factory gate – here, the forest road. The system boundaries with the input and output are closely aligned with those of the European datasets in ecoinvent. Figure 2 gives an overview.

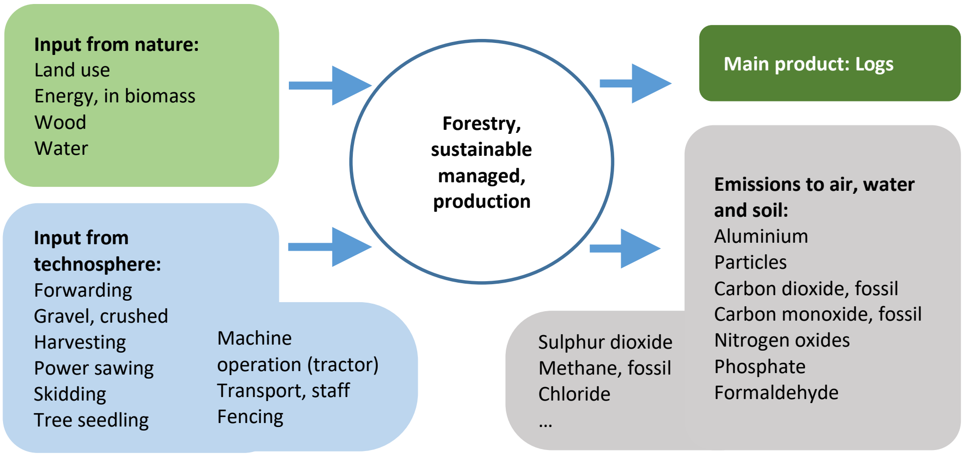

Fig. 2. Simplified cradle-to-gate system boundary (based on ecoinvent database v 3.6 [13]).

The functional unit is the provision of 1 m^3 of wood (measured as under bark) at the forest road. The life cycle impact assessment applies the 16 impact categories as recommended by the European Commissions for LCA/Environmental Footprint in Europe [2] and provides sub-indicators for the carbon footprint, which is important for bio-based materials.

The European Forestry Operations Life Cycle Inventory (EFO-LCI) contains LCI for forest management practices of European forests [1]. The LCI is based on published and unpublished scientific studies, national reports, and national laws along with data that were collected from national forestry expertise. To describe all possible forest types, EFO-LCI has classified European forests based on the adopted silvicultural systems and species composition; the combination of results has been named a Forest Unit. The 49 total forest units identified in EFO-LCI includes and allows all the major types of European forests and their management to be described. EFO-LCI describes a total of 235 forest units in 29 European countries. This contribution explores the use of this database [1]. Data from EFO-LCI have been extracted and calculated to fit to the ecoinvent dataset input and output (see Figure 2). Table 1 summarizes some key data from EFO-LCI. Background life cycle data (e.g. input from technosphere in fig. 2) are from ecoinvent 3.6 [13], while the amounts are based on EFO-LCI [1]. Additional background data on fencing have been gathered from Cambria and Pierangeli [14].

Table 1. Some key data from the EFO-LCI database [1].

Tree type	Country	Forest Unit	Timber [m^3 (u.b.)/ha]	Pulp logs [m^3 (u.b.)/ha]	Forest area [ha/m^3 (u.b.)]	Rotation period [a]	Road ˈlength [m/ha]
Coniferous	AT	3-B	629	176	12.4	103	48
Non-coniferous	AT	3-E	521	169	14.5	118	48
Non-coniferous	AT	3-F	657	234	11.2	108	48
Coniferous	AT	4-A	310	110	23.8	108	48
Coniferous	SI	3-B	506	127	15.8	138	10
Non-coniferous	SI	3-E	277	34	32.2	98	15
Non-coniferous	SI	3-F	261	43	32.9	143	10
Coniferous	SI	4-A	147	36	54.8	98	10

Not all forest types in Slovenia and Austria are in the scope of this contribution; therefore, the results are not representative for Slovenia and Austria as countries but describe only the investigated forest units.

The life cycle impact assessment method applied is that for construction products (EN15804+A2:2019) [15], the normalisation and weighting factors are from the EU Environmental Footprint [2] as implemented in the LCA software used (SimaPro 9.1 [16]).

3 Results

Table 2 shows the characterised results for 1 m^3 of raw wood at the forest road for selected forest units in Austria and Slovenia.

Table 2. Characterised results of 1 m^3 of raw wood at the forest road.

Data source	EFO-LCI								ecoinvent	
Geography	Austria				Slovenia				DE	EU
Management group	Even-aged									
	with shelterwood			Uniform clear-cut system	with shelterwood			Uniform clear-cut system		
Species type	Coniferous	Non-coniferous		Coniferous		Non-coniferous		Coniferous		
	Shade tolerant	Slow growing light demanding	Slow growing shade tolerant	Light demand.	Shade tolerant	Slow growing light demand.	Slow growing shade tolerant	Light demand.	Spruce	Spruce and pine
Forest unit code / Impact category	3B	3E	3F	4A	3B	3E	3F	4A		
CC, total	-766	-1080	-1080	-771	-759	-1053	-1054	-758	-766	-806
CC-F	18.8	15.9	13.8	20.1	15.5	27.9	26.5	20	11.4	11
CC-B	-785	-1096	-1095	-791	-777	-1085	-1085	-779	-778	-817
CC-LULUC	0.22	0.38	0.45	0.24	2.2	4.16	4.16	0.21	0.91	0.56
OD	3.84	3.18	2.76	4.03	3.13	5.61	5.36	4.13	2.28	2.2
IR	1.15	0.97	0.84	1.25	0.87	1.57	1.48	1.22	0.69	0.67
POF	0.11	0.14	0.15	0.12	0.57	1.07	1.06	0.11	0.27	0.18
PM	5.56	4.92	4.32	6.17	7.81	12.9	12.2	5.87	5.5	5.98
HT-NC	1.96	3.01	3.42	2.22	14.1	26.6	26.4	2.05	6.16	3.83
HT-C	1.08	1.47	1.6	1.23	6.11	11.4	11.3	1.16	2.62	1.65
AC	98.6	81.4	69.6	105	64.9	117	110	101	58.6	59.9
Eu-F	1.5	2.41	2.82	1.64	13.3	25.2	25.1	1.43	5.58	3.45
Eu-M	34.8	28.7	24.8	36.5	29.3	52.9	51.1	35.3	23.2	22.9
Eu-T	0.38	0.3	0.25	0.39	0.21	0.37	0.35	0.38	0.21	0.23
EcoT-F	218	203	184	241	307	580	550	238	180	152
LU	43.1	60.5	43.8	92.8	74.9	109	162	184	36.8	50
WU	2.53	3	3.06	2.96	7.47	14	13.8	1.61	4.15	2.66
RU-F	267	223	193	286	205	369	350	284	157	153
RU-M&M	0.32	0.31	0.28	0.38	0.29	0.62	0.51	0.38	0.19	0.15

Abbreviations and units [] per m^3 of raw wood: Climate change (CC), total; CC Fossil (CC-F); CC, Biogenic (CC-B); CC, Land use and LU change (CC-LUCUC) [kg CO_2 eq]; Ozone depletion (OD) [mg CFC11 eq]; Ionising radiation (IR) [kBq U^{-235} eq]; Photochemical ozone formation (POF) [kg NMVOC eq]; Particulate matter (PM) [10^{-7} disease inc.] ; Human toxicity, non-cancer (HT-NC) [10^{-7} CTUh]; Human toxicity, cancer (HT-C) [10^{-8} CTUh]; Acidification (AC) [m mol H^+ eq]; Eutrophication, freshwater (Eu-F) [g P eq]; Eutrophication, marine (Eu-M) [g N eq]; Eutrophication, terrestrial (Eu-T) [mol N eq]; Ecotoxicity, freshwater (EcoT-F) [CTUe], Land use (LU) [1000 Pt]; Water use (WU) [m3 depriv.]; Resource use, fossils (RU-F) [MJ]; Resource use, minerals and metals (RU-M&M) [g Sb eq].

There is a considerable variation between the different forest units, e.g., for climate change, fossil, the impact ranges from 11 kg CO_2e for the European ecoinvent dataset on spruce and pine, 13.8 kg CO_2e for the Austrian 3F forest unit to a maximum of 27.9 kg CO_2e for the Slovenian 3E forest unit - also between Austria and Slovenia, where Slovenia non-coniferous forest units 3E and 3F have considerably overall higher impacts than Austria.

Normalised (clustered column, left axis) and weighted (clustered column, right axis) results are depicted in Figure 3, which show that the selected datasets for Austria and Slovenia have higher environmental impacts than the reference datasets from ecoinvent.

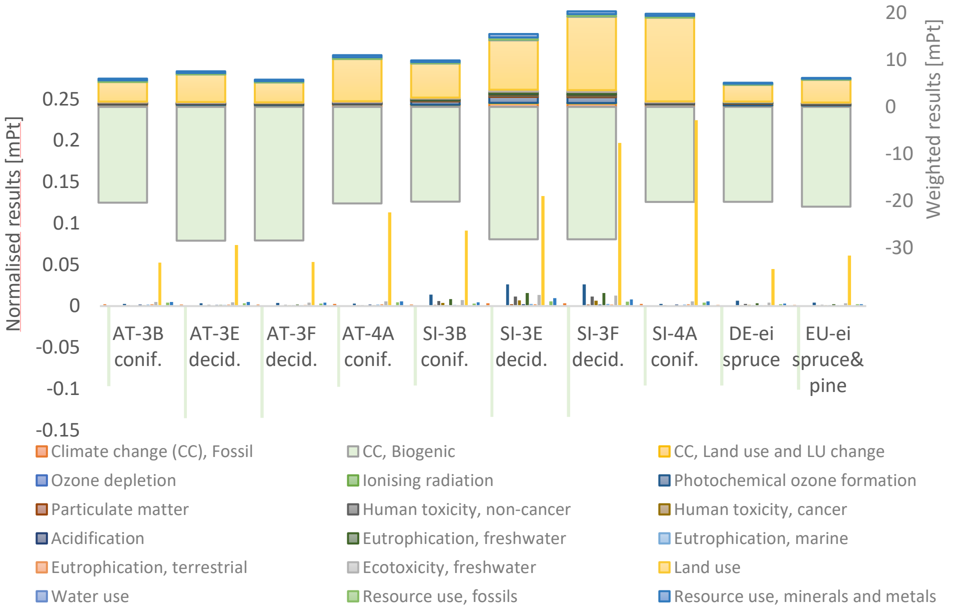

Fig 3. Normalised results (clustered column, left axis) and weighted results (stacked, right axis).

Land use is a hot spot; however, interestingly, the climate change sub-category, land use and land use change, is not so important. For all investigated forestry datasets, the weighted total impact is negative due to the amount of carbon stored in the wood.

4 Conclusion and further work

The environmental impact of Slovenian and Austrian forestry is most important for its occupation of land. The harvesting (cutting) of trees is a main contributor to emission to air. However, this is offset by the ability of trees to store carbon from CO_2 in the atmosphere. The investigated database (EFO-LCI) could provide life cycle inventory data for Slovenian and Austrian forestry and importing countries for other LCA needs, for example, LCAs in the construction or biorefinery sectors and for benchmarking purposes.

The EFO-LCI is static in nature. However, temporal variation may play a crucial role as shown by the example of Slovenian roundwood production, which almost tripled between 1995 and 2016 [17]. Such a massive surge can only be a consequence of significant changes in forest management practices. In view of a continued intensification of wood use to be expected in the future, further research could investigate the effects of changed rotation times, intervention frequencies, and distributions of forest units on biogenic carbon flux dynamics and other impact categories, such as land use and fossil climate change. This is a particularly relevant question for consequential LCA research addressing the potential of bio-based products for climate change mitigation.

Acknowledgement: The authors gratefully acknowledge the European Commission for funding the InnoRenew project (Grant Agreement #739574) under the H2020 Widespread Teaming programme and the Republic of Slovenia for investment funding from the Republic of Slovenia and the European Union's European Regional Development Fund and the Slovenian and Austrian research funding organisations for the research grant no. BI-AT/20-21-006.

References

1. G. Cardellini, T. Valada, C. Cornillier, E. Vial, M. Dragoi, V. Goudiaby, V. Mues, B. Lasserre, A. Gruchala, P. K. Rørstad, M. Neumann, M. Svoboda, R. Sirgmets, O. P. Näsärö, F. Mohren, W. M. J. Achten, L. Vranken, and B. Muys, Environ. Manage. **61**, 1031 (2018)
2. European Commission (EC) *Commission recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations*. 2013/179/EU. Brussels (2013)
3. United Nations, Chapter XXVII - Environment - 7.d; *Paris Agreement* 2015. United Nations Treaty Collect. Secretary-General, United Nations (2021):
4. IPCC, in *Glob. Warm. 1.5°C. An IPCC Spec. Rep. Impacts Glob. Warm. 1.5°C above Pre-Industrial Levels Relat. Glob. Greenh. Gas Emiss. Pathways,* edited by P. R. S. Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, et al. (2018)
5. Eurostat, *Greenhouse gas emission statistics - carbon footprints,* in Statistics explained (2021)
6. P. Leskinen, G. Cardellini, S. Gonzalez-Garcia, L. Gustavsson, E. Hurmekoski, R. Sathre, J. Seppälä, C. Smyth, T. Stern, and H. Verkerk, in *From Sci. to Policy 7*, edited by L. Hetemäki (European Forest Institute, 2018) Doi: 10.36333/fs07
7. Material Economics. *EU Biomass Use In A Net-Zero Economy - A Course Correction for EU Biomass* (2021)
8. EEA, *Land cover 2006 and changes country analysis* (Austria and Slovenia) (2011)
9. Eurostat, *Land use overview by NUTS 2 regions* (LAN_USE_OVW) (2018)
10. BFW, *Waldinventur 2007/2009.* Austrian Research Centre for Forests, Vienna (2011).
11. *SiStat database*. Statistical Office of the Republic of Slovenia (2020).
12. Österreichische Energieagentur. *Holzströme in Österreich 2019* (2021).
13. G. Wernet, C. Bauer, B. Steubing, J. Reinhard, E. Moreno-Ruiz, and B. Weidema, Int. J. Life Cycle Assess. 21, 1218 (2016)
14. D. Cambria and D. Pierangeli, J. Clean. Prod. **23**, 37 (2012)
15. EN15804+A2. *Core rules for the product category of construction products* (2019)
16. PRé Consultants. *SimaPro v 9.1*. (2020)
17. FAOSTAT, *Forestry production and trade* (2021)