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Original Research Article

From the Wood-Based Community to the Circular, Carbon-Neutral and Sustainable Bioeconomy: Recommendations for the Transition

Zlatko Nedić[*1], Ivan Ambroš[1], Ivan Janić[1], Ana Bošković[1], Danijel Cestarić[2], Biljana Kulišić[3]*

[1]Competence Centre Ltd. for research and development, Vinkovci, Croatia
e-mail: nedic@cekom.hr, ambros@cekom.hr, janic@cekom.hr, boskovic@cekom.hr
[2]Croatian Forests Ltd., Forest department Vinkovci, Croatia
e-mail: danijel.cestaric@hrsume.hr
[3]Energy Institute Hrvoje Požar, Zagreb, Croatia
e-mail: bkulisic@eihp.hr

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ABSTRACT

Bioeconomy is becoming a more interesting field for investments in the Republic of Croatia, especially in its small regions and local administrative units. Vukovar-Srijem county is one such unit in eastern Croatia with noticeable potential for development in a circular, carbon-neutral, and sustainable bioeconomy. Due to the nature potential represented by one of the largest forest reservoirs in Europe-Spačva basin, forestry is one of the most important county branches. Aiming to provide more inputs on the wood biomass management, the study on the biomass flow of Vukovar-Srijem county was conducted in 2020 by collecting data from local stakeholders and official reports. The study results have shown that Vukovar-Srijem county has the potential to increase the efficiency level of biomass use, but specific actions on the value-chain strengthening, finalisation of wood products, and innovative ecosystem establishment are still needed. The results highlight the predominant use of sawdust for heating purposes in the VSC region, suggesting potential for optimizing its utilization towards a circular, carbon-neutral, and sustainable bioeconomy, thus offering novel insights for future research and initiatives aiming to maximize economic and environmental benefits from wood biomass residues.

KEYWORDS

Bioeconomy, Carbon, Circularity, Wood, Biomass flow, Vukovar-Srijem county, Croatia.

INTRODUCTION

One of the significant aims of all EU member states is the implementation of European strategic goals that support the development of bioeconomy [1]. Bioeconomy is a special discipline that cannot be treated as an autonomous sector due to its interconnection with many other sectors and disciplines related to the sustainable development of the environment, industry, and society [2]. It builds a strong connection between biotechnology and the economy as well as between science, industry, and society, depending simultaneously on many factors such as environmental, industrial, societal, public perception, and public awareness [3]. According to many authors and European strategies, bioeconomy offers new opportunities for the growth of forest-abundant regions through novel ways of biomass utilisation that create

[*] Corresponding author

high value-added, either by establishing short-chain supplies for the emerging bio-based industries or creating new business models to increase the competitiveness of the traditional forest-based industry [4]. Quantifying the production and flow of wood-based biomass is crucial for developing a circular bio-based economy in such regions [4]. This fact contributes to the justification of this study because there are no available similar studies that concern the biomass flow of Vukovar-Srijem county (VSC), although this region is forestry-oriented.

Croatian bioeconomy mostly relies on two branches, agriculture and forestry and its forest-based sector is widely recognised as a reservoir of wood biomass, primarily due to Spačva basin (**Figure 1**), which is one of the most important reservoirs of forest biomass in Europe [5]. Consequently, Croatia is classified as a country with a high rate of wood biomass and forest biodiversity [6]. Spačva basin is geographically located in VSC and Vojvodina (Serbia), recognised as a heterogeneous lowland and forestland with an ecological dominant species of Slavonian pedunculate oak (*Quercus robur* subsp. *slavonica* (Gáyer) Mátyás) and other domestically important taxa such as *Fraxinus angustifolia*, *Alnus glutinosa*, *Carpinus betulus*, etc. [7]. The importance of the Slavonian oak is in its high-quality raw material characteristics, where it has been used in domestic industry and for export to other EU member states [6].

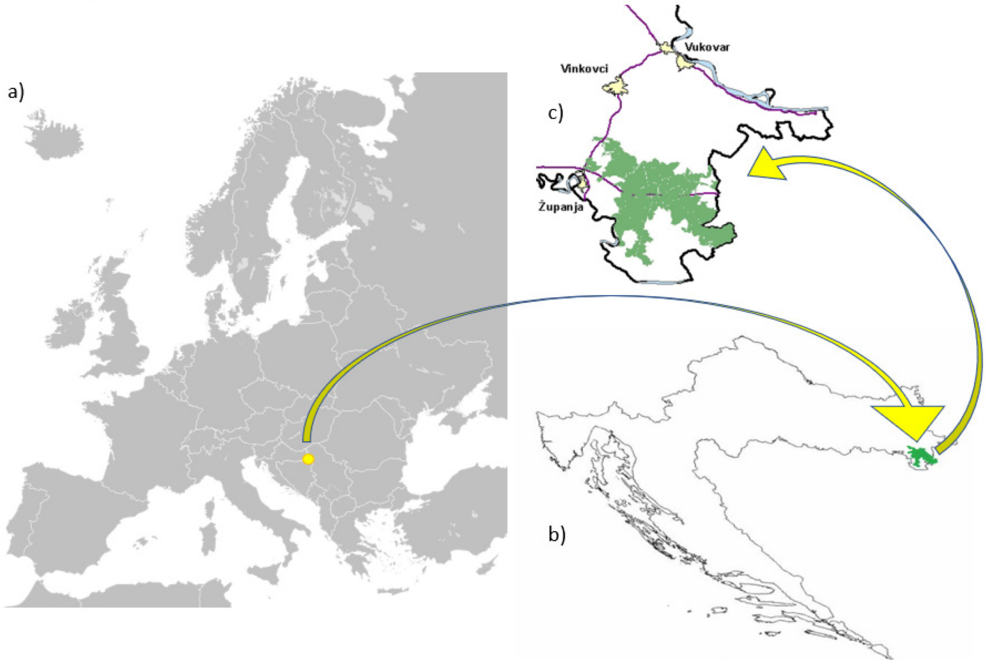

Figure 1. Geographic location of the Spačva basin on the map of a) Europe, b) Croatia, and c) VSC

Unfortunately, the Croatian forest-based sector is mostly export-oriented, with the leading export markets in Italy (21%), Germany (13%), Slovenia (10%), and China (7%). Besides, Croatia imports a certain amount of biomass, mostly from Serbia, Bosnia and Herzegovina, Albania, Kosovo, and Montenegro [8]. Although there is a deficit in scientific evidence discussing Croatian forest-based potential, especially regarding circularity, carbon-neutrality, and sustainable bioeconomy, some older studies give a comprehensive insight into the strengths, weaknesses, opportunities and threats of these potentials. It was stated that the most critical strengths of the forest-based sector are favourable geographic location, long industry tradition, and high-quality raw materials. As weaknesses, the study identified old technologies, high export rate, low added-value, low rate of investments, and low rate of knowledge transfer and innovation driving. Besides identifying threats such as globalisation, the financial crisis, and the rise of energy costs, the authors identified opportunities for eco-product production and EU funds [6]. This shows that the forest-based sector of VSC needs to be transformed to fulfil the demands of the EU strategies and policies.

It is crucial to foster the cascading use of wood biomass in finalising high-value-added wood (green) products to ensure the stability of a circular and sustainable bioeconomy in the VSC wood industry sector [9]. The exploitation of biomass for heating purposes and combustion is definitely not a sustainable solution. According to some previous studies, the initial assessment of the biomass used for construction and industry will be needed to increase sustainable use of wood biomass [10]. This study can identify every cascade that can be improved using biomass residues for technical purposes without using biologically and ecologically important forest values such as Slavonian pedunculate oak. Such a study can be developed only in cooperation with wood processors, research organisations, and business support organisations through a multidisciplinary quadruple helix-based approach [11]. That includes knowledge transfer on biomass innovative use, which identifies factors that influence an innovative performance of wood processing SMEs [12]. Shifting towards a sustainable green economy is particularly relevant for endeavours originating from the utilization of existing natural resources such as forestry and the water industry [13]. The adoption of industry 4.0 technologies can also enhance efficiency, competitiveness, and profitability, with potential benefits including increased investment in research and development, improved labour productivity, and greater market access, thus highlighting the importance of government support in fostering a conducive environment [14].

In alignment with EU guidelines advocating for greenhouse gas reduction through circular economy strategies in natural communities [15], recent analyses have underscored the imperative of sustainable bioresource management to scrutinize the environmental viability of the EU's bioeconomy initiative [16]. While recognizing the pivotal role of transitioning to renewable energy sources like biomass in mitigating CO_2 emissions [17], it becomes apparent that addressing the existing disparity between biomass demand and sustainable production capacity necessitates a comprehensive integration of the organic chemical sector into the bioeconomy, alongside partial energy integration and enhanced recycling efforts [17]. Furthermore, investigations into rubber and rubberwood biomass management highlight challenges confronting smallholders, underscoring the need for strategies to bolster production efficiency and empower stakeholders in the rubber industry [18]. Moreover, a recent systematic assessment of forest biomass dynamics in Portugal has shed light on sector-specific circularity disparities, emphasizing the need for complementary indicators to capture diverse resource utilization within the bioeconomy [19]. Expanding on these findings, this study delves into the wood-based sector, elucidating the imperative for transformative changes, such as new business models and technological advancements, while advocating for tailored governance approaches and sustainable criteria to optimize circularity and effectively close value retention loops [20].

This study aims to quantify the wood biomass in VSC, which is classified as a less developed region of Croatia according to the Decision on the classification of local and regional government units, according to their index of development (Official Gazette 132/2017). In addition, the second aim is to recommend future actions needed to improve the sustainable bioeconomy in this region. As the presented potential of VSC biomass shows, it should be standard for VSC to make significant strides towards an advanced bioeconomy, but is that so? Unfortunately, some studies state that the Republic of Croatia occupied 19th place among 24 EU member states regarding circularity, which is below the standard that Croatia needs to achieve in order to implement EU strategic goals [21]. This raises the following question: What are the obstacles in the sustainable bioeconomy of VSC's forest-based industry, what are its advantages, and where is the space for progress? These questions will be discussed in this work, contributing to existing scientific data as a good base for future comprehensive biomass studies in Croatia, especially in less developed regions. The study contributes to the following sectors: a) science and research by providing data on biomass flow that can be used in future studies, b) industry by promoting VSC as a high forest-biomass abundant region ready for investment, c) policy by providing recommendations for future transformation that need to be supported by local and regional authorities, and d) community-through awareness raising on biomass importance and forest protection.

MATERIAL AND METHODS

The study was conducted in the year 2020 in the Republic of Croatia (VSC) through two phases:

- Collection, selection, and analysis of data on the management of public and private forests, export, import, and way of wood biomass use (**Table 1**);
- Semi-structured interviews with SME representatives from the forest-based sector of VSC. The interviews were conducted using a simple questionnaire with questions about wood biomass use and raw wood materials exploitation as follows:
    1) How much wood do you purchase per year from the market? The word "wood" would be defined precisely during the interview, whether plank, timber, etc. The quantity will also be defined during the interview (t or m^3).
    2) What kind of residues do you produce?
    3) Can you estimate the annual quantity? If the company does not have any evidence, it is allowed to estimate the quantity approximately.
    4) How do you use your residues?
    5) What fuel is used for the heating process for your needs?
    6) If wood, what kind of wood (wood logs, wood residues, pellets)?
    7) Is the wood fuel produced from wood residues? If possible, please estimate the wood demand per heating season.
    8) Do you produce high-value-added wood products ready for export?
    9) If yes, which products are these?

Table 1. Data types and their sources collected during the research

Wood biomass sources	Type of wood biomass	Source of assessment	Data
State forests Private forests	Forest biomass	Croatian Forests	Annual increment, annual exploitation, export, import
Biomass from agriculture	Branches, vineyards and orchards, short rotation coppice, canal biomass	Administrative Department for Agriculture of VSC, EIHP	Data collection on the biomass amount and use
Biomass of landscape	Branches	Administrative Department for Agriculture of VSC, Croatian Forests, available data from official reports (VSC)	Data collection on the biomass amount and use
Production of wood products and use of the wood biomass by VSC's companies	Wood biomass (timber), biomass residues	Interviews, NACE Rev. 2	Biomass amount, ways of the biomass use, finalisation of wood products, use of existing biomass for own purposes, export, import, economic activities related to wood processing

The Sankey diagram has been chosen to visualise the wood biomass flow in VSC because it visualises the biomass flow by the strips of proportional size in different phases, sectors and branches. Biomass flow is presented to allow deeper analysis and long-term planning for developing local bioeconomy based on short supply chains. Sankey diagram shows the flow of wood biomass in VSC from wood stocks of the natural ecosystems to its use in industry, households and other purposes. Although it shows the annual availability of biomass, it does not show any specific year, including the yearly deviations of wood biomass caused by disasters (pests, diseases, etc.).

RESULTS AND DISCUSSION

Quantifying wood products and defining their use and production are significant challenges today, especially in less developed regions **[4]**. Besides existing European strategies, there is still a lack of scientific data on the implementation of bioeconomy strategy in Croatia and the SEE countries, which can occur primarily due to fragmented value chains **[22]**. In order to reduce the above deficit and create conditions for further sustainability and stability of less developed regions, it is necessary to conduct similar studies continuously that would have the function of knowledge transfer, networking, idea development, recommendation giving, and timely informing. Creating such an environment can contribute to environmentally and socially sustainable economic growth, sustainable development, and a climate-neutral society, which are crucial for less developed EU regions in reflecting EU-added values **[23]**.

According to the NACE Rev. 2 **[24]**, ten different economic activities are included in the wood biomass consumption and processing in Croatia: 1. agriculture (A01), 2. forestry (A02), 3. manufacture of wood products (C16), 4. manufacture of paper (C17), 5. production of chemicals and chemical products (C20), 6. production of non-metal mineral products (C23), 7. manufacture of wooden furniture (C31), 8. specialised construction activities (F43), 9. wholesale and retail sale (G46) and 10. landscaping services (N83). These activities represent the base on which the forest-based innovation potential should be built. Such potential includes stakeholders that need to be connected according to the quadruple helix principles (with the inclusion of policy and community), which is a precondition for the creation of a bioeconomy based on knowledge, best practice examples, and high value-added **[25]**. According to the heterogeneity in economic activities that include biomass manipulation and exploitation, the authors describe a strong existing potential for future investments in the forest-based sector of VSC, especially in the innovation ecosystems that need to be established according to the previously mentioned principles. This should lead to less exploitation of semi-final products and raw wood materials and more development of high-value-added green products **[26]**. Heterogeneous economic activities in biomass flow contribute to creating such an environment that can be the starting point for establishing the innovative less developed region. To achieve this, the role of competence centres needs to be in focus because they connect local stakeholders (local needs) with the European vision expressed through EU funding instruments that can be detected by competence centres and through which the strategic bioeconomy projects of VSC can be implemented (partially or completely). According to the data collected by CEKOM, it is noticeable that the Republic of Croatia and VSC have made a significant effort towards the EU missions, strategies, and policies, achieving many milestones in its transformation from a socialistic system towards a modern, green, circular, and sustainable European bioeconomy. Although the progress is visible, the effort will still be needed to improve circular, carbon-neutral, and sustainable bioeconomy.

According to the data collected for the study purposes, it is evident that VSC has a significant living forest potential **[27]**. The total wood stock is mainly represented by the forest stock with about 20.87 million m^3 located on 69 398 ha or 28% of the County (**Figure 3**) with a dominant Slavonian pedunculate oak, narrow-leaved ash, and common hornbeam **[28]**. That amount of wood biomass indicates that 96% of living forest ecosystems fulfil the ecosystem services function after the wood processing biomass enters VSC. The wood biomass amount that enters the bioeconomy of the County is about 0.66 million m^3 (**Figure 3**). The Sankey diagram (**Figure 3**) represents the flow of wood biomass that continues to the data from supply and is further divided into different branches and activities (industry, households, energy, or exports) until its final use. The mentioned biomass is mostly used for the production of wood assortments, heating purposes for industry and households, and production of solid fuels (mostly pellets), but the production of high-value-added final wood products ready for export was not detected.

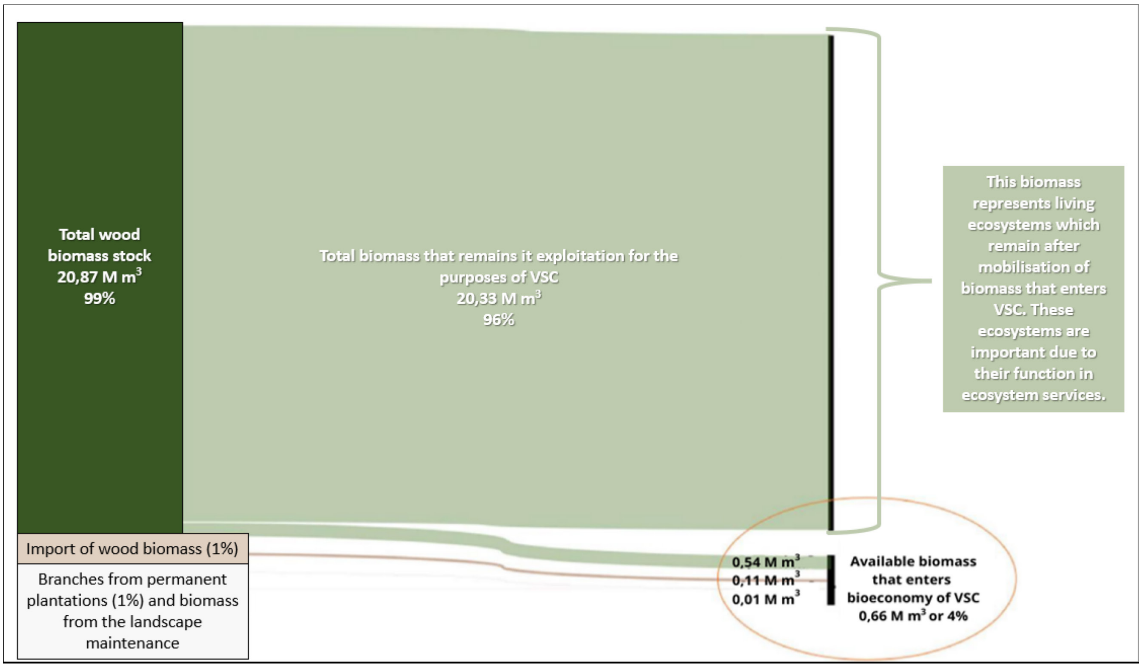

Figure 2. Sankey diagram of the wood biomass stock in VSC

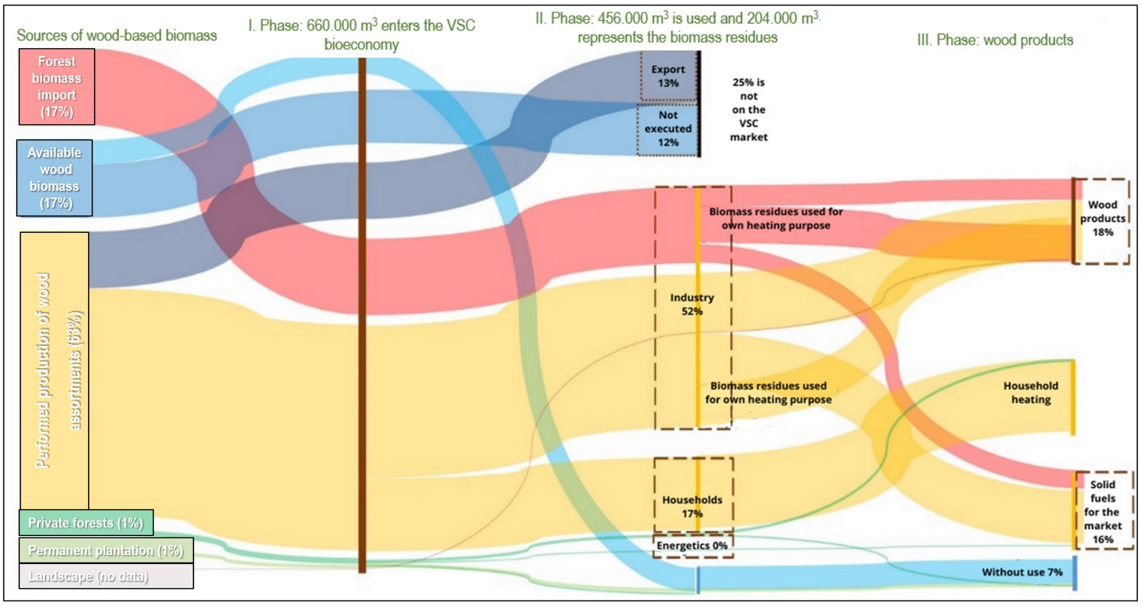

Figure 3. Sankey diagram of the wood biomass flow in VSC

According to the data collected during the study, 660 000 m^3 and 456 000 m^3 were mostly used for industry and heating purposes, and 204 000 m^3 were classified as biomass residues, mostly used for pellets and briquets production. Results of the questionnaire identified sawdust as the most common wood residue formed after wood processing, and the analysis also showed its use by almost all surveyed wood processors (from the total of 14 wood processing companies of the County, 13 wood processors have sawdust as a significant residue). The Sankey diagram

(**Figure 3**) undoubtedly shows that the most exploitation of wood biomass residues is for heating purposes (**Figure 4**).

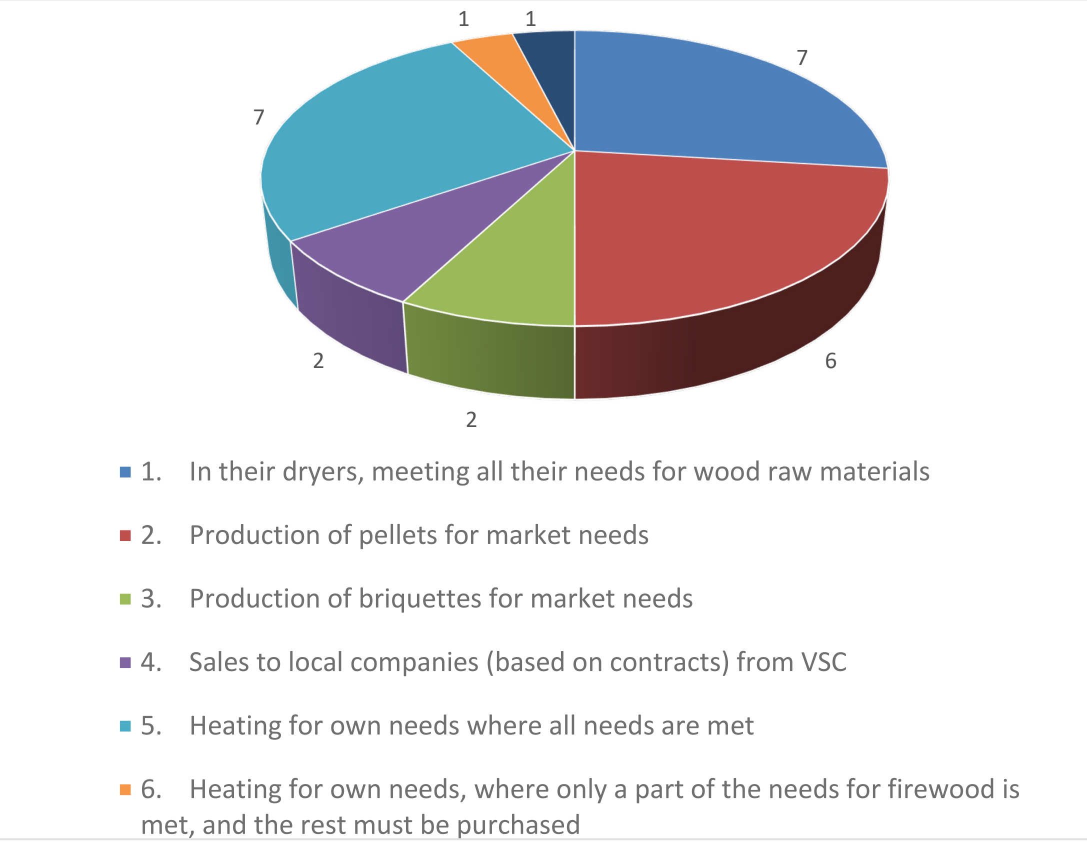

Figure 4. Results on how many wood biomass processors use biomass in VSC

The transnational, multisectoral, and multidisciplinary approach is needed to drive innovation and to step out from export and semi-final products. The great challenge for small rural areas such as VSC is the transnationality and connection with EU-recognised wood processing companies. This can be achieved through existing EU financial instruments and programmes (HORIZON, INTERREG, LIFE, I3 and other national programmes) and the common work on new innovative ideas and products. The recommendation is to educate the main actors on the opportunities for participation in the "EU great project stories". This can create new ways of effectiveness in the wood biomass cascading use through the creation of possibilities for the finalisation of wood products with high value-added [26].

According to **Figure 2** of this study, it is visible that the final products of surveyed companies were mostly pellets and briquets. This shows progress towards the EU Green Deal's objectives, but it is still not the solution for the exploitation of existing high-value-added wood potentials (**Figure 4**). A transnational approach and openness can show the way for the production of smart, digital, and green wood products in line with the I4.0 principles and standards with the previously conducted I4.0 readiness assessment [29].

In order to develop high-value-added wood products, we strongly believe that introducing the carbon footprint/carbon storage model would provide added value by providing information on industrial products and their carbon content. This has an important impact on awareness raising among citizens, similar to some previously conducted actions and developed calculation models [30]. Knowledge transfer about such models will be needed to understand better climate change [30] and anthropogenic influence [31] that harms their environment. Carbon sequestration is still a massive enigma for Croatian organisations, thus, partnerships, education, workshops, and the mentioned innovative environment will be needed to strengthen competencies in this complex field [32]. Such a partnership can be implemented through some ongoing projects, such as DaWetRest [33], where VSC represents an important pilot location on which the strategy for carbon sequestration needs to be developed. The application of short rotation coppice (SRC) is of importance in achieving climate neutrality because it absorbs atmospheric CO_2, which can later be stored in materials or replaced by fossil carbon with renewable carbon from biomass [34]. Plant species such as willow, poplar, alder, birch, hornbeam, chestnut, ash and acacia that grow in short rotations of two to eight years are energetically very important. Addressing the implications of biomass import on circularity and sustainability, particularly through the promotion of fast-growing crops and diversification of feedstock sources, enhances ecosystem resilience and reduces pressure on native hardwood exploitation while fostering the production of higher value-added green products. The planting and cultivation of SRC can ensure more wood biomass for energy purposes and release more quality wood for developing high-value-added products based on innovation. This will reduce low-value raw material exports from VSC and increase the export of final, green, smart, added-value wood products. Such actions should be fostered by local and regional authorities in charge of forestry and forest-based sectors.

CONCLUSION

The wood-based biomass potential of VSC can be considered as high, but the exploitation of wood biomass is mostly oriented to the export of semi-formal products or the production of wood products intended for heating purposes (pellets). The production of high-value-added wood products, recognised in Europe, was not detected. In order to ensure sustainability, circularity and carbon neutrality, it is necessary to ensure a stable connection between sectors that are components of the quadruple helix. The forest-based sector in VSC should be oriented towards EU high standards regarding green transition (clean energy, carbon sequestration rate increase, green projects and ecosystems, openness to Europe) and digital transformation (incorporation of I4.0 into the business model of SMEs in VSC). This can be achieved through knowledge and know-how transfer on existing EU financial instruments that can provide sources for financing the finalisation of wood, green, high-value-added products.

Moreover, the identification of biomass residues, particularly sawdust, and their predominant use for heating purposes underscore both opportunities for value-added utilization and potential areas for improvement. The recognition of sawdust as a significant residue among wood processors emphasizes the importance of optimizing its utilization for higher value-added applications, aligning with the objectives of a sustainable bioeconomy. The findings regarding the utilization of wood biomass residues, particularly for heating purposes, offer insights into current practices and potential areas for optimization. By identifying the predominant usage patterns and potential value-added applications, such as pellet and briquet production, the study lays the groundwork for future interventions aimed at enhancing the circularity and value extraction from wood biomass residues. Overall, the results presented provide a comprehensive understanding of the wood biomass flow within the VSC region and offer valuable insights into opportunities for advancing towards a circular, carbon-neutral, and sustainable bioeconomy. The findings serve as a foundation for future research, policy development, and industry initiatives aimed at maximizing the economic and environmental benefits of wood biomass utilization in the region.

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