Environmental and economic assessment of using wood to meet Paris Agreement greenhouse gas emission reductions in Slovenia

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Abstract. More than one hundred ninety nations, including the European Union, have signed the Paris Agreement to limit the temperature increase to 1.5 °C above pre-industrial levels. Meeting these conditions requires a steep decline in greenhouse gas (GHG) emissions by the year 2030 and zero GHG emissions by 2050. In this study, we investigated the role that wood products can play within Slovenia to reach the 2030 goal of a 55 % reduction in GHG, as compared to 1990 levels. Slovenia, with over 58 % forest cover, is well-positioned to utilize wood products to meet these climate goals. However, questions exist on how increased tree harvesting and local production, and the use of wood products contribute to replacing fossil-based materials and to lower lowering GHG emissions. To better understand the importance of wood products to GHG emission reduction, this study aimed to present a model showing how the forest-based value chain (including construction) could help reach the Paris Agreement goals. We investigated the associated environmental impacts and their related economic costs. The results indicated that Slovenia could reach the 55 % GHG emission reduction goal within 2030 through increasing tree harvesting and using these resources to increase the number of durable wood products produced within Slovenia that store carbon for long periods and substitute for other high GHG emitting materials. However, realizing these potential reductions would rely on the building industry within Slovenia to replace fossil- and mineral-based materials with wood products.

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) [1]. Meeting these conditions requires a steep decline in greenhouse gas (GHG) emissions by the year 2030

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(with a 55 % reduction goal) and zero emissions by 2050 [2]). Slovenia emitted 14.2 million t CO_2e in the reference year 1990, but 17 million t CO_2e in 2019 (total excluding memo items) [3] and therefore would need to reduce the GHG emissions by 10.6 million t CO_2e by 2030. Given the availability of timber within Slovenia, the country is well-positioned to utilize wood products to meet these climate goals.

Specifically, forests in Slovenia cover 58 % of the total area with 1 million ha of economic value [4]. From 2016 – to 2020, the annual harvest in Slovenia accounted for an average of 5.3 million gross cubic meters (m^3) of timber removal. The production of wood-based products during this period averaged 4.8 million m^3, with a majority of 75 % being the production of industrial wood. Within industrial wood products' manufacturing, 78 % of the timber utilized came from softwood species. The largest use thereof, 75 %, was as sawlogs and veneer. Of hardwoods, the largest use, 56 %, was for heating. In recent years, the consumption of roundwood was, on average, 3 million m^3, for which an average of 2 million m^3 was represented by industrial wood [5].

Given these current harvesting and utilization rates, a key question is, how local production and use of wood products and increased tree harvesting contribute to replacing fossil-based materials and lowering GHG emissions. Today, logs harvested in Slovenia are mainly used as firewood or are exported, as the necessary processing capacity within Slovenia is missing to transform them into higher-value wood products (e.g., building materials and composites). Given this situation of low-value utilization and exporting, the Wood Industry Directorate of the Slovenian Ministry of Economic Development and Technology (MEDT) has set the following goals [6]:

- To process 3 million m^3 roundwood in Slovenia each year (today: 1.8 million m^3)
- To increase turnover to at least EUR 2.5 billion per year (from EUR 1.2 billion)
- To increase the added value in the wood sector to the level on par with the average for other Slovenian processing industries
- To increase the number of employees in the wood industry to 18,000 – 20,000

In close cooperation with MEDT, this research investigated optimizing the economic and environmental (carbon footprint) impact of the use of 3 million m^3 of timber in Slovenia up to 2030 (7 years, from the end of 2022). To better understand the importance of wood products in reducing GHG emissions, this study aimed to present a model showing how the forest-based value chain, including construction, could help reach the Paris Agreement goals. We investigated the associated environmental impacts, with a focus on climate change and the related economic implications.

2 Methods and data

To investigate optimizing the economic and environmental (carbon footprint) impact of the Slovenian wood-value chain, the study first extrapolated current wood production patterns and volume to reach the 3 million m^3 wood production goal. In doing this, each type of wood product group was defined. Then a calculation of expected revenues for the different product groups was performed. Once determined, an optimization model was used to obtain optimal quantities of wood for different product groups to maximize expected revenue. Once the volumes of each product group were optimized, an estimation of carbon footprints and average GHG savings (substitution factors) was determined for individual products within each product group. Finally, the optimization model was then used to calculate expected revenue and potential total GHG savings in three scenarios based on different levels of state contribution to investment: basic; higher prices; and advanced. Lower investment (basic) assumed just enlarging the volume of processed wood. Intermediate investment (higher prices) adds technological improvement to achieve better prices of currently manufactured products. Advanced investment changes the structure of production (e.g., more high-end products, biorefining, etc.).

2.1 Product groups

Twelve wood-based product groups were identified as a result of the discussion between the MEDT and the researchers based on the most common engineered wood products currently used in construction, pulp and paper, bio-refining, and energy sectors. In each group, wood-based products were compared with non-wood-based alternatives possessing similar performance properties. Table 1 shows an example of a product group and one of the individual wood products and substitution materials for use ventilated roofs or ventilated façades. The rest of the product groups and individual products are shown in detail in the supplementary materials.

Tab 1: Example of selected products in Group 1, their descriptions, and calculated quantities. (*Non-wood-based products chosen for comparison study).

Product group No	Product group Name	Product Name	Product Description	Volume [m^3]	Mass [kg]
1	Sawn wood	Wooden batten	b/h = 5/5 cm, L = 100 cm	0.0025	1.05
		*Aluminium "U" channel profile	b/h/t = 50/50/3 mm, L = 100 cm	0.00043	1.17
		* Steel "U" channel profile	b/h/t = 50/50/2 mm, L = 100 cm	0.00029	2.26

For each of the product groups, expected revenues (market prices of materials, intermediate products, and products) were collected directly from wood products companies and re-sellers (personal communication) and online sources, as needed.

2.2 Optimization and carbon footprint

To optimize the distribution of wood and associated residual materials according to the constraints of MEDT, a linear programming (LP) mathematical model was formulated to characterize the flow of resources among different product groups. The model is presented in the Supplementary material. As an input, the model receives the available roundwood biomass, the various product groups, and their most important characteristics. The following characteristics were considered: resources to be allocated; the ratio of residuals after processing the input; volume needed for a unit of product; and revenue for a unit of product. Solving this model with an optimization tool resulted in the optimal distribution of the primary and residual resources between the product groups.

The carbon footprint of the wood-based products within the defined product groups and their non-wooden counterparts was assessed using standardised life cycle assessment methods (ISO 14040) with the use of ecoinvent v 3 [7] to provide life cycle inventory data. A cradle-to-gate assessment was performed, starting with the provisions of fuel and equipment needed for forestry/timber harvesting activities, building and maintenance of forest roads, and processing activities (e.g., debarking and sawing) to result in the finished products. For building materials, this equals an A1-A3 scope according to EN 15804+A2:2019 [8]. The chosen impact assessment method was the EU recommended Environmental Footprint/EN 15804:A2:2019[†], as this procedure includes the most up-to-date characterisation factors for climate change according to IPCC 2013 [9]. The potential GHG

[†] Compared to the Environmental Footprint, the EN 15804 (2019) differs for the characterisation factors (CFs) of biogenic CO_2 uptake and emissions, which were set in the EN 15804 standard as equal to "-1" (CO_2 uptake) and "+1" (CO_2 release).

savings were then calculated as the difference in the carbon footprint of the selected wood-based and non-wooden products within each product group, multiplied by the volume of wood (knowing the volume of wood in each representative wooden product) that the Model allocated to each product group (substitution effect). Carbon storage potential was calculated per each product group from the therein allocated wood volume (sequestration effect). The final result was the addition of all the product groups' potential substitution and sequestration effects.

2.3 Data used and assumptions

The investment costs were set directly by MEDT, as medium-term Slovenia's budget projections, combined with expectations from the European Structural and Investment Funds (ESIF) contributions. Conversion factors for roundwood biomass were obtained from UNECE/FAO [10]. Ecoinvent [7] was used (unless for the group biorefinery product [11]) to calculate the carbon footprint of wood products and their non-biobased substitutions. Prices used in the calculations for potential revenue are from November 2020 and underlie temporal variation. Especially in 2021, the prices have increased significantly [12].

3 Results

The model allocated 2.7 million m^3 raw wood in the case of basic (B) and higher price (HP) scenario and 2.8 million m^3 in the advanced (A) scenario. Figure 1 shows the breakdown of the different product groups and residual streams.

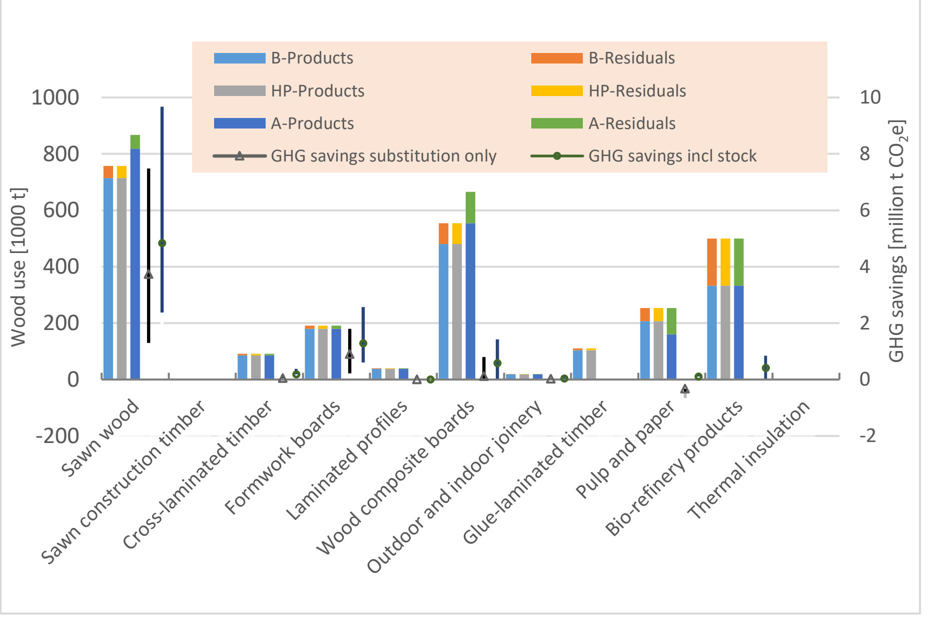

Fig. 1: Intermediate results: Wood flows (left axis, stacked column) for three different scenarios and GHG savings (right axis, markers with min, max lines) into the different product groups.

On the left axis, the wood flows (stacked column) with products and residuals on the top are depicted. Sawn wood, wood composite plates, and biorefinery products are allocated the highest amount of roundwood. Sawn construction timber and wood wool receive no allocation of roundwood in the model because their potential price was lower than all the other product groups. The basic and high price scenarios were equal in terms of wood allocation, while the advanced scenario allocated more roundwood to sawn wood and wood composite boards. On the right axis in Fig 1, the GHG savings, excluding and including stock effects for each of the product groups are shown. The sawn wood product group showed the highest GHG savings (3.7 million tonnes CO_2e) for substitution of other materials. When including stock effects, the GHG savings increased to 4.8 million tonnes CO_2e. For the other product categories, the GHG savings were more moderate. For those product categories where there is no wood flow, the GHG savings are naturally non-existent. Figure 2 shows the final GHG savings' results.

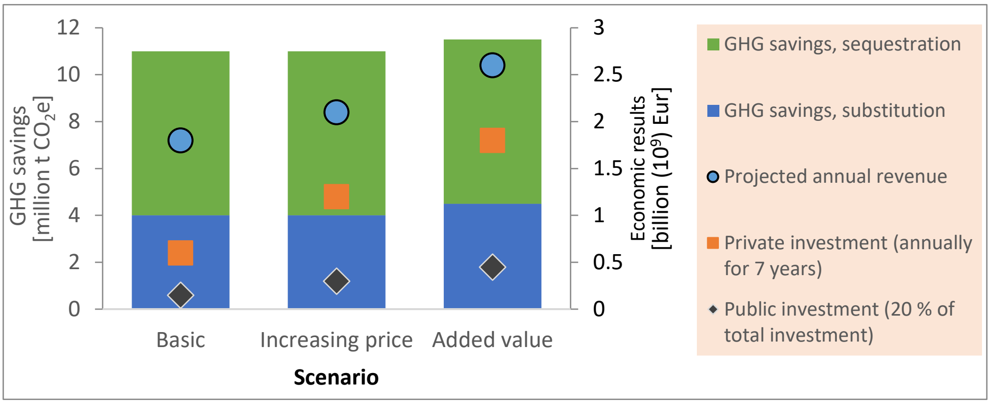

Fig. 2: Environmental (left axis, stacked column) and economic (right axis, markers) results

The final environmental results here expressed as GHG savings due to substitution and sequestration, are relatively equal for the three different scenarios, due to the same amount of wood entering the model, starting with 4 million tonnes per year (after 2030) of substitution and 7 million tonnes of CO_2e stored in stock for the basic scenario. The higher price scenario does not notably change the environmental results. In the added value scenario, substitution savings rose to 4.5 million t CO_2e while the sequestration effect remained the same which resulted in a total of 11.5 million t CO_2e savings compared to the fossil alternatives for all nine product groups with allocated roundwood and residual flow.

The economic results, calculated by the model for the three mentioned scenarios, also indicated that only the "advanced" scenario with EUR 2.6 billion achieves the goal of the MEDT of at least EUR 2.5 billion projected revenue from 3 million m^3 processed wood in 2030. In the "basic" and "higher prices" scenarios, the projected revenue reaches EUR 1.8 billion and EUR 2.1 billion, respectively.

4 Discussion and limitations

Primary production investment leads to more economic revenue and has the potential for huge potential GHG savings (substitution and sequestration effects). However, the results indicated that both an increase in the volume of wood processed and transformation in the structure of the industry (product groups) are necessary to meet the MEDT goals. Furthermore, the described model does not evaluate if wood-based textiles could replace cotton and fossil-based textiles. This type of analysis should be considered in future models as other studies expect substitutions with wood-based feedstock in these sectors to provide a large greenhouse gas savings [13]. The economic results also have not accounted for European carbon markets (ETS system) where the emission of CO_2 into the atmosphere from several sectors are traded. These markets were not considered, as currently the non-ETS sectors cannot trade saved CO_2 emissions. The price for emission of 1 tonne of CO_2 in 2020 was about EUR 25, however, in Sept 2021, the price for 1 tonne rose to approximately EUR 60/tonne and is expected to further increase as the EU “Fit for 55” [14] and the “Green deal” [15] become realized. GHG savings from sectors other than ETS-included are expected to become monetised with these policy changes. Monetization would further improve the economic soundness of wood processing facility investments in Slovenia. However, the calculations in this study did not account for external costs of climate change, which in Germany were calculated to be between 201 and 690 Euro/tonne CO_2 in 2021 [16]. Such cost calculations are not known in Slovenia but are relevant for policymakers as they reflect the societal cost of CO2 emissions.

The study is a bottom-up study, with a starting point on the building material levels. The market acceptance in Slovenia and export markets should be further investigated.

The method applied is cradle-to-gate LCA, where the use and end of life are not included, as these are well into the future and for most products investigated end of life is well after the year 2050.

The substitution effects are calculated with a static approach at the time of the study and do not take into account that the rest of the building and material sector also need to reach the Fit for 55 % goal within the year 2030 and net climate neutral in 2050. This means that the substitution effects are expected to be reduced in the future. However, the wood sector is also expected to reduce its fossil carbon footprint, such that in sum the future substitution effects are encumbered with large uncertainty but expected to decrease in absolute numbers.

The carbon uptake by growing trees has been calculated based on the biogenic carbon in the wood products in line with the Ecoinvent database employed. Fluctuations in forest carbon storage, especially below ground like in soil have not been investigated. We have assumed that the forestry, where the wooden building materials are coming from, are sustainably managed.

5 Conclusion and outlook

This study aimed to investigate how the forest-based value chains (including construction) could help reach the Paris Agreement goals. We maximised the expected revenue of three different scenarios with 12 different product groups and modeled the associated environmental impacts (carbon footprint). Wood-based products store carbon for long periods and substitute for other high GHG emitting materials, thereby creating the potential for keeping GHG away from the atmosphere. The results indicate that Slovenia could reach the 55 % GHG emission reduction goal within 2030 using harvested wood resources to increase the number of durable wood products produced within the country. However, a realisation of these potential reductions through the use of wood products relies on the industry growth and restructuring within Slovenia, where fossil- and mineral-based material consumption would need to be replaced with wood and other natural, renewable material-based products. The required (high) investment in the wood processing industry is expected to create increases in GDP (6 %) and employment (17 %) growth by 2030 but requires further research to verify these levels.

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References

1. United Nations, Chapter XXVII - Environment - 7.d; *Paris Agreement* 2015 (2021)
2. IPCC, *Global Warming 1.5°C. An IPCC Special Report.* (2018)
3. Eurostat, *Greenhouse gas emissions by source sector*, [ENV_AIR_GGE] (27 Aug 2021)
4. Slovenia Forest Service, Poročilo zavoda za gozdove Slovenije o gozdovih za leto 2020 [SFS Annual Report 2020] (2021)
5. SiStat, *Statweb*: https://www.stat.si/StatWeb/en (17. Sep 2021)
6. Ministry of Economic Development and Technology, Slovenska industrijska strategija [*Slovene Industrial Strategy*] 2021-2030 (16 Sept 2020)
7. G. Wernet, C. Bauer, B. Steubing, J. Reinhard, E. Moreno-Ruiz, and B. Weidema, Int. J. Life Cycle Assess. 21, 1218 (2016)
8. EN 15804+A2, *Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products* (2019)
9. Fazio, S. Castellani, V. Sala, S., Schau, EM. Secchi, M. Zampori, L., *Supporting Information. to the characterisation factors of recommended EF Life Cycle Impact Assessment methods*, European Commission, Ispra, (2018), doi:10.2760/671368
10. UNECE/FAO. *Forest products conversion factors for the UNECE region*. DP49, Geneva, (2010)
11. Y. Liao, S.-F. Koelewijn, G. Van den Bossche, J. Van Aelst, S. Van den Bosch, T. Renders, K. Navare, T. Nicolaï, K. Van Aelst, M. Maesen, H. Matsushima, J. Thevelein, K. Van Acker, B. Lagrain, D. Verboekend, and B. F. Sels, Science (80). 1385 (2020)
12. Eurostat, *Input prices for materials – Residential buildings* [sts_copi_m] (2021)
13. S. Rüter, F. Werner, N. Forsell, C. Prins, E. Vial and A.-L. Levet, *ClimWood2030 – Climate benefits of material substitution by forest biomass and harvested wood products: Perspective 2030* (Braunschweig, 2016)
14. European Commission, 2021 *'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality*, COM/2021/550 final URI: CELEX:52021DC0550
15. European Commission, 2019, The European Green Deal, COM(2019) 640 final. URI: COM:2019:640:FIN
16. UBA, *Gesellschaftliche Kosten von Umweltbelastungen,* Dessau, 10 Aug. (2021)