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National Wood Product Material Flow Analysis: PRODCOM Data on Wood Products Supporting Improved Macro-Level Sectoral Assessments in Slovenia

Nacionalna analiza toka materijala za drvene proizvode: podatki PRODCOM-a o drvnim proizvodima koji podržavaju poboljšane sektorske procjene na makrorazini u Sloveniji

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ABSTRACT • *The study investigates the production of harvested wood products in Slovenia by applying the volumetric material flow analysis (MFA) from processed roundwood to secondary product. The study provides the methodological approach for data collection and consistency assessment to support nation-wide wood MFA by complementing FAOSTAT data with selected data categories of PRODCOM data. Consistency between the two datasets was found to be satisfactory, suggesting that the two datasets can together support wood product MFA. However, for PRODCOM to be applied without extensive prior analysis, further methodological improvements of the databases would be required. MFA for Slovenia for the period 1994 – 2021 was carried out to understand pathways and magnitudes of wood flows in Slovenia. The MFA demonstrated that for many secondary products produced in Slovenia, there is clearly a lack of domestic resources (veneer, particle boards, and sulphite chemical and mechanical wood pulp). On the contrary, despite the abundance of the primary resource, few secondary products are made using non-coniferous wood. This research highlights the importance of detailed and accurate wood product data to support the MFA in identifying missed opportunities to create value and/or reduce environmental footprint of the national wood products industry.*

KEYWORDS: *harvested wood products; material flow analysis; PRODCOM database; FAOSTAT Forestry Production and Trade; secondary wood products*

SAŽETAK • *U radu se istražuje proizvodnja artikala od drva posječenoga u Sloveniji, i to volumetrijskom analizom toka materijala (MFA) od prerađene oblovine do sekundarnog proizvoda. Studija donosi metodološki pristup*

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prikljupanju podataka i procjeni konzistentnosti kako bi se podržala nacionalna analiza toka materijala drva dopunjavanjem podataka FAOSTAT-a odabranim kategorijama podataka PRODCOM-a. Utvrđeno je da je konzistentnost između dva skupa podataka zadovoljavajuća, što sugerira da dva skupa podataka zajedno mogu podržati MFA drvnih proizvoda. Međutim, da bi se PRODCOM primijenio bez opsežne prethodne analize, potrebna su daljnja metodološka poboljšanja baza podataka. Volumetrijska analiza toka materijala za Sloveniju za razdoblje 1994. – 2021. provedena je kako bi se razumjeli putovi i veličine tokova drva u Sloveniji. Analiza je pokazala da za mnoge sekundarne proizvode proizvedene u Sloveniji očito nedostaje domaćih resursa (furnira, iverice te sulfite kemijske i mehaničke drvene pulpe). Usto, unatoč obilju primarnih resursa, malo se sekundarnih proizvoda proizvodi od listača. U istraživanju se naglašava važnost detaljnih i točnih podataka o drvnim proizvodima kako bi se podržala MFA u prepoznavanju propuštenih prilika za stvaranje vrijednosti i/ili smanjenje utjecaja nacionalne industrije drvnih proizvoda na okoliš.

KLJUČNE RIJEČI: proizvodi od posječenog drva; analiza toka materijala; baza podataka PRODCOM-a; šumarska proizvodnja i trgovina FAOSTAT-a; sekundarni drveni proizvodi

1 INTRODUCTION

1. UVOD

Environmental aspects of wood use are becoming increasingly important due to the global societal climate and biodiversity crises (Ripple *et al.*, 2020). In Slovenia, forests are sustainably managed using close-to-nature management techniques which avoids clear cuts. On average, around 50 % of the yearly stock increase is harvested (Pisek *et al.*, 2023). Slovenia managed to strengthen the role of forestry, wood processing and the paper industry in the circular bioeconomy in recent years (Ščap and Triplat, 2023). However, there are still unexploited opportunities to substitute carbon intensive materials with wood as well as improve the environmental footprint of industry and construction in line with the Strategy of Development of Slovenia (Šooš *et al.*, 2017), which aims to increase the GDP per CO₂ emission eq. by at least 10 % by 2030. Wood-based carbon storage can offset a significant share of CO₂ emissions in the mid-term (Steel, 2021) if the industry favours the production of long-lasting products, such as construction wood as opposed to using wood for short-lived products like wood fuel or paper products.

Besides the favourable environmental profile of wood use, wood products manufacturing is also an important sector of economic activity. The added value of forestry, primary wood processing, the furniture industry and the paper sector, has accounted for an average of 2 % of gross domestic product in the period 2021–2023 (SORS, 2024). The bottleneck of Slovenian wood-based value chain is the poorly integrated and technologically outdated wood-processing industry (Arnič *et al.*, 2024). Forest-based industry experienced a significant down-sizing in the last 30 years after Slovenia's independence, Slovenia's entrance to the European Union, and change of the currency from tolar to euro. According to the Slovenian Forestry Institute, the share of exported forest wood assortments for industrial processing has been gradually decreasing since

2016. However, it was still estimated to account for 39 % of forest wood assortment production in 2023 (Ščap, 2024). According to available sources, Slovenia exports more wood-based products with a low added value (e.g. roundwood) and less products with high added-value (e.g. furniture) (Sodja, 2018).

Due to the great potential of wood manufacturing in the societal transition towards a low carbon, green, circular society, an understanding of the material flows of wood from harvest to final product is important.

Nation-wide assessments of the environmental potential of wood use in Slovenia have been undertaken a few times in the recent past. Piškur and Krajnc (2009) outlined the roundwood flow from harvest to primary wood product, including waste streams. Schau *et al.* (2023), Kutnar *et al.* (2020), and Tavzes *et al.* (2024) concluded that the lack of data currently represents a limitation for the optimisation of the Slovenian wood-processing chains in environmental, economic, and social terms. While there are several studies available on primary wood products (Ščap, 2020; Ščap, 2024), few analyses of national production of secondary wood products have been carried out.

Internationally, there are studies of life cycle analyses that compare single wood products to non-wooden alternatives abroad (D'Amato *et al.*, 2020), but for upscaling the results of micro level studies to macro scale circularity studies of the sector, more comprehensive data on manufactured products and wood flows is needed. According to existing studies, the coupling of the established methodologies of life cycle and material flow analysis (Barkhausen *et al.*, 2023; Merli *et al.*, 2017) holds promise for more accurate macro-level assessments. For Slovenia, currently available data in the FAO Forestry Production and Trade database (FAO, 2024) includes sawmill products, cellulose/boards and secondary paper products. This dataset does not include secondary wood products, specifically wooden consumer goods and secondary products used in construction. However, these products represent the largest potential of wood as a resource to improve soci-

etal environmental performance, as they are characterised not only by a lower environmental footprint than the alternatives used today but also by high substitution potential (Hurmekoski *et al.*, 2021). Comprehensive material flow analysis of the wood value chain would enable the advancement of the methodology of macro level (regional or national scale) environmental performance of wooden products (Wang and Haller, 2024), which is currently still challenging to quantify due to the lack of comprehensive data on final products (Elia *et al.*, 2017; Hurmekoski *et al.*, 2021).

The present study aims to merge the FAOSTAT (FAO, 2024) and PRODCOM (SORS, 2009) wood product data for the period of 1994 – 2021, evaluate their usability and analyse their data. The first objective was to examine the methodological approach to data collection for nation-wide wood MFA, including an evaluation of accuracy of the identified data sources. The second objective was to undertake an analysis of historical wood MFA for Slovenia to understand pathways and magnitudes of wood flows. The research question of the study was whether PRODCOM data can complement FAOSTAT data for secondary wood product categories and whether the resulting joined dataset can support a national MFA.

2 MATERIALS AND METHODS

2. MATERIJALI I METODE

The paper followed the established methodological guidelines on wood material flow analysis (Marques *et al.*, 2020) as well as the community guidelines for the presentation of results (Pauliuk, 2021). After undertaking the steps for obtaining wood flows and analysing their accuracy, a network of input and output flows of the system defined is presented in Figure 1.

2.1 System boundaries

2.1. Granice sustava

Due to the fact that most products in FAOSTAT and PRODCOM datasets are reported in volumetric units, this was the selected approach for the material flow analysis. Figure 1 shows volumetric flows from harvested wood until the secondary wood products, limiting the system boundaries to the domestically harvested wood. However, it is important to note that intermediate producers could have imported the resource to produce their products and that the wood harvested in Slovenia could have been directly exported, both of which was not observed in this study. However, the producers have to report all manufactured quantities to PRODCOM, even if the products are later exported. The MFA therefore corresponds to quantities produced in Slovenian factories and not to quantities that enter the market or are consumed domestically.

In relation to residues and wastes, only a small part is reported in the framework of PRODCOM/FAOSTAT data, as most residues are used already internally by the manufacturers, either as a filler or as a source of heat/electricity. The known amounts of residues (agglomerates – pellets and briquettes, sawdust, chips and particles) were categorised as ‘wood fuel products’, which includes all wood products intended for the production of heat and/or electricity. It is still important to note that some of these quantities could have also re-entered the material flow elsewhere (for example board manufacturing), but in the present study we did not have the information to what extent and where this occurs.

There are other important factors to consider when observing volumetric flows. Moisture content is generally reduced from harvest to secondary product, going from 20 % of the total mass to as low as 6 % of the total mass in boards or secondary products (FAO, ITTO and United Nations, 2020). The volume of harvested wood in Slovenia is recalculated to 20 % moisture even if it contains more in reality, to ensure comparability of data regardless of the time and weather conditions around the harvest (Geršak, 2021). Below 20 % moisture content, 1 % moisture causes a decrease of 0.25 in volume, meaning that going from a mass content moisture of 20 % to 6 % in the investigated MFA in certain products introduces an error of 3.5 % in the entire MFA. Considering the poor availability of moisture content data and relatively low effect on the volumetric flow, the moisture content was not observed in this study.

Another factor affecting volumetric flows are additives, which are mostly added in the production of paper products and boards. For cellulose products, a recalculation into solid wood required per metric ton of product was made, using conversion factors as provided by Slovenian Pulp and Paper Institute (Table 1). For boards, additives account for about 10 % of total mass. However, as they mostly fill empty spaces in the product (fibreboard, plywood), their effect was neglected in this study.

2.2 Materials

2.2. Materijali

FAOSTAT Forestry data is annually prepared by the Statistical Office of the Republic of Slovenia (SORS) in cooperation with the Slovenian Forestry Institute – SFI (Ščap *et al.*, 2019; Ščap *et al.*, 2020; Ščap *et al.*, 2021) via an analysis of roundwood production structure obtained at the source, which is further broken down to end-uses. The SFI obtains this data annually, directly from stakeholders of the forest-wood chain (Ščap, 2022). PRODCOM, on the other hand, is managed by the SORS and includes the quantities of industrial products (in case of wood products volume,

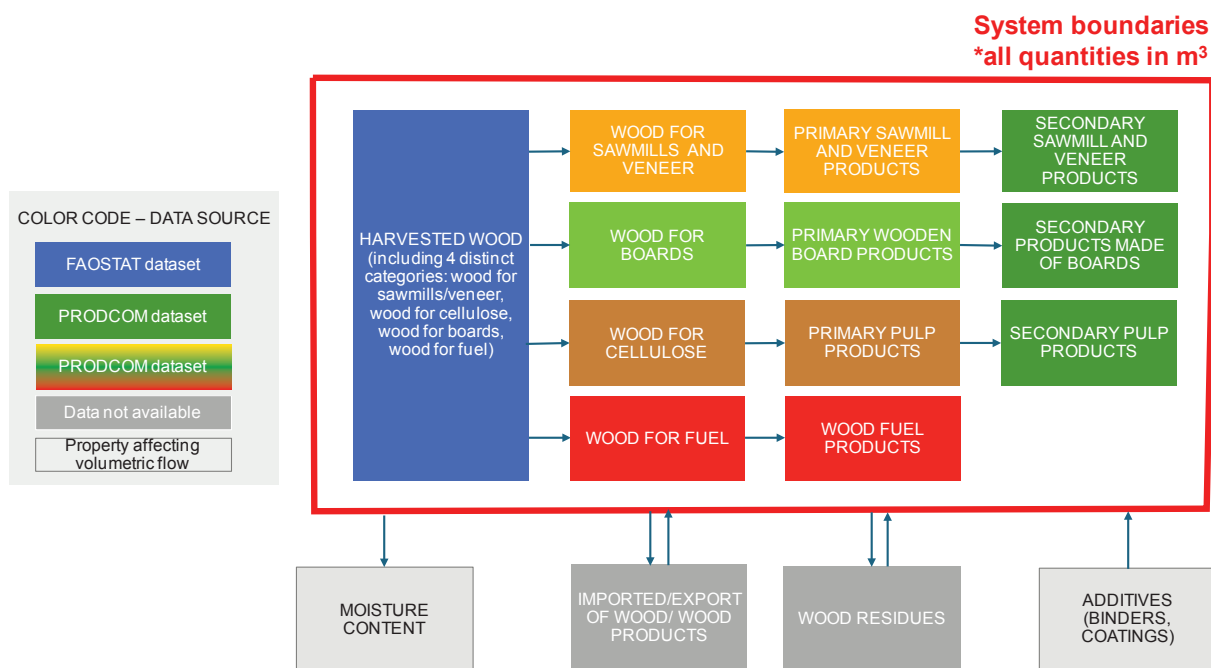


Figure 1 System boundaries of the study (red dotted line) and the dataset used (blue boxes: FAOSTAT, yellow/green/brown/red boxes: PRODCOM)

Slika 1. Granice sustava studije (crvena isprekidana linija) i uključeni skup podataka (plavi okviri: FAOSTAT, žuti/zeleni/smeđi/crveni okviri: PRODCOM)

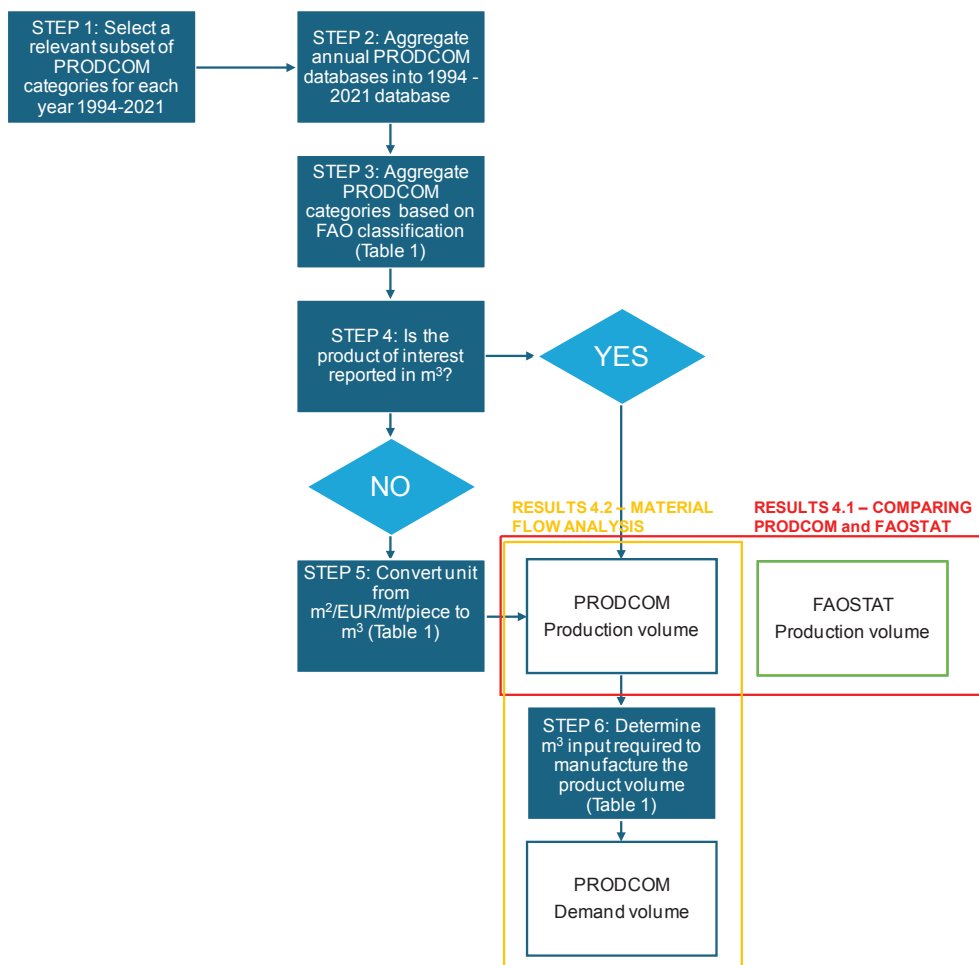


Figure 2 Flowchart illustrating the steps for restructuring PRODCOM databases into the studied FAO wood product categories

Slika 2. Dijagram toka koji ilustrira korake za restrukturiranje PRODCOM-ovih baza podataka u proučavane FAO kategorije drvnih proizvoda

mass, number of items, or the value of items), which have undergone a process of industrial transformation, annually reported by the companies according to EU Regulation (Regulation (EU) 2019/2152 of the European business statistics, 2019).

Data selection, cleaning, aggregation and unit conversion had to be carried out to ensure that the data was robust and comparable with FAOSTAT data. PRODCOM Classification underwent changes during the observed period 1994 – 2021, which means that the categories of registered products were not identical in every year and reconciliation between years was needed.

During data processing, PRODCOM categories were selected (Step 1, Figure 2) and aggregated (Step 2, Figure 2) applying SPSS to categories of wood products,

which existed throughout the observed period and also appeared in the FAO database (Step 3, Figure 2). Then, all categories of interest were converted into the unit of volume of wood (Step 4 and 5, Figure 2), since in PRODCOM one finds not just volumetric units, but also mass (categories of wood chips, particles, flour, consumer products), number of items (consumer products) and value (wooden houses). All products, reported in a unit other than volumetric, were recalculated to m³ product according to forest product conversion factors (FAO, ITTO and United Nations, 2020) and are summarised in Table 1. From the resulting production volume of a specific product, the wood demand for the manufacturing was calculated (Step 6, Figure 2) based on the input – output ratios found in literature (Table 1).

Table 1 List of categorised wood products included in the study (obtained from both FAOSTAT and PRODCOM databases) with corresponding conversion units

Tablica 1. Popis kategoriziranih drvnih proizvoda uključenih u studiju (dobivenih iz baza podataka FAOSTAT-a i PRODCOM-a) s odgovarajućim konverzijskim jedinicama

Category <i>Kategorija</i>	Wood product <i>Drvni proizvod</i>	PRODCOM Reporting unit <i>PRODCOM-ova izvještajna jedinica</i>	Unit conversion / <i>Pretvorba jedinica</i>	
			Factor for converting PRODCOM unit into m ³ <i>Faktor za pretvorbu PRODCOM-ove jedinice u m³</i>	Input required for 1 m ³ product (roundwood in case of primary products and sawnwood/particle boards in case of secondary products) <i>Ulaz potreban za 1 m³ proizvoda (oblovine za primarne proizvode i piljene građe/iverice za sekundarne proizvode)</i>
Primary sawmill and veneer products <i>primarni pilanski i furnirski proizvodi</i>	Coniferous sawnwood <i>piljena građa četinjača</i>	m ³	Already in m ³ <i>već izraženo u m³</i>	1.8 m ³ roundwood / <i>oblovine</i>
	Non-coniferous sawnwood <i>piljena građa listača</i>	m ³	Already in m ³ <i>već izraženo u m³</i>	1.7 m ³ roundwood / <i>oblovine</i>
	Boards with rounded edges or ends <i>piljenice zaobljenih rubova ili krajeva</i>	m ³	Already in m ³ <i>već izraženo u m³</i>	1.8 m ³ roundwood / <i>oblovine</i>
	Veneer <i>furnir</i>	m ³	Already in m ³ <i>već izraženo u m³</i>	1.8 m ³ roundwood / <i>oblovine</i>
Primary pulp products <i>primarni proizvodi od pulpe</i>	Plywood <i>uslojene furnirske ploče</i>	m ³	Already in m ³ <i>već izraženo u m³</i>	2.3 m ³ roundwood / <i>oblovine</i>
	Particle boards <i>ploče iverice</i>	m ³	Already in m ³ <i>već izraženo u m³</i>	1.3 m ³ roundwood / <i>oblovine</i>
	Fibreboard <i>ploče vlaknaticе</i>	m ³	already in m ³ <i>već izraženo u m³</i>	1.7 m ³ roundwood / <i>oblovine</i>
	Mechanical wood pulp <i>mehanička drvena pulpa</i>	t	2.6 m ³ wood per ton <i>2,6 m³ drva po toni</i>	1.04 m ³ roundwood / <i>oblovine</i>
	Sulphite chemical wood pulp / <i>sulfitna kemijska drvena pulpa</i>	t	4 m ³ wood per ton <i>4 m³ drva po toni</i>	1.04 m ³ roundwood / <i>oblovine</i>
Wood fuel products <i>proizvodi za ogrjev</i>	Chips and particles <i>iverje i čestice</i>	kg	150 kg/m ³	1 m ³ roundwood (waste product) <i>1 m³ oblovine (drvnih ostataka)</i>
	Pellets and agglomerates <i>peleti i aglomerati</i>	kg	652 kg/m ³	1 m ³ roundwood (waste product) <i>1 m³ oblovine (drvnih ostataka)</i>
	Wood waste agglomerates <i>aglomerati drvnog otpada</i>	kg	652 kg/m ³	1 m ³ roundwood (waste product) <i>1 m³ oblovine (drvnih ostataka)</i>

Table 1 Nastavak
Tablica 1. Continued

Category <i>Kategorija</i>	Wood product <i>Drvni proizvod</i>	PRODCOM Reporting unit <i>PRODCOM-ova izvještajna jedinica</i>	Unit conversion / <i>Pretvorba jedinica</i>	
			Factor for converting PRODCOM unit into m ³ <i>Faktor za pretvorbu PRODCOM-ove jedinice u m³</i>	Input required for 1 m ³ product (roundwood in case of primary products and sawnwood/particle boards in case of secondary products) <i>Ulaz potreban za 1 m³ proizvoda (oblovine za primarne proizvode i piljene građe/iverice za sekundarne proizvode)</i>
Secondary sawmill and veneer products <i>sekundarni pilanski i furnirski proizvodi</i>	Packing boxes <i>kutije za pakiranje</i>	kg	470 kg/m ³	1.1 m ³ sawnwood / <i>piljenog drva</i>
	Pellets / <i>peleti</i>	no. of items <i>broj komada</i>	0.04012 m ³ /per pellet	1.1 m ³ sawnwood / <i>piljenog drva</i>
	Windows / <i>prozori</i>	no. of items <i>broj komada</i>	18.27 kg/window, density 470 kg/m ³ <i>18,27 kg/prozor; gustoća 470 kg/m³</i>	2.04 m ³ sawnwood for glulam (calculated from yield 48.8 %), 2.08 m ³ glulam for window glulam (calculated from yield 48 %) <i>2,04 m³ piljenog drva za lijepljeno lamelirano drvo (izračunano prema iskorištenju 48,8 %), 2,08 m³ lijepljenoga lameliranog drva za prozore (izračunano prema iskorištenju 48 %)</i>
	Doors / <i>vrata</i>	no. of items <i>broj komada</i>	29.7 kg/door, density 728.9 kg/m ³ <i>29,7 kg/vrata, gustoća 728,9 kg/m³</i>	1.2 m ³ sawnwood / <i>piljenog drva</i>
	Concrete shuttering <i>betonske oplata</i>	kg	450 kg/m ³	1.1 m ³ sawnwood / <i>piljenog drva</i>
	Flooring panels <i>podne ploče</i>	cm	1.5 cm/m ²	1.1 m ³ sawnwood / <i>piljenog drva</i>
	Office furniture <i>uredski namještaj</i>	no. of items <i>broj komada</i>	item weight 39 kg, material density 728.9 kg/m ³ / <i>masa jedinice 39 kg, gustoća materijala 728,9 kg/m³</i>	1.2 m ³ particle board / <i>ploča iverica</i>
	Salesroom furniture <i>namještaj za prodajni prostor</i>	no. of items <i>broj komada</i>	item weight 21.2 kg, material density 728.9 kg/m ³ / <i>masa jedinice 21,2 kg, gustoća materijala 728,9 kg/m³</i>	1.2 m ³ particle board / <i>ploča iverica</i>
	Kitchen furniture <i>kuhinjski namještaj</i>	no. of items <i>broj komada</i>	item weight 33.2 kg, material density 728.9 kg/m ³ / <i>masa jedinice 33,2 kg, gustoća materijala 72,9 kg/m³</i>	1.2 m ³ particle board / <i>ploča iverica</i>
	Bed slats <i>letvice za krevet</i>	no. of items <i>broj komada</i>	item weight 9.6 kg, material density 470 kg/m ³ / <i>masa jedinice 9,6 kg, gustoća materijala 470 kg/m³</i>	1.2 m ³ sawnwood / <i>piljenog drva</i>
	Bedroom furniture <i>namještaj za spavaću sobu</i>	no. of items <i>broj komada</i>	item weight 40.1 kg, material density 470 kg/m ³ / <i>masa jedinice 40,1 kg, gustoća materijala 470 kg/m³</i>	1.2 m ³ sawnwood / <i>piljenog drva</i>
	Dining and living room furniture <i>namještaj za blagovaonicu i dnevni boravak</i>	no. of items <i>broj komada</i>	item weight 38.4 kg, material density 470 kg/m ³ / <i>masa jedinice 38,4 kg, gustoća materijala 470 kg/m³</i>	1.2 m ³ sawnwood / <i>piljenog drva</i>
	Other wooden furniture <i>ostali drveni namještaj</i>	no. of items <i>broj komada</i>	item weight 30 kg, material density 728.9 kg/m ³ / <i>masa jedinice 30 kg, gustoća materijala 728,9 kg/m³</i>	1.2 m ³ particle board / <i>ploča iverica</i>

Table 1 Nastavak
Tablica 1. Continued

Category <i>Kategorija</i>	Wood product <i>Drvni proizvod</i>	PRODCOM Reporting unit <i>PRODCOM-ova izvještajna jedinica</i>	Unit conversion / <i>Pretvorba jedinica</i>	
			Factor for converting PRODCOM unit into m ³ <i>Faktor za pretvorbu PRODCOM-ove jedinice u m³</i>	Input required for 1 m ³ product (roundwood in case of primary products and sawnwood/particle boards in case of secondary products) <i>Ulaz potreban za 1 m³ proizvoda (oblovine za primarne proizvode i piljene građe/iverice za sekundarne proizvode)</i>
Secondary paper and pulp products <i>sekundarni proizvodi od papira i pulpe</i>	Graphic papers <i>grafički papiri</i>	t	3.7 m ³ of roundwood per ton product <i>3,7 m³ oblovine za tonu proizvoda</i>	1.01 m ³ chemical/mechanical pulp <i>1,01 m³ kemijske/mehaničke pulpe</i>
	Sanitary and household papers <i>sanitarni papir i papir za kućanstvo</i>	t	4.9 m ³ of roundwood per ton product <i>4,9 m³ oblovine za tonu proizvoda</i>	1.01 m ³ chemical/mechanical pulp <i>1,01 m³ kemijske/mehaničke pulpe</i>
	Packaging materials <i>materijali za pakiranje</i>	t	4 m ³ of roundwood per ton product <i>4 m³ oblovine za tonu proizvoda</i>	0.01 m ³ chemical/mechanical pulp <i>1,01 m³ kemijske/mehaničke pulpe</i>
*Conversion factors come from FAO, ITTO and UN (2020) report "Forest product conversion factors" and are provided by experts from InnoRenew CoE, Slovenian forestry Institute and Pulp and Paper Institute of Slovenia. * <i>Faktori konverzije potječu iz izvješća FAO-a, ITTO-a i UN-a (2020.) „Faktori konverzije šumskih proizvoda”, kao i od stručnjaka iz InnoRenew CoE-a, Slovenskoga šumarskog instituta i Slovenskog instituta za celulozu i papir.</i>				

2.3 Methods

2.3. Metode

2.3.1 Accuracy of PRODCOM wood product data in relation to FAOSTAT data

2.3.1. Točnost PRODCOM-ovih podataka o drvnim proizvodima s obzirom na podatke FAOSTAT-a

PRODCOM data of wood products were analysed observing the accuracy of the data in relation to FAOSTAT. While undertaking the analysis, historical trends were examined to provide additional insights into the discrepancies where they appear.

The accuracy of PRODCOM data in relation to FAOSTAT data is evaluated by calculating relative percentage difference between wood products volumes of both datasets. The relative percentage difference (RPD) between two product values is calculated by determining the relative difference between both quantities across different measurements or samples and dividing it with a mean value of the quantities (Tornqvist *et al.*, 1985) as described in Eq. 1, while Eq. 2 specifies average relative percentage difference, RPD_A . Based on the visual characteristics of the data, the following cut-off values were used to visualise the result more easily: 20 % RPD as satisfactory, up to 30 % as acceptable, and over 30 % indicates an issue in PRODCOM data accuracy. Low data accuracy means that more research is needed to explain the high RPD, and a further data validation study should be done prior to using PRODCOM data for the MFA.

$$RPD = \frac{|FAOSTAT - PRODCOM|}{\left(\frac{FAOSTAT + PRODCOM}{2}\right)} \cdot 100 \quad (1)$$

For an overall RPD, an average of annual RPD values was calculated for each category of wood products (Eq. 2).

$$RPD_A = \frac{|RPD_{1994}| + |RPD_{1995}| + \dots + |RPD_{2021}|}{No.RPD} \quad (2)$$

2.3.2 Material flow model based on PRODCOM and FAOSTAT data

2.3.2. Model toka materijala utemeljen na podacima PRODCOM-a i FAOSTAT-a

Material flows of the volumes (m³) of wood from roundwood produced to secondary products in Slovenia for the years 1994 and 2021 are demonstrated and analysed with the help of Sankey diagrams. The arrows in diagrams demonstrate the transformations of wood volume from one state to another, whereby the width is proportional to the flow rate.

Sankey diagrams also contain volumes of losses at the production stage, which are calculated based on the difference between the roundwood going into sawmills/pulpmills/fuelwood production and the quantity of products coming out of this process. This difference was considered as production waste.

In cases where primary wood products do not satisfy the demand to produce a given secondary product, the Sankey diagram includes a depiction of 'imported resource'. This is not a representation of the total imported resource in a given year, but rather the minimum import required to produce the secondary products as specified in the PRODCOM database.

Categories of products, which were produced in quantities of less than 10.000 m³, were excluded from

the chart. Additional limitation of the study is that it does not include real data on trade of wood products (import and export). The limitation was mitigated by defining the system boundaries to be domestically manufactured products. The method assumed that the available quantity of (domestically sourced) input material is converted in the manufacturing process, although we are aware that in reality some of the resource is exported and some is imported, depending on the market dynamics.

3 RESULTS AND DISCUSSION

3. REZULTATI I RASPRAVA

3.1 Trends in quantities of wood products for different product groups 1994 – 2021

3.1.1. Kretanje količina drvnih proizvoda za različite skupine proizvoda od 1994. do 2021.

Historical trends in wood product manufacturing are a result of numerous factors, such as natural processes in the forests (e.g. bark beetle infestations, severe weather events, fires) and business environment (government measures, trade dynamics, closures/openings of production lines and other changes in the value chain). Small deviations between PRODCOM and FAOSTAT data are expected, as the sources are different, but large discrepancies might indicate reduced accuracy of PRODCOM data. Therefore, it is important to know in which categories of products PRODCOM data shows good accuracy, as it means that it can effectively complement other datasets in wood MFA.

3.1.1 Manufactured primary sawmill and veneer products

3.1.1.1. Proizvedeni primarni pilanski i furnirski proizvodi

The data on manufactured sawmill and veneer products in Slovenia in the period 1994 – 2021 is presented in Figure 3. PRODCOM data shows a marked increase of sawmill products from the 90s (approximately 600,000 m³) to the present day (1,200,000 m³). Coniferous and non-coniferous sawn wood production was constant until 2007, after which a reduction was observed until 2013, followed by a 3-to-4-fold growth in the last 10 years (Figure 3). The amount of coniferous sawnwood produced in 2021 was much higher compared to 1994 (ca. 1,002,000 m³ vs 258,000 m³). The amount of non-coniferous sawnwood steadily dropped from 160,000 m³ to 53,000 m³ in 2010 and then gradually increased again to 179,000 m³ in 2021. Production of non-coniferous products stagnated after 2013. Boards with rounded edges were no longer existent in the PRODCOM classification after 2016. This might explain a part of the increase in the coniferous sawn wood. Production of veneer was already low in 1994 (23,000 m³), but ceased by 2021, due to the closure of the production lines.

Most product quantities are within 20 % relative difference between both sources (Figure 3), some within 30 %, and the only years that surpass this are 2010 – 2013 (Table 2), with an average of absolute RPD_A of 21 %, so excluding RPD > 30 %, the RPD_A is 13 %.

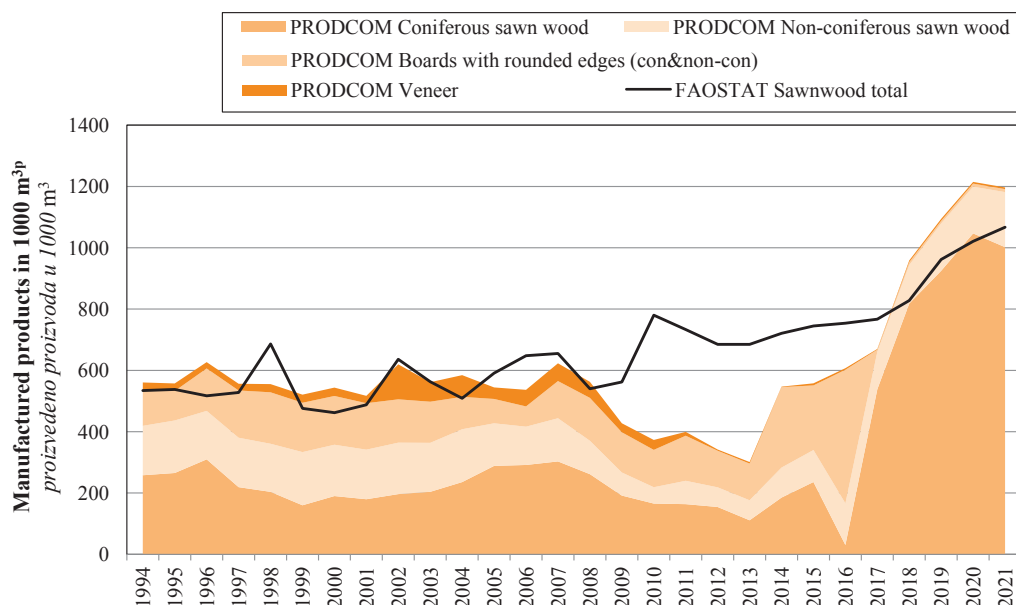


Figure 3 Manufactured primary sawmills and veneer products in 1000 m³ according to FAOSTAT and PRODCOM
Slika 3. Količina proizvedenih primarnih pilanskih i furnirskih proizvoda u 1000 m³ prema podatcima FAOSTAT-a i PRODCOM-a

Table 2 Relative percentage differences in specific years and product categories (gray marks RPD below 20 %, light orange marks RPD between 20 and 30 % and orange marks RPD above 30 %)**Tablica 2.** Relativne postotne razlike u određenim godinama i kategorijama proizvoda (siva označava RPD niži od 20 %, svjetlo narančasta predočuje RPD između 20 i 30 %, a narančasta označava RPD viši od 30 %)

Year Godina	RPD Manufactured primary sawmill and veneer products RPD proizvedenih primarnih pilanskih i furnirskih proizvoda	RPD Manufactured primary pulp products RPD proizvedenih primarnih proizvoda od pulpe	RPD Manufactured primary wooden board products RPD proizvedenih primarnih proizvoda od drvnih ploča	RPD Manufactured wood fuel products RPD proizvedenih proizvoda za ogrjev
1994	5 %	18 %	5 %	71 %
1995	4 %	24 %	6 %	72 %
1996	19 %	23 %	36 %	39 %
1997	5 %	22 %	3 %	6 %
1998	21 %	22 %	16 %	9 %
1999	9 %	18 %	9 %	12 %
2000	16 %	18 %	7 %	24 %
2001	6 %	14 %	3 %	75 %
2002	-3 %	15 %	12 %	68 %
2003	0 %	7 %	14 %	39 %
2004	14 %	18 %	7 %	27 %
2005	-8 %	4 %	15 %	37 %
2006	-19 %	61 %	23 %	1 %
2007	-5 %	93 %	15 %	170 %
2008	4 %	163 %	20 %	150 %
2009	27 %	123 %	14 %	157 %
2010	71 %	4 %	27 %	172 %
2011	59 %	0 %	23 %	172 %
2012	67 %	2 %	23 %	166 %
2013	78 %	7 %	16 %	148 %
2014	27 %	1 %	12 %	152 %
2015	29 %	5 %	14 %	113 %
2016	22 %	2 %	16 %	112 %
2017	14 %	2 %	22 %	81 %
2018	15 %	0 %	27 %	12 %
2019	13 %	0 %	21 %	6 %
2020	17 %	0 %	28 %	15 %
2021	11 %	0 %	29 %	7 %
Average of absolute RPD_A Prosjek apsolutnog RPD_A	18 %	24 %	13 %	75 %

3.1.2 Manufactured primary pulp products

3.1.2. Proizvedeni primarni proizvodi od pulpe

Total volume of wood pulp products according to PRODCOM data (sum of sulphite chemical wood pulp and mechanical wood pulp) grew from 1994 – 2000 and then dropped from around 180,000 tonnes (90 % dry matter) to less than 20,000 tonnes (90 % dry matter) and reached around 80,000 tonnes (90 % dry matter) in 2021 (Figure 4). After 2007, there has been no sulphite chemical wood pulp production in Slovenia due to bankruptcy of the producers, while mechanical wood pulp remained relatively stable at around 20,000 – 40,000 tonne per year until 2007, after which it steadily grew to over 80,000 tonnes (90 % dry matter).

This could be due to the conversion of some of the sulphite chemical wood pulp production lines.

Important to note here is that the data presented in Figure 4 is in metric tonnes (90 % dry matter), while in the following sections the quantities are converted to m³ roundwood equivalent using the factors from Table 1.

The RPD values (Table 2) show that PRODCOM wood pulp production values are well comparable with FAOSTAT, except for the years 2006 – 2009, in which the RPD surpasses 30 %. The abrupt gap between data sources in the years 2006 – 2009 indicates poor accuracy of PRODCOM data in relation to FAOSTAT. This could be due to the time lag of information on quantities. Excluding these few years where the gap is large, there is good coherence in the

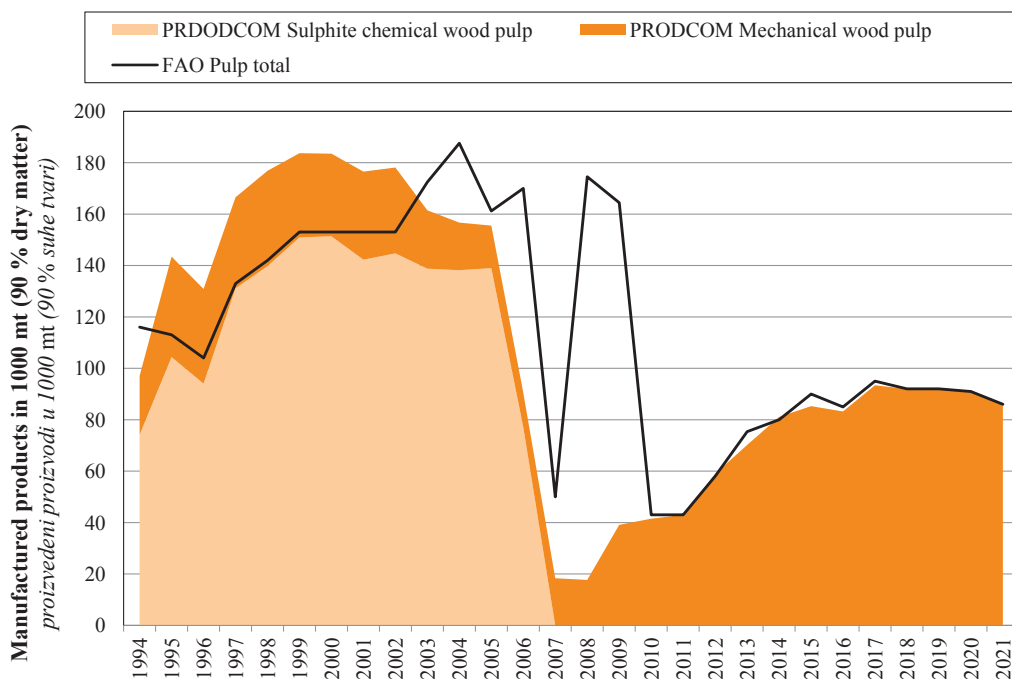


Figure 4 Manufactured primary pulp products in 1000 tonnes (90 % dry matter) according to FAOSTAT and PRODCOM data
Slika 4. Količina proizvedenih primarnih proizvoda od pulpe u 1000 tona (90 % suhe tvari) prema podacima FAOSTAT-a i PRODCOM-a

manufacturing trend of wood pulp products between the two datasets, (RPD_A of 9 %).

3.1.3 Manufactured primary wooden board products

3.1.3.1. Proizvedeni primarni proizvodi od drvnih ploča

PRODCOM data indicates an increase in production of wooden boards from 1994 until 2002 (from 400,000 m³ to 500,000 m³), occurring due to an increase in particle board production (Figure 5). This is followed by a drop in veneer and particle board manu-

facturing until 2005, an increase up to 2008, followed by a sustained decline in manufacturing of veneer and particle boards until 2011 and 2014, respectively, when the production was stopped completely. Plywood production, on the other hand, first peaked in 2009, then decreased and grew again until 2021, similar to fibreboard. Observing the sum of the total volume of boards produced, a decline can be seen from 2007 to 2016 and stagnant levels of production until 2021, when it summed to around 300,000 m³.

Most product quantities are within RPD of 20 % (Figure 5), some within 30 % and the only year when

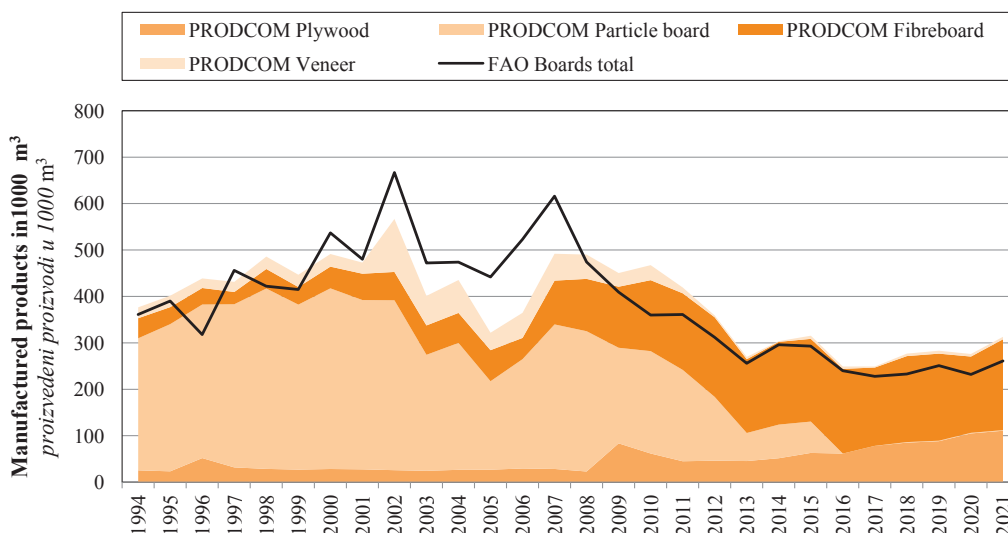


Figure 5 Manufactured primary wooden board products in 1000 m³ according to FAOSTAT and PRODCOM data (stacked chart in orange represents PRODCOM data and black line chart FAOSTAT data)
Slika 5. Količina proizvedenih primarnih proizvoda od drvnih ploča u 1000 m³ prema podacima FAOSTAT-a i PRODCOM-a (složeni grafikon u narančastoj boji predočuje podatke PRODCOM-a, a crni linijski grafikon podatke FAOSTAT-a)

this was surpassed is 1996 (Table 2). The RPDA is 13 %. This indicates good accuracy of PRODCOM data when compared to FAOSTAT for this category of wood products.

3.1.4 Manufactured wood fuel products

3.1.4. Proizvedeni ogrjevni proizvodi

The data on manufactured wood fuel products together with wood residues in the period 1994 – 2021 is presented in Figure 6. The RPDs are the highest in this category (Table 2). The RPDA, which was below 35 % for sawnwood, wood pulp and wooden boards categories, was 75 % for wood fuel products. A particularly large gap between the data sources is noticeable between 2007 and 2017.

It is important to note that FAOSTAT data include an estimation of roundwood used for firewood in households, where people burn wood (often from their private forest) in furnaces to heat their homes. This is not included in the PRODCOM data, as no industrial transformation takes place. Furthermore, PRODCOM classification did not contain an adequate category for reporting of wood pellets until 2016, as the only three available categories were chips and particles, sawdust and wood waste agglomerates. After the introduction of wood pellets in 2015, PRODCOM data becomes more in line with the FAOSTAT data source. On the other hand, categories of sawdust and wood waste agglomerates only appear in PRODCOM until 2006. Therefore, it is assumed that the gap in manufactured wood fuel products between both data sources is due to

classification categories for reporting in the PRODCOM database.

Better coherence between the two data sources is seen in the most recent years. After 2014, RPD becomes acceptable. After 2016, the trends demonstrate an increase in chips and particles production in both data sources – from 100,000 m³ to almost 10-fold in 2021. An increase in production of pellets and agglomerates is recorded from 2017 – 2021 from 50,000 m³ to almost 100,000 m³. In total, since 2019, production of wood fuel has been decreasing slightly due to a small decrease in chips and particles production.

Due to high RPD values, PRODCOM data is less adequate to be used for material flow analysis of wood fuel products until the year 2018 because the classification did not include appropriate categories to account for wood pellets and to distinguish what amount of sawdust, chips and particles and wood waste agglomerates was destined to be used as wood fuel. PRODCOM records the type of industrial transformation but does not distinguish products obtained based on their end use as is needed when considering wood fuel products.

3.2 Material flow analysis of wood products

3.2. Analiza toka materijala drvnih proizvoda

As demonstrated in Section 3.1, FAOSTAT and PRODCOM datasets show good data coherence in the following categories: Sawnwood products 1994 – 2009 and 2016 – 2021, wood pulp products 1994 – 2006 and 2010 – 2021 as well as production of boards for the entire period and wood fuel products 2018 – 2021. For

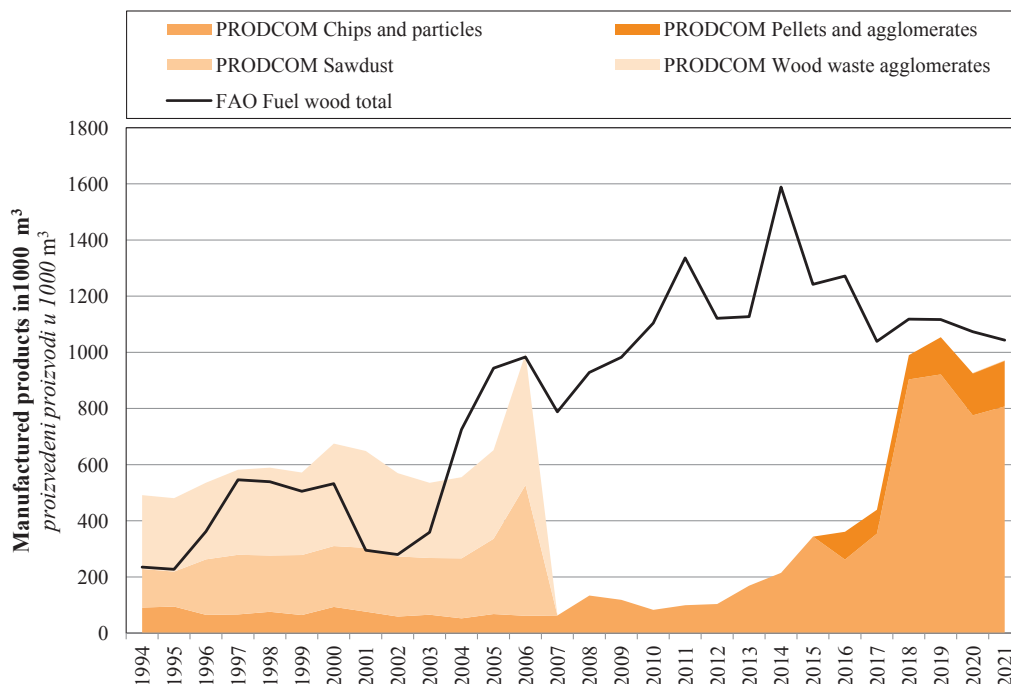


Figure 6 Manufactured wood fuel products in 1000 m³ according to FAOSTAT and PRODCOM data (stacked chart in orange represents PRODCOM data and black line chart FAOSTAT data)

Slika 6. Količina proizvedenih ogrjevnih proizvoda u 1000 m³ prema podatcima FAOSTAT-a i PRODCOM-a (složeni grafikon u narančastoj boji predočuje podatke PRODCOM-a, a crni linijski grafikon podatke FAOSTAT-a)

the years 1994 and 2021 the accuracy of quantities as recorded by PRODCOM was satisfactory when compared to the FAOSTAT data, except for the category of wood fuel in 1994.

The first blue arrows in Figure 7 and 8 represents FAOSTAT data on roundwood produced. After that, PRODCOM data is used to further detail the wood material flow with arrows in yellow, green and red, representing the input volumes of the categories of wood for sawmills, pulpmills and wood fuel products. Further right are the manufactured volumes of intermediate (primary) wood products, which are further processed into secondary wood products (dark green arrows). Grey arrows are not a part of the analysed system boundaries (Table 1), but as they highlight important trends, they are used where the data regarding input and output product do not match. A grey outwards pointing arrow indicates a loss of resource, either due to the efficiency property of the manufacturing process or because export of the preceding resource occurred. A grey inward pointing arrow is used when nationally available resource does not satisfy the production demand; a box depiction of 'import needed to satisfy demand' was therefore included in the flow model.

Figures 7 and 8 show a balanced material flow of wood volume, even though two different data sources have been used. Generally, this indicates that PRODCOM data can complement FAOSTAT data for the selected years and products.

Comparing wood volume flows as demonstrated in Figure 7 and 8, a significant increase in roundwood produced can be noted. This increase is translated mostly into production of coniferous sawn wood and wood fuels. In 1994, coniferous sawn wood and wood fuel products represent a total of 28 % of the total roundwood produced, and in 2021, the same two categories have a share of 51 % of the total roundwood produced. The share of production of cellulose and boards decreased from 44 % in 1994 to 24 % in 2021. Similar trend can be observed in the manufacturing of non-coniferous sawn wood, which represented a share of 8 % of the total roundwood produced in 1994 and 5 % of roundwood produced in 2021. The complete cessation of the production of particle boards and sulphite chemical pulp is also evident. Particle boards decreased from 15 % of total roundwood produced in 1994 to zero in 2021, and sulphite chemical pulp decreased from 12 % of total roundwood produced to zero in 2021. On the other hand, more fibreboard, plywood and mechanical wood pulp were produced. All these products were not produced at all in 1994, but in 2021, and the share of volume quantities of these products in relation to total roundwood produced was 5 %, 3 % and 6 %, respectively.

Although the study did not include import and export of products, certain observations can be made

based on wood flows and differences in quantities when industrial transformations occur. In 1994, FAOSTAT data on produced roundwood plus is lower than the demand based on the primary products recorded by PRODCOM. This means that a part of the resource must have either been imported from abroad, or production waste was used as input. For both parameters, data was not easily attainable to be included in this study. However, as the amount of waste seen in the flow diagram can potentially cover this demand, the reuse of waste streams was considered to be a more likely scenario. In 2021, roundwood produced as per FAOSTAT and PRODCOM database data on production of goods match well, meaning that the domestic roundwood satisfies domestic demand for production of primary products.

Based on the differences in quantities between the secondary products produced and the available primary product used as a resource, we could determine where importing resource was needed to fulfil the resource demand for secondary product production. In 1994, this was the case with pulp, where 187,000 m³ had to be imported (10 % of the total roundwood produced), which increased to 666,000 m³ in 2021 (17 % of the total roundwood produced). Furthermore, in 2021, import of particle boards of 102,000 m³ was required to satisfy the demand of the furniture industry, as there was no domestic production of particle boards. Based on the PRODCOM database, currently there is no secondary wood product manufactured in Slovenia that would utilise non-coniferous sawn wood (category of flooring exists but was not shown in the material flow model as the quantities were not significant).

The wood volume flow analysed showed that despite an increase in roundwood produced, the demand for resources has been met less by domestic resources in 2021 than in 1994 as the need for import of particle boards and wood pulp increased.

Beyond the wood flow analyses available before this study, MFA also includes secondary wood products. In 1994, there has been 774,000 m³ of secondary wood products, 587,000 m³ of which have been produced with domestic resources (75 %). In 2021, there have been 1,245,000 m³ of secondary wood products (579,000 m³ of those from domestic roundwood, 47 %). When calculating the amount of secondary products as a percentage of roundwood produced, it is seen that it was 43 % in 1994 and only 15 % in 2021. It is evident that despite the increase in quantity of secondary wood products, they are produced by using less m³ of domestic roundwood than in 1994.

MFA shows that in 2021 Slovenia produced 12,000 m³ of wood that was used in construction, which is only about 0.3 % of the roundwood produced annually in 2021 (in previous years the quantities were

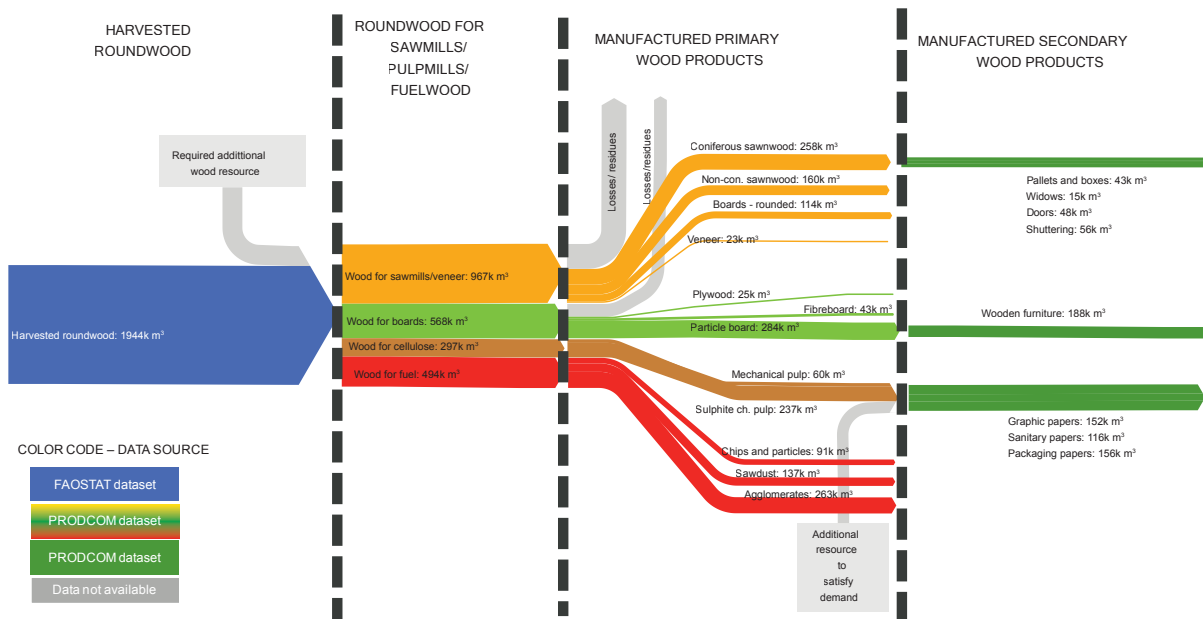


Figure 7 Wood product flow from processed roundwood in blue (FAOSTAT data) to primary products in light green, yellow, red and secondary wood products in dark green (PRODCOM data) for 1994 in 1000m³. The numbers reported refer to the volume of roundwood/manufactured products with the moisture content as is.

Slika 7. Tok materijala drvnih proizvoda od prerađene oblovine označen je plavom bojom (podatci FAOSTAT-a) do primarnih proizvoda označenih svjetlozelenom, žutom i crvenom bojom te sekundarnih drvnih proizvoda označenih tamnozelenom bojom (podatci PRODCOM-a) za 1994. godinu u 1000 m³. Prikazani brojevi odnose se na volumen oblovine/proizvoda s jednakim sadržajem vode.

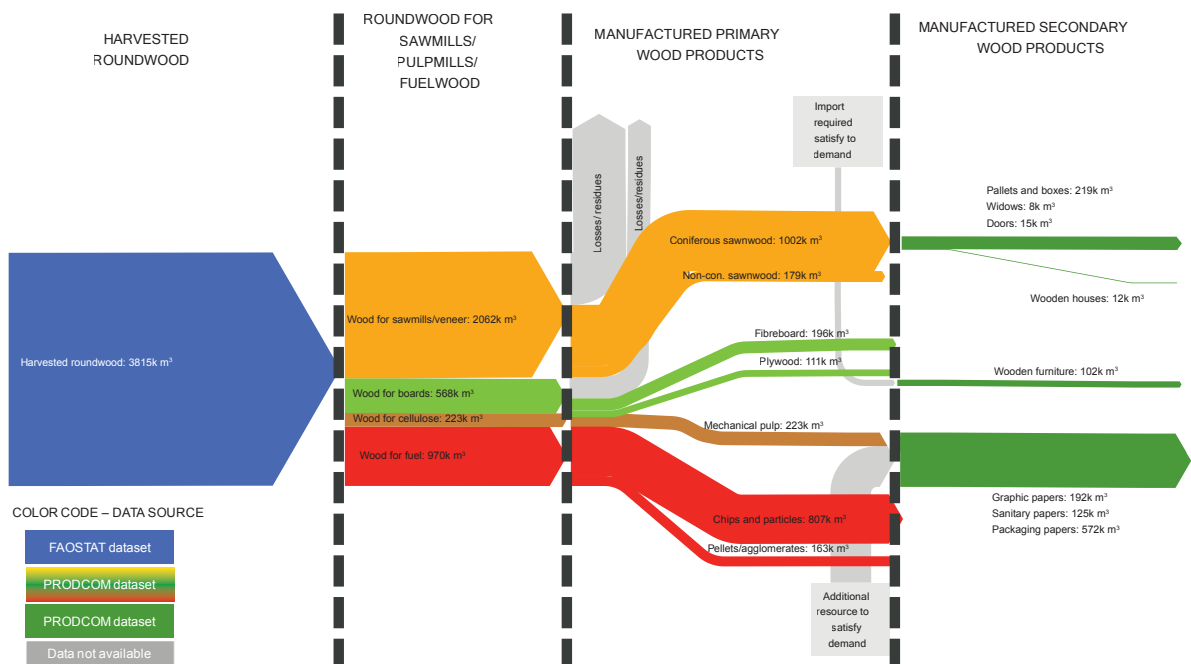


Figure 8 Wood product flow from processed roundwood in blue (FAOSTAT data) to primary products in light green, yellow, red and secondary wood products in dark green (PRODCOM data) for 2021 in 1000m³. The numbers reported refer to the volume of roundwood/manufactured products with the moisture content as is.

Slika 8. Tok materijala drvnih proizvoda od prerađene oblovine označen je plavom bojom (podatci FAOSTAT-a) do primarnih proizvoda označenih svjetlozelenom, žutom i crvenom bojom te sekundarnih drvnih proizvoda označenih tamnozelenom bojom (podatci PRODCOM-a) za 2021. godinu u 1000 m³. Prikazani brojevi odnose se na volumen oblovine/proizvoda s jednakim sadržajem vode.

insignificant). Contrary to the idea of using wood products as an opportunity to store carbon, Slovenia used a quarter of domestic roundwood production for fuel. As the roundwood produced for fuel from private forests was not reported, this number is likely even higher. Considering that wood produced in Slovenia is sustainable and locally produced, failing to (a) scale up wood construction and (b) failing to use domestic resource for long lasting products is environmentally unacceptable. Government should take into account the fact that the share of wood used for fuel in Slovenia is increasing and consider measures to encourage cleaner alternatives for fuel and utilise wood for long-lasting products instead.

4 CONCLUSIONS

4. ZAKLJUČAK

The applied methodology to arrive to a complete dataset of wood products, primary as well as secondary, by complementing FAOSTAT data with selected data categories of PRODCOM data was found to be appropriate to perform the MFA of wood products. The answer to the research question is that PRODCOM data was found out to be of satisfactory quality in most categories of products to complement FAOSTAT data on wood flows with some specificities. Poorer accuracy of PRODCOM has been discovered in the category of sawn wood in the period 2009 – 2016, wood pulp from 2006 – 2009 and selected wood fuel products wood data in general.

One scientific limitation was the lack of data about wood loss and residue streams stemming from the manufacturing of the product. The most accurate way of collecting this additional data would be to make this issue an integral part of PRODCOM questionnaire or by linking it with other existing reports/datasets.

Another shortcoming of PRODCOM is that there are no meta information or disclaimers included with the reported data (such as density, thickness, or sometimes even volume). Without knowing the dimensions of items, errors are possible when converting the number of items into volume of wood.

Another difficulty encountered while analysing PRODCOM data were changes in classification from one year to another. Such changes in the data classification should be avoided in the future as they negatively affect data integrity and hinder longitudinal comparisons. Between the year 1994 and 2021, such changes in PRODCOM occurred at least 5 times, adding complexity to analysis. Effort should be made to internationally harmonise databases such as FAOSTAT and PRODCOM and make available the conversion keys to ease the work of analysts who wish to extract meaningful results from data. In the category of wood fuel products,

more clarity regarding the aggregated category of 'Manufactured wood fuel products' would be welcome. Here, limitations of PRODCOM remain, such as clarity of final use of the categorised products and inclusion of the data of the non-industrially produced wood fuel products (such as firewood and in a smaller degree, coal). Furthermore, it is hard to determine for some products where they re-enter the material flow, whether it is production of boards or wood fuel products.

Despite these noted differences and shortcomings between PRODCOM and FAOSTAT quantities, PRODCOM has been found to be usable for filling the gaps in current knowledge of wood flows in Slovenia. The study demonstrated the type of insights one can acquire using wood product data from PRODCOM and FAOSTAT data jointly to support MFA. It is widely known that the positive environmental impact of wood products can be maximised by using wood for long-lasting applications. However, the MFA of wood products in Slovenia have indicated trends contrary to this logic. The MFA showed that Slovenian forest-based sectors are increasingly less oriented towards the production of secondary, long lasting, high value wood products and positioned more towards the export of unprocessed wood as well as to consumption of wood as an energy source (Arnič *et al.*, 2024; Ščap *et al.*, 2023). Despite a growing production of roundwood, the MFA suggests that for many secondary products produced, there is no resource available domestically, meaning that it is likely imported. Based on the MFA, the opportunities for domestic production in Slovenia could be the lack of industrial capacities and subsequent low volume of production of veneer, particle boards, and sulphite chemical and mechanical wood pulp (Straže *et al.*, 2023; Kropivšek, 2017). Similar is true for the production of non-coniferous sawnwood (Arnič, 2023). According to Slovenian forestry Institute (SFI) data, the share of non-coniferous tree species in the growing stock is 56 % (Pintar *et al.*, 2024), but in Slovenia few high added-value products are made from this wood. Furthermore, a stagnation of non-coniferous wood is evident, despite the fact that non-coniferous wood-based materials can also be used for construction (Ozarska, 1999) and are gaining traction (Straže *et al.*, 2023). The described trends lead to an unexploited opportunity to avoid carbon emissions by replacing other intensive materials with lasting wood products.

The MFA analyses as presented in the study play a key role in the design of effective and sustainable policies in the forest-wood sector, as they provide a comprehensive overview of biomass flows – from harvest to final product (Khan *et al.*, 2024). The present MFA results can support strategic decisions and sustainable environmental policies such as assessing how the forest-wood chain can contribute to climate change

mitigation. Based on the results, government can design measures to increase the use of wood, which enables carbon storage over longer periods. The results of the study will also contribute to the implementation of EU policies, e.g. the New EU Forest Strategy for 2030 (COM (2021) 572 final), which support a sustainable forest-based bioeconomy by promoting the processing of wood into durable wood products as well as the updated EU Bioeconomy Strategy (COM (2018) 673 final), whose main objective is to develop a sustainable and circular bioeconomy that serves Europe's society, environment, and economy. Policy makers should consider the trends observed and introduce measures to stimulate:

- carbon mitigation in wood products through a discouragement of wood fuel products and encouragement of long-lasting products;
- value creation in industry by implementing measures to encourage domestic processing of harvested wood instead of importing secondary wood products, with an initial focus on products that are currently imported to fill gaps in domestic production (particle boards, pulp);
- value creation by implementing measures for processing of non-coniferous wood into high value-added items.

In conclusion, while caution is required when utilising data from PRODCOM together with more established datasets like FAOSTAT, the insights gained are significant. This study highlights the potential of using PRODCOM for MFA, despite the current methodological shortcomings and data limitations. It represents an important step toward a more comprehensive understanding of Slovenian wood flows, providing a foundation for future research and policy development aimed at enhancing the sustainability of the forest-wood sector.

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